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Optimal devanning time and detention charges for container supply chains

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ABSTRACT

This paper develops the laden and empty container supply chain model based on three scenarios that differ with regard to tardiness in the return of empty containers and the decision process for the imposition of detention charges with the goal of determining optimal devanning times. The effectiveness of each type of policy - centralized versus decentralized - is determined through computational experiments that produce key performance measures including the on-time return ratio. Useful managerial insights on the implementation of these polices are derived from the results of sensitivity analyses.

1. Introduction

Since the development of containerization, international trade has shown rapid growth. However, total trade volumes have shown sharp decreases and subsequent rapid recoveries over the history of the container trade. For example, the United Nations Conference on Trade and Development (UNCTAD) reported rapid recoveries in the annual growth of total trade after sharp declines in 2010 and 2017 and implied that seaports could suffer from severe congestion due to increases in container traffic. An International Association of Ports and Harbors (IAPH) report noted that container traffic among the top 20 global ports increased by an average of 137% from 2007 to 2016. This rapid increase in container traffic seemingly accounts for many of the issues associated with the return of empty containers from consignees to the locations designated by shipping companies.

To maintain an uninterrupted flow of empty containers, the shipping company imposes a detention charge on the consignee if the return of a container is overdue (Lee, 2014). After the grace period or *free time*, detention charges accumulate until the empty containers are returned by the consignee to the port or depot. The period from retrieval of laden containers from the port to the return of empty containers to the same port for reuse is referred to as *devanning time* (Moon et al., 2010). Devanning time can be impacted by detention tariffs imposed by the shipping company, especially when a consignee encounters far more strict conditions with regard to the imposition of a tariff. According to Yu et al. (2015), a port terminal operator also provides pre-specified free times to a shipping company for inbound containers, which a consignee is responsible for retrieving. A shipping company usually collects the storage fees from a consignee to pay the terminal operator, without any contract between the terminal operator and a consignee. This exchange implicitly shows that a shipping company publishes detention tariffs based on the container storage pricing contract between the terminal operator and a shipping company. Therefore, in this paper, we assume that the free times set by a shipping company and a terminal are the same. Devanning time also can be impacted by unexpected events such as natural disasters, road traffic, equipment

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Notation

Indices

i	scenario based on level of tardiness for return, $i = 1, 2, 3$
j	type of container, $i = s,f$

Parameters

n_j	number of container type j to be shipped
A_s	setup cost of shipping company
A_r	fixed cost of consignee
hj_s	additional handling cost of empty container type j for shipping company
hj_r	inventory holding cost of laden container type j for consignee
LC_j	leasing cost of container type j
pn_{j1}	detention charge for container type j incurred during the first interval
pn_{j2}	detention charge for container type j incurred during the second interval
e_j	investment effort in withdrawal rate for container type j
t_r	inland transportation cost between consignee and port of destination
L_0	endpoint of free time for exemption on detention charge
p_i	probability of scenario i to occur ($p_i > 0$, $p_1+p_2+p_3=1$)

Decision variables

L_1	endpoint of first interval of detention charge after free time
w_j	withdrawal rate for container type j
α	fraction of compensation for leasing standard containers ($0 \le \alpha < 1$)
β	fraction of compensation for leasing foldable containers ($0 \le \beta < 1$)

Cost functions

π_s^i	cost function of shipping company under scenario i
π_r^i	cost function of consignee under scenario i

malfunctions, labor strikes, and inspection and repair of damaged containers. Thus, uncertainties during the devanning process have substantial impact on container return. In addition, significant delays in the return of empty containers can affect the shipping company's planning horizon, particularly when determining whether to lease containers to meet the demands of empty containers for new shipments. Therefore, both parties are subject to the following crucial decisions with regard to container flow:

- To adjust free time or to penalize a consignee who fails to return containers within the shipping company's desired time period
- To manage investment in emptying capabilities to minimize detention charges for the consignee

Although few quantitative scientific studies on container return timing have been performed, mass media reports have identified several causes of delays in the return of empty containers. Pauka (2019) reported that sudden and frequent re-direction notices for returning empty containers to designated empty container parks without extension of the free time caused significant additional costs for consignees. For example, in Sydney, Australia, estimated additional costs of \$90 to \$200 per container were incurred based on the level of tardiness of the return. Delays were closely related to insufficient storage space due to the huge increase in seaborne trade volumes and resulted in large additional costs being unfairly imposed on consignees. Meanwhile, demurrage and detention tariffs levied by global shipping companies are being made more stringent. New tariffs for most service routes reduce flexibility in free times for container returns but increase detention charges for all types of containers (Aktan, 2019).

In terms of import, consignees are liable for both demurrage and detention charges when they fail to retrieve laden containers from a port and to return empty containers to a port within specified free times. A shipping company aims to facilitate the circulation of its containers by levying these penalty costs. In practice, the company uses the following two methods for imposing the charges:*joint* and *individual*. If the company charges jointly, a consignee has the option to allocate the desired number of free times for each charge on condition that the total free times of both charges are satisfied; that is, a single free time is given to a consignee. However, in the case of individual charging method, a detention period would start immediately after a demurrage period ends. In this case, the calculation of each individual charge is conducted in isolation with two separate free times, a more popular practice, according to Fazi and Roodbergen (2018). They analyzed the impact of both joint and individual free times of demurrage and detention charges on a multimodal planning problem without explicitly considering the operation of a consignee. Rather, they instead focused on the routes between seaports and inland terminal with two transport modes including barges and trucks to minimize the dwell times of containers at seaports along with the time duration of both charges. From this perspective, the consideration of both charges seemed reasonable (Light, 2017). An opposing study by Yu et al. (2018), however, similarly studied detention decisions on empty containers to determine optimal free detention time for a shipping company, along with dispatching time of empty containers for a hinterland container operator. Although this study investigated the impact of different decision variables, it implied that detention charges had the most significant relevance to the empty container flow process. For the purposes of this study, which focused solely on detention charges, these charges alone appear to be sufficient to study the impact of charges on empty returns.

Because of the uncertainty in container returns due to unforeseen circumstances, the potential for conflicts between a shipping company and a consignee remains high under the current situation; that is, the shipping company seeks to impose higher detention tariffs against the consignee as a source of profit generation resulting from port congestion rather than limiting revenues to the shipment of the freight itself in an effort to gain a control over empty container flow (Wackett, 2019).

To address these uncertainties in the devanning process, the following scenarios based on the level of tardiness of an empty return are introduced to explore the effects of variation in devanning times significantly affected by withdrawal rates, free times, and detention charges.

Scenario 1: Empty containers are returned within the interval of free time and the entire process operates on the assumption that additional inventory holding costs for empty containers at the origin accrue during the first detention interval. Even though all containers are returned within the free time, this additional cost cannot be neglected due to the significant amount of storage costs incurred at a port.

Scenario 2: Empty containers are partially returned after free time, and then inventory holding costs for empty containers at origin are calculated. It is a common practice that detention charges are incurred immediately at the beginning of this interval. Nevertheless, the shipping company is still willing to accept detention charges for containers not returned on time. Hence, the remaining containers will all be returned within the first interval of detention. Thus, operations in this scenario are terminated at the first interval of detention in an effort to reduce the charges.

Scenario 3: When some empty containers are not returned to the origin for a long time period due to the unexpected events, a shortage of empty containers at the port of origin may result. The shortage due to late returns can be met by leased containers, thus it is worthwhile for the shipping company to consider use of leased containers for the next cycle. Higher detention charges are applied after the first interval of detention has passed, and time-varying detention charges are prevalent in the industry. The shipping company attempts to reduce losses incurred by leasing costs by optimizing the detention charge of the second interval.

These scenarios are proposed based on the plausibility derived from the container flow process in Fig. 1. Shintani et al. (2007) devised a penalty cost function, composed of storage and short-term leasing costs incurred at a port, when they designed a configuration for optimal shipping routes. It is inferred that a detention charge, a form of penalty for decreasing the circulation of containers, is used for a leasing activity to ensure that the demand in the next cycle can be satisfied. Furthermore, they permitted leasing containers immediately when a shortage occurred in the next cycle.

The structure of this paper is as follows: Section 2 reviews existing literature involving several key topics treated as the foundation of this study. A detailed problem description along with underlying assumptions is presented in Section 3. The mathematical models of each scenario under decentralized and centralized policies are developed in Section 4. In Section 5, computational experiments including numerical examples and sensitivity analyses on three policies are extensively conducted. A comprehensive view on managerial insight is provided in Section 6. A conclusion is given in Section 7.

2. Literature review

To the best of our knowledge, the impact of detention charges on maritime logistics has not been extensively investigated even

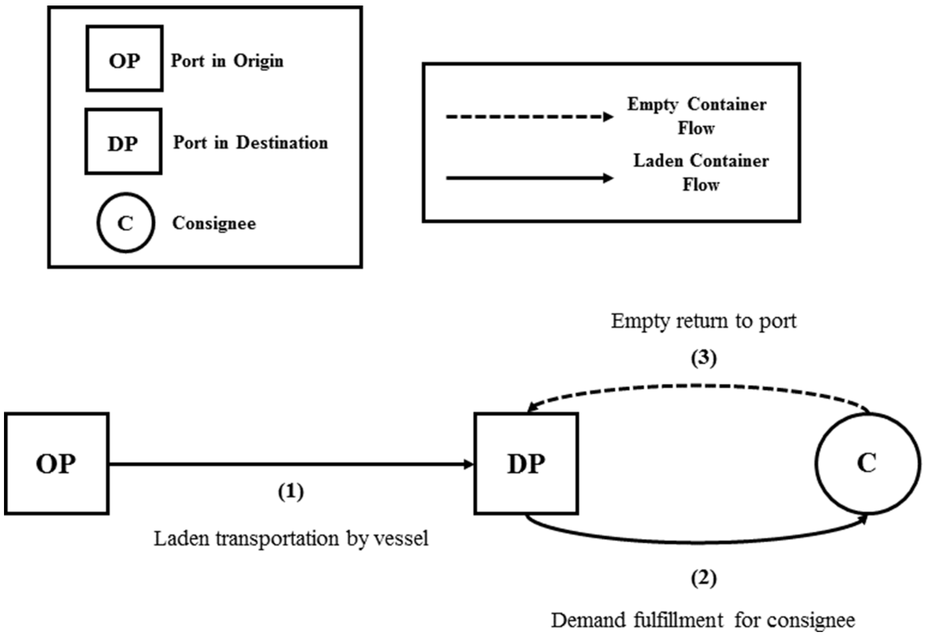

Fig. 1. Overview of container flow process from shipper to consignee.

though the imposition of such charges on consignees is common practice. Only a few studies have examined this topic. For example, Kang et al. (2012) studied empty container reuse transportation for both imports and exports with a match-back strategy. They examined the incorporation of detention charges in match-back transportation costs but did not explicitly develop mathematical models. Fransoo and Lee (2013) addressed issues in detention charges from the perspectives of a shipping company and a consignee and claimed that detention charges have a great impact on the return behavior exhibited by container users or consignees. Lee (2014) used several strategies to optimize a network flow problem for the replenishment of empty containers that considered detention charges and free times as parameters but did not explicitly solve for them through their model.

The problem of empty container repositioning (ECR) is another important topic that has received attention in the literature with regard to the return of empty containers. Jeong et al. (2018) examined empty container management strategies such as ECR, reuse, and leasing for a direct shipping service network between two countries by developing a mixed–integer programming model. A number of useful managerial insights can be derived from their sensitivity analyses to promote green efforts; that is, ECR and reuse activities were simultaneously encouraged while the leasing of new containers for fulfillment of shippers' empty container demands was discouraged. Luo and Chang (2019) proposed contract coordination to solve the ECR problem for an intermodal transport system when customer demand switching occurred between a dry port and a seaport. They showed that both parties could achieve win–win outcomes through the proposed ECR coordination as well as reduced inventory levels. ECR was also applied to the routing of barge container ships by Alfandari et al. (2019). They found that the encouragement of ECR activities was useful in optimizing routes and maximizing the barge shipping company's profits by reducing leasing or storage costs for empty containers. An ECR strategy along with cooperation scheme can provide enormous benefits for maritime shipping companies with regard to cost reduction and green activities. Song and Xu (2012) developed an operational activity-based method, and their results from two case studies showed that their method is a more accurate estimator of CO_2 emissions than the traditional method. Thus, an efficient ECR strategy contributes to a reduction in CO_2 emissions in shipping service routes. A simulation conducted by Irannezhad et al. (2018) showed significant reductions in transportation costs and pollutant emissions for shipping companies through cooperation scenarios; the researchers claimed that a street-turn, or triangulation, strategy could be realized in a real-world case to reduce the movement of empty containers. In addition, because foldable containers play a crucial role in ECR strategy due to the advantages of the decreased size of folded containers, many studies have reported the potential for cost savings resulting from their use in transportation and storage (Moon and Hong, 2016;Moon et al., 2013; Myung, 2017;Zhang et al., 2018). Zheng et al. (2016) also studied the impact of foldable containers on ECR activity in an attempt to reduce ECR movements. Wang et al. (2017) analyzed the effect of foldable container usage with ship type decisions with regard to ECR activity and identified the conditions under which a shipping company could use foldable containers effectively. In essence, foldable containers could play beneficial role in the management of empty returns.

A number of studies have been performed on empty container management policies (Song et al., 2019). Li et al. (2004) studied the empty container allocation problem based on both positive and negative demand for importing and exporting empty containers. They showed through a discounted infinite horizon case that two critical points play a key role in obtaining the optimal policy; that is, bounds for the imports and exports of empty containers. Song and Dong (2008) investigated an optimal ECR policy in a dynamic and stochastic environment to minimize expected total costs. They presented a three-phase threshold control policy as well as three heuristic repositioning policies to provide for optimal selection of a shipping liner. Similar research using a Markov decision process was conducted to identify optimal policies for repositioning containers in a periodic-review shuttle service system (Song, 2007). To deal with uncertainty in demand and supply, Di Francesco et al. (2009) addressed deterministic and multi-scenario policies to perform a demand fulfillment evaluation of an ECR problem. The effectiveness of the multi-scenario policy was verified with unexpected demands in future periods. Moreover, Chen et al. (2017) highlighted the importance of supply chain collaboration to gain sustainability with the various research methodologies and different supply chain structures. In line with the recent research trend, our focal research interest is to improve coordination between a shipping company and a consignee under the uncertain situation of container returns. In this paper, both upstream and downstream collaborations are highlighted, with particular attention given to the role of the customer.

Therefore, this paper aims to investigate the laden and empty container supply chain under decentralized and centralized policies (LESC-DC) from the perspective of determining devanning times through three plausible scenarios based on the level of tardiness in returning empty containers. The advantages of the proposed LESC-DC are as follows: (i) the decision makers of a shipping company and a consignee properly manage their own decisions regarding the container return process under a high level of uncertainty; (ii) it allows the practical application of decentralized and centralized policies to various cases in which the degree of tardiness in returns varies; and (iii) it obtains managerial insights by exploring the effects of each policy through sensitivity analyses.

3. Problem description

This study examines two aspects with regard to the return of empty containers in the LESC-DC: (1) a shipper and a port of origin and (2) a consignee and a port of destination. Note, however, that the operation costs of the shipper are not explicitly considered here in an effort to simplify our model.The following is a brief description of the steps of container flow, as shown in Fig. 1 of this paper. The laden containers returned by a shipper are transported to the port of destination by a vessel (step 1). It is assumed, for the purpose of this study, that the containers would then be transported to a consignee as soon as they are unloaded from a vessel, in order to satisfy the consignee's demands (step 2). After unpacking the containers, the consignee is then obligated to return the empty containers within a specified free time period, at which point the containers are stored at a port for the next cycle (step 3).

In this paper, we refer to the time intervals in steps 2 and 3 as *devanning time* as well as a detention period. As these terms share the same process along with the aforementioned uncertainties, they are significantly affected by each other. Because the process of detention is completely independent from that of demurrage when penalties are calculated individually, the detention charge alone is considered in analyzing the impact on devanning time in this paper. As more specifically shown in Fig. 2, significant variation occurs in the return process depending on the time when the return process is being initiated under the scenarios we proposed in Section 1. In this regard, such uncertainty should be taken into account to optimize the process for real-world situations. In this context, a shipping company levies detention tariffs after free times on a consignee based on the consignee's tardiness in returning the container and the type of container (standard vs. foldable) to account for the risks involved in late returns. A number of variables influence the return of containers by the consignee; that is, the withdrawal rate of laden containers can be determined by the consignee's investment in container handling equipment, the cargo handling area, manpower, etc. In this way, a consignee could manage these controllable decisions, especially with regard to whether emptying capabilities should be accelerated or decelerated for laden containers. We note in this study, however, that uncertainties mentioned in the Introduction still exist and could delay the devanning process.

The underlying assumptions for the problem are as follows:

(i) Laden containers are consumed based on withdrawal rates.
(ii) Free time for the return of an empty container is set by the agreement made between the shipping company and the consignee. It is a common practice in the shipping industry to impose a detention charge against the consignee to facilitate the reuse of owned empty containers (De Langen et al., 2013).
(iii) A stack of foldable empty containers consists of *four units* (Moon et al., 2013).
(iv) Detention charge is discretely imposed based on a level of tardiness in the following manner:

$$\text{Detention charge} = \begin{cases} 0 & \text{if every container is returned within } L \in (0, L_0] \\ pn_{j1} & \text{if container type } j \text{ is returned within } L \in (L_0, L_1] \\ & (j = s, f;\ where\ s = standard,\ \ f = foldable) \\ pn_{j2} & \text{if container type } j \text{ is not returned within } L_1 \end{cases}$$

(v) When the return time reaches L_1, the entire operation is terminated for a single cycle.
(vi) All of laden containers unloaded from a vessel are immediately transported to a consignee.

The following parameters and decision variables are used throughout this paper to develop the proposed models:

4. Model development

In this section, we formulated each scenario based on the level of tardiness for the return of an empty container under centralized and decentralized decision making protocols. Because this paper primarily focuses on issues regarding the return of empty containers, the decisions of both a shipping company and a consignee in managing the return of empty containers are examined. Specifically, a shipping company strives to maintain control over an entire container flow by determining the intervals and detention charges, whereas the consignee manages withdrawal rates for standard and foldable containers through investment efforts to keep up with due dates. It is well known that withdrawal rates of both standard and foldable containers can be differentiated based on the higher handling costs for foldable containers. Therefore, the mathematical models are used to show that both parties can minimize the total relevant costs in the following scenarios.

Scenario 1:

Under this scenario, all of the containers are returned within the free time, $L \in (0, L_0]$. Thus, the expected total cost for a consignee and a shipping company is formulated as follows:

$$\begin{aligned} \pi_r^1(w_s, w_f) = {} & \frac{A_r}{L_0} + \frac{hs_r}{L_0}\left[\frac{n_s(L_0-1)L_0}{2} - \frac{w_s L_0(L_0-1)(2L_0+1)}{6}\right] \\ & + \frac{hf_r}{L_0}\left[\frac{n_f(L_0-1)L_0}{2} - \frac{w_f L_0(L_0-1)(2L_0+1)}{6}\right] \\ & + \frac{e_s w_s^2}{L_0} + \frac{e_f w_f^2}{L_0} + \frac{(2n_s + 5n_f/4)t_r}{L_0} \end{aligned} \tag{1}$$

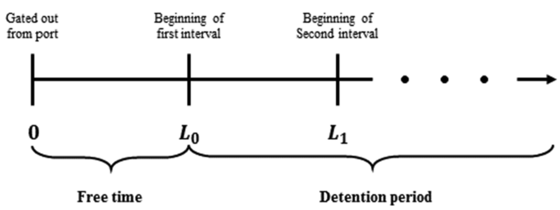

Fig. 2. Variation in container return.

$$\pi_s^1(L_1) = \frac{A_s}{L_1} + \frac{n_s(L_1 - L_0)hs_s}{L_1} + \frac{n_f(L_1 - L_0)hf_s}{4L_1} \tag{2}$$

In Eq. (1), the first term represents the fixed costs incurred for a folding facility. Because all laden containers are stored at a consignee's site and consumed based on withdrawal rates, w_s, and w_f, a consignee is responsible for the handling costs of standard and foldable containers until they are completely processed, as shown in the second and third terms, respectively. The fourth and fifth terms depict investment efforts in withdrawal rates for both types of containers by a consignee. It is noted that quadratic forms for investment efforts are used in an attempt to realize analytical tractability (Sarkis, 2019). Inland transportation costs between a consignee and a port are given in the last term. In Eq. (2), the first term shows setup costs incurred at the origin, and the second and third terms indicate additional inventory holding costs for standard and foldable empty containers during $L_1 - L_0$ after every container is returned within L_0. According to Assumption (iii), foldable empty containers are stacked in groups of four units to reduce storage, transportation, and handling costs. Thus, the ratio 1/4 indicates the same size as standard containers in inland transportation and additional inventory holding costs, as shown in Eqs. (1) and (2).

Scenario 2:

In Scenario 2, a fraction of laden containers is not returned until L_0 due to an unforeseen events such as peak season for the trucking company, a labour strike, etc, but that the containers will be fully returned within L_1, as shown in Eqs. (3) and (4):

$$\pi_r^2(w_s, w_f) = \frac{A_r}{L_1} + \frac{hs_r}{L_1}\left[\frac{n_s L_1(L_1-1)}{2} - \frac{w_s L_1(L_1-1)(2L_1+1)}{6}\right] + \frac{hf_r}{L_1}\left[\frac{n_f L_1(L_1-1)}{2} - \frac{w_f L_1(L_1-1)(2L_1+1)}{6}\right]$$
$$+ \frac{e_s w_s^2}{L_1} + \frac{e_f w_f^2}{L_1} + \frac{(2n_s + 5n_f/4)t_r}{L_1} + \frac{pn_{s1}(n_s - L_0 w_s)}{L_1} + \frac{pn_{f1}(n_f - L_0 w_f)}{L_1} \tag{3}$$

$$\pi_s^2(L_1) = \frac{A_s}{L_1} + \frac{L_0 w_s(L_1 - L_0)hs_s}{L_1} + \frac{L_0 w_f(L_1 - L_0)hf_s}{4L_1} \tag{4}$$

Scenario 2 was formulated in the same manner as Scenario 1 except for detention charges payable to the shipping company. In Eq. (3), these detention charges for standard and foldable containers are illustrated in the seventh and eighth terms, respectively. Although Eq. (4) shows similar cost terms as Eq. (2), only containers returned until L_0 are calculated for inventory holding costs during $L_1 - L_0$ as shown in the second and last terms. It is common practice for a shipping company not to charge inventory holding costs during the free time, due to another exemption on these costs caused by free times set by a port.

Scenario 3:

When some containers are not returned to the port of origin for an exceptionally long period, the shipping company will be faced with a shortage of empty containers for use in the next cycle. The formulation of each party in this scenario is established in the following equations:

$$\pi_r^3(w_s, w_f) = \frac{A_r}{L_1} + \frac{hs_r}{L_1}\left[\frac{n_s L_1(L_1-1)}{2} - \frac{w_s L_1(L_1-1)(2L_1+1)}{6}\right] + \frac{hf_r}{L_1}\left[\frac{n_f L_1(L_1-1)}{2} - \frac{w_f L_1(L_1-1)(2L_1+1)}{6}\right] + \frac{e_s w_s^2}{L_1} + \frac{e_f w_f^2}{L_1}$$
$$+ \frac{(n_s + n_f + L_1 w_s + L_1 w_f/4)t_r}{L_1} + \frac{pn_{s1}(L_1 - L_0)w_s}{L_1} + \frac{pn_{s2}(n_s - L_1 w_s)}{L_1} + \frac{pn_{f1}(L_1 - L_0)w_f}{L_1} + \frac{pn_{f2}(n_f - L_1 w_f)}{L_1} \tag{5}$$

$$\pi_s^3(L_1) = \frac{A_s}{L_1} + \frac{L_0 w_s(L_1 - L_0)hs_s}{L_1} + \frac{L_0 w_f(L_1 - L_0)hf_s}{L_1} + \frac{(LC_s - pn_{s2})(n_s - L_1 w_s)}{L_1} + \frac{(LC_f - pn_{f2})(n_f - L_1 w_f)}{L_1} \tag{6}$$

In Eq. (5), inland transportation costs differ from those used in the first and second scenarios. For empty containers, $L_1 w_s$ and $L_1 w_f$ will be transported back to a port until L_1. Leasing costs for standard and foldable containers are included in Eq. (6). The equation highlights that a shipping company can compensate for these costs by collecting detention charges incurred during the second interval, pn_{s2} and pn_{f2}, as shown the in fourth and last terms.

Based on the modeling assumptions, the expected total cost could be divided by L_0 and L_1, depending on when it has been decided to terminate operations in each scenario. If one can recall the cost structure of EOQ or EPQ in Operations Management literature, each cost component, including a fixed cost, is divided by the common cycle to calculate the total relevant costs per unit time. In this case, L_0 and L_1 play roles in common cycles based on the level of tardiness in container returns. Meanwhile, the handling costs and transportation costs are assumed to be variable costs, even though they could be involved in fixed costs. As shown in the cost functions of a consignee in Scenarios 1–3, the handling cost terms of standard and foldable containers are affected by withdrawal rates, which are controlled by a consignee. In other words, handling costs are computed based on the degree of investment efforts in withdrawal rates. Hence, the handling cost terms should remain as variable costs for this study. Although transportation costs in Scenarios 1 and 2 could be included in fixed costs, they also are affected by decision variables w_s and w_f in Scenario 3.

4.1. Centralized policy

With centralized policy, both parties come to an agreement to cooperate with each other and function as a single-decision maker. In this regard, the shipping company and the consignee do not attempt to minimize their expected total costs individually, but rather bring out the best benefits for the entire supply chain. Using Eqs. (1)–(6), the expected total cost of each party can be shown as:

$$E(\Pi_R) = p_1\pi_r^1 + p_2\pi_r^2 + p_3\pi_r^3 \tag{7}$$

$$E(\Pi_S) = p_1\pi_s^1 + p_2\pi_s^2 + p_3\pi_s^3 \tag{8}$$

For simplicity, the expected cost function of centralized policy is given as follows:

$$E(\Pi_C)(L_1, w_s, w_f) = E(\Pi_R) + E(\Pi_S) \tag{9}$$

Accordingly, the optimization problem is:

$$\begin{cases} \min\limits_{(L_1, w_s, w_f)} \; E(\Pi_C) \\ \textit{subject to} \\ L_0 < L_1 \\ w_s L_1 \leqslant n_s \\ w_f L_1 \leqslant n_f \\ w_s \geqslant 0, \;\; w_f \geqslant 0 \end{cases} \tag{10}$$

Proposition 1. The expected cost function of centralized policy is always convex if $\Psi_1 \geqslant 0$.

Proof. See Appendix A.

Because the objective function is convex and the corresponding constraints are linear in nature, the implication of this proposition proves that the optimal values of decision variables can be obtained if the corresponding parameters remain within the boundary of feasibility.

4.2. Decentralized policies (Policies I and II)

With regard to the two decentralized policies (Policies I and II), each party is solely interested in minimizing its own cost. Therefore, a game theoretical approach is incorporated to obtain solutions. In this sense, Policy I, whereby the shipping company imposes detention charges based on the degree of tardiness committed by the consignee, is widely practiced. Many companies consider detention charges an important revenue stream and a way to retain control over container returns (Storm, 2011). Using Eqs. (7) and (8), the expected total cost of each party under Policy I can be derived as follows:

$$\begin{cases} \min\limits_{(L_1)} E(\Pi_S) \\ \textit{subject to} \\ L_0 < L_1 \\ \textit{subject to} \\ \min\limits_{(w_s, w_f)} \; E(\Pi_R) \\ \textit{subject to} \\ w_s L_1 \leqslant n_s \\ w_f L_1 \leqslant n_f \\ w_s \geqslant 0, \;\; w_f \geqslant 0 \end{cases} \tag{11}$$

Proposition 2. The expected cost function of a consignee is always convex with respect to w_s and w_f, along with the expected cost function of a shipping company with respect to L_1 if $\Psi_2 \geqslant 0$.

Proof. See Appendix B.

For the solution approach for Policy I, we employed the Stackelberg game in which the leader takes action first and the follower moves subsequently thereafter to achieve the best benefit for each individual party. Because the detention tariff is always announced by the shipping company, it would act as the leader, whereas the consignee affected by the tariff for managing the return plays the follower. Accordingly, the backward induction is used to find the best reaction function of a consignee, $E(\Pi_R)$, with the known strategy of the leader and then acquire the best response of the leader through solving $E(\Pi_S)$. The solutions to Policy II can be obtained through the same approach.

As described in Section 3, if some containers are not returned far beyond the current cycle due to extremely high uncertainties in the return process, a shipping company has no other option than to lease containers to meet its demand for empty containers for use in the next cycle. In this sense, leasing containers may seem promising, whereas the practicality of Policy II, where detention charges may partially be used for leased containers, has been implicitly shown in existing literature on ECR problems to prevent shortages in supplying containers (Alfandari et al., 2019;Luo and Chang, 2019; Moon et al., 2010;Moon and Hong, 2016). The shipping company would compensate for the leasing costs by increasing the detention charge for the second interval; that is, α and β are introduced to address such a situation. Therefore, using Eqs. (5) and (6), the expected cost function in Scenario 3 is reformulated as follows:

$$\pi_r^{3'}(w_s, w_f) = \frac{Ar}{L_1} + \frac{hr_s}{L_1}\left[\frac{n_s L_1(L_1-1)}{2} - \frac{w_s L_1(L_1-1)(2L_1+1)}{6}\right] + \frac{hr_f}{L_1}\left[\frac{n_f L_1(L_1-1)}{2} - \frac{w_f L_1(L_1-1)(2L_1+1)}{6}\right] + \frac{e_s w_s^2}{L_1} + \frac{e_f w_f^2}{L_1} + \frac{(n_s + n_f + L_1 w_s + L_1 w_f / 4)t_r}{L_1} + \frac{pn_{s1}(L_1 - L_0)w_s}{L_1} + \frac{pn_{s2}\alpha(n_s - L_1 w_s)}{L_1} + \frac{pn_{f1}(L_1 - L_0)w_f}{L_1} + \frac{pn_{f2}\beta(n_f - L_1 w_f)}{L_1} \tag{12}$$

$$\pi_s^{3'}(L_1, \alpha, \beta) = \frac{A_s}{L_1} + \frac{L_0 w_s(L_1 - L_0)hs_s}{L_1} + \frac{L_0 w_f(L_1 - L_0)hf_s}{L_1} + \frac{(LC_s - pn_{s2}\alpha)(n_s - L_1 w_s)}{L_1} + \frac{(LC_f - pn_{f2}\beta)(n_f - L_1 w_f)}{L_1} \tag{13}$$

Therefore, Policy II is formulated with modified Eqs. (12) and (13) as follows:

$$\begin{cases} \min\limits_{(L_1,\alpha,\beta)} \; E(\Pi_S') \\ \textit{subject to} \\ L_0 < L_1 \\ \alpha\ pn_{s2} \leqslant LC_s,\ \ \beta\ pn_{f2} \leqslant LC_f \\ pn_{s1} \leqslant \alpha\ pn_{s2},\ \ pn_{f1} \leqslant \beta\ pn_{f2} \\ \alpha \geqslant 0,\ \ \beta \geqslant 0 \\ \textit{subject to} \\ \min\limits_{(w_s,w_f)} \; E(\Pi_R') \\ \textit{subject to} \\ w_s L_1 \leqslant n_s,\ \ w_f L_1 \leqslant n_f \\ w_s \geqslant 0,\ \ w_f \geqslant 0 \end{cases} \tag{14}$$

Proposition 3. The expected cost function of a consignee is always convex with respect to w_s and w_f, along with the expected cost function of a shipping company with respect to L_1, α, and β if $\Psi_3 > 0$.

Proof. See Appendix C.

5. Computational experiment

To validate the proposed models for centralized policy and Policies I and II, computational experiments including a numerical example and sensitivity analysis were conducted to reveal the impact on decision variables and the efficiency of the LESC-DC.

5.1. Numerical example

The dataset was generated from literature on the ECR problem and adjusted to our problem setting on the basis of daily unit (Konings, 2005;Moon and Hong, 2016). The expected total costs per unit time for both parties are computed. In addition, note that a shipping service route is arbitrarily selected with a certain period of each operation. The operation costs of the origin and destination differ with regard to higher price indexes, salaries, etc., along with different handling costs for standard and foldable containers. In addition, relevant activities such as loading and unloading operations and transportation by a vessel are included in the setup costs of the shipping company, while the fixed costs of the consignee include folding facilities for foldable containers. The values of the following parameters are derived from the example of hinterland transportation between Busan and Seoul, Korea.

$p_1 = 0.3$, $p_2 = 0.5$, $p_3 = 0.2$, $t_r = \$800$ per unit, $n_s = 200$ units, $n_f = 220$ units, $L_0 = 10$ days, $pn_{s1} = \$20$ per unit, $pn_{f1} = \$70$ per unit, $pn_{s2} = \$40$ per unit, $pn_{f2} = \$100$ per unit, $e_s = \$100$ per unit, $e_f = \$200$ per unit, $hs_r = \$7$ per unit per day $hf_r = \$9$ per unit per day, $hs_s = \$5$ per unit per day, $hf_s = \$7$ per unit per day, $A_r = \$28,000$, $A_s = \$81,000$, $LC_s = \$480$ per unit, $LC_f = \$960$ per unit.

Under these parameters, the optimal solutions and the expected total costs of centralized policy and Policies I and II are shown in Table 1.

The results show that centralized policy outperformed Policies I and II in terms of L_1^*, w_s^*, w_f^*, and expected total costs. This policy brings a far longer L_1^* and less investment effort in withdrawal rates for both types of containers; that is, a consignee can enjoy greater flexibility in returning empty containers at least before L_1 with a significant reduction in $E(\Pi_R^*)$ compared to those of the other policies. In the end, a shipping company can also benefit from centralized policy with a reduction in $E(\Pi_S^*)$ by sacrificing its return ratio on time, which will be discussed further in the following subsection. Comparing the performance of Policies I and II, $E(\Pi^*)$ and

Table 1
Results of numerical example.

Decision type	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$
Centralized	37.02	5.40	5.94	–	–	46,549	2,683	49,232
Policy I	16.37	7.84	13.44	–	–	56,994	5,665	62,659
Policy II	16.42	9.93	13.40	12.00	0.70	57,200	5,296	62,496

L_1^* for the two policies do not differ significantly from each other. However, under Policy II, a shipping company increases pn_{s2} to LC_s by α^* to lead a consignee boost up w_s^* while decreasing pn_{f2} by β^*. As a result, a shipping company reduces its expected total costs whereas a consignee bears higher costs in comparison with Policies I and II.

5.2. Sensitivity analyses

Sensitivity analyses on decision variables, expected total costs, and return ratios with respect to varying key parameters were conducted for a centralized policy and Policies I and II (see Tables D1,D2,D3,D4,D5,D6,D7,D8,D9,D10,D11,D12,D13 in Appendix D). Each analysis was conducted with the parameter settings introduced in Section 5.1. The return ratios of each type of container within L_0 and L_1 were calculated in the following manner:

$$L_0-\text{ and }L_1-\text{ based return ratios}=\begin{cases}\frac{L_0 w_s}{n_s} & \text{for standard containers within } L_0\\ \frac{L_0 w_f}{n_f} & \text{for foldable containers within } L_0\\ \frac{L_1 w_s}{n_s} & \text{for standard containers within } L_1\\ \frac{L_1 w_f}{n_f} & \text{for foldable containers within } L_1\end{cases}$$

5.2.1. Effect of varying degree of risk in container return

Extensive sensitivity analyses on the degree of risk in container return were conducted to explore the effect of each policy on key performance, as shown in Table D1 in Appendix D. The centralized policy outperforms the other decentralized policies in terms of $E(\Pi)$. In particular, the long duration of the first interval of detention charge enables a consignee to make a significantly smaller investment in w_s and w_f for itself. Consequently, L_0-based return ratios for standard and foldable containers appear to be low compared to those under Policies I and II, but a centralized policy ensures that every container is returned by L_1, as shown in Fig. 3. With regard to Policy I, a consignee is increasingly exposed to a higher risk of late returns in terms of L_0- and L_1-based return ratios when p_2 and p_3 increase. In such circumstances, they drastically decrease w_s whereas increasing w_f to speed up L_1-based return ratio for foldable containers minimizes detention charges. Likewise, returning foldable containers has an advantage of cost savings in hinterland transport. Furthermore, due to the high return ratios for foldable containers in every policy, a consignee could even reduce $E(\Pi_R)$ while a shipping company must bear more $E(\Pi_S)$. However, a consignee is encouraged to exploit the return of more standard containers by increasing α, but decreasing β under Policy II.

Employing the results from this sensitivity analysis, three cases are defined as low, moderate, and high risk in container returns for various sensitivity analyses on different key parameters. The probabilities of each case are (i) $p_1 = 0.7$, $p_2 = 0.2$, $p_3 = 0.1$, (ii) $p_1 = 0.3$, $p_2 = 0.6$, $p_3 = 0.1$, and (iii) $p_1 = 0.1$, $p_2 = 0.4$, $p_3 = 0.5$.

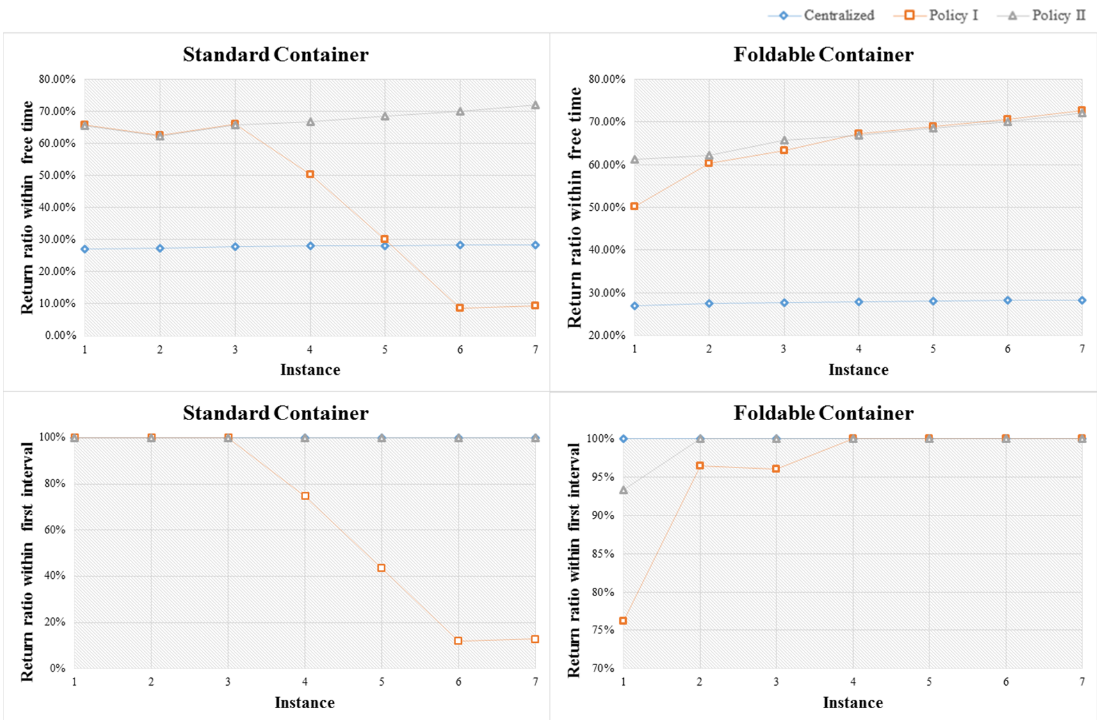

Fig. 3. L_0- and L_1-based return ratios with varying p_1, p_2, and p_3 for each policy.

5.2.2. Effect of increasing L_0

The results of another sensitivity analysis on L_0 with three cases are provided in Tables D2 and D3 in Appendix D. For every policy, a longer L_0 reduces L_1^*, $E(\Pi_R^*)$, and $E(\Pi^*)$ while increasing $E(\Pi_S^*)$ under all cases. It implies a positive impact on the entire supply chain even though a shipping company must bear more $E(\Pi_S^*)$. Fig. 4 shows higher L_0- and L_1-based return ratios with a longer L_0 and indicates that a shipping company could gain better control over its own containers to ensure its ability to meet upcoming demand by shippers. However, in Case 3, Policy I is significantly vulnerable to high risk, with the return ratios for standard containers comparable to those of other policies. Moreover, the cost savings from a longer L_0 rapidly diminish with higher risk in container returns for all policies. As a result, an increase in L_0 caused a slight reduction in L_1 but gradual increases in both withdrawal rates and total costs. This suggests that a longer free time guarantees cost savings, especially for a consignee. In terms of the return ratio, the risk of late returns was substantially reduced in all cases as L_0 increased.

5.2.3. Effect of increasing t_r

Sensitivity analysis was also conducted on t_r to investigate the impact of increasing t_r. Tables D4 and D5 in Appendix D show that higher t_r adversely affects return ratios for standard containers, but the ratio for foldable containers increases due to its space savings in hinterland transportation. Unlike Cases 1 and 2, Fig. 5 indicates that a shipping company suffers from more $E(\Pi_S^*)$ under Policy I in Case 3, along with a drastic reduction in return ratios for standard containers.

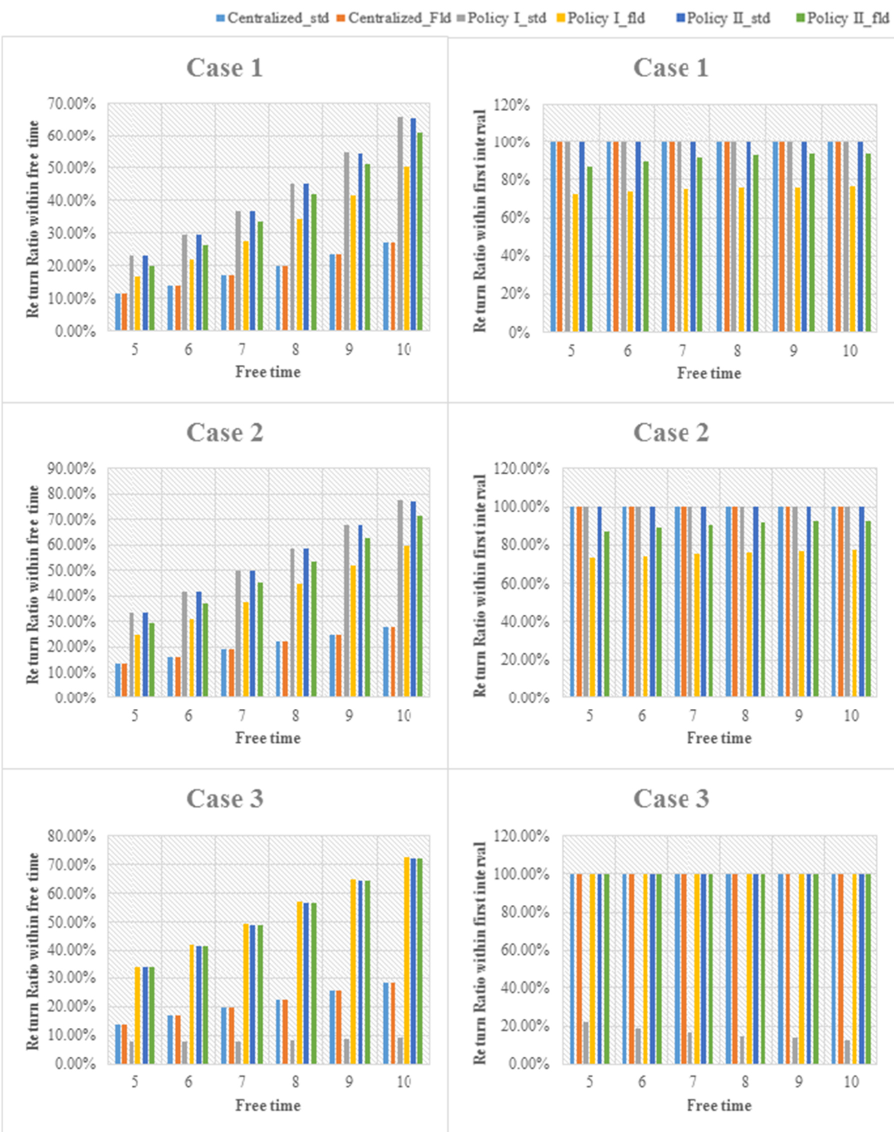

Fig. 4. L_0- and L_1-based return ratios with increasing L_0 for each policy.

5.2.4. Effect of decreasing e_s and increasing e_f

The results of sensitivity analysis on the discounting effect of e_s are presented in Tables D6 and D7. Fig. 6 illustrates that in Cases 1 and 2, both decentralized policies increase L_0-based return ratios for standard containers, $E(\Pi_S^*)$, and $E(\Pi_R^*)$ while significantly decreasing L_1-based return ratios for foldable containers. Although one might expect that reduction in e_s could bring cost savings at least for a consignee, decreasing return ratios for foldable containers cause higher additional costs in inland transportation. In Case 3, Policy II seems more beneficial to both parties in terms of key performances comparing to Policy I. The results of sensitivity analysis on the effect of increasing e_f in contrast, are presented in Tables D8 and D9. Every policy shows that $E(\Pi_S^*)$ and $E(\Pi_R^*)$ gradually rise with increasing e_f but this increase is insensitive to L_1 and w_s except for Case 3. Fig. 7 indicates that under Policies I and II, increasing e_f brings a cost savings in $E(\Pi_S^*)$ and $E(\Pi_R^*)$ by increasing the L_0-based return ratio for n_s and L_1^*, respectively. This finding indicates the robustness of the proposed policies to manage a high level of uncertainty with regard to returns.

5.2.5. Discounting effect of pn_{f1} and pn_{f2}

Tables D10 and D11 explore the impacts of pn_{f1} and pn_{f2} on optimal solutions, expected total costs, and return ratios. Return ratios for both types of decisions were fully investigated when pn_{f1} and pn_{f2} were decreased to pn_{s1} and pn_{s2}, respectively. Case 3 is more sensitive to the discounting effect compared to Cases 1 and 2 because L_0-and L_1-based return ratio fluctuate in Case 3. In Fig. 8, both Policies I and II slightly decrease L_0-based return ratios for foldable containers with the discounting effect but significantly increase them when the degree of risk in container return is intensified. Especially under Policy II, L_1-based return ratios for foldable containers remain high due to the penalization of a consignee for late returns, as shown in β^*. A consignee could be less motivated to return foldable containers on time with discounted pn_{f1} and pn_{f2} due to relative high e_f but be better off with the high return ratios along with increasing risk in the return. Unlike in Cases 1 and 2, the discounting effect has a positive impact on a shipping company by decreasing $E(\Pi_S^*)$ in Case 3, as shown in Table D11.

5.2.6. Effect of different container fleet sizes

Different container fleet sizes are used to explore the effects of each policy and case. Each instance represents 20%, 40%, 60%, and 80% of 400 total containers, respectively. Tables D12 and D13 show that each party prefers specific container fleet sizes in terms of the first interval of detention charge and expected total costs according to each case. For Case 1 in Fig. 9, a shipping company attains the minimum expected total costs at Instances 4, 2, and 2 for the centralized policy and Policies I and II, respectively, whereas a consignee achieves minimum costs at Instances 4, 4, and 3, respectively. These findings show that maximum use of foldable containers does not guarantee minimum costs and high return ratios due to the additional handling costs for foldable containers and higher detention charges. Hence, the shipping company should carefully consider the usage rate of standard and foldable containers to maintain control over empty returns and to minimize the cost.

6. Managerial insights

In the computational experiments, centralized and decentralized policies often showed significant variation in optimal solutions, return ratios until free time and first interval of detention for standard and foldable containers, and the expected total costs of each party according to the different degree of risk in container returns represented by each case. Throughout the sensitivity analyses, the centralized policy had far higher return ratios both for two-time intervals, but every container was returned within the first interval of detention. This implies that both parties could gain economic benefits for their operations with a longer first interval under full cooperation, whereas relatively low return ratios until free time might hinder efficient operations for a shipping company.

Overall, decentralized policies, Policies I and II, did not reveal a significant difference in the expected total costs of each party under low and moderate risks in container returns, but Policy II presented higher return ratios for foldable containers than did Policy I. Owing to the decisions on compensating for the loss in profits because of leasing containers, a shipping company could manage such decisions by adjusting compensation levels to lease containers and not force a consignee to put a large amount of investment effort into withdrawal rates for both container types in such a financially burdensome manner. However, Policy II entails a high risk for a consignee when return ratios until the first interval of detention for foldable containers becomes extremely low. Moreover, both decentralized policies increased the duration of the first interval while decreasing a withdrawal rate for foldable containers. This

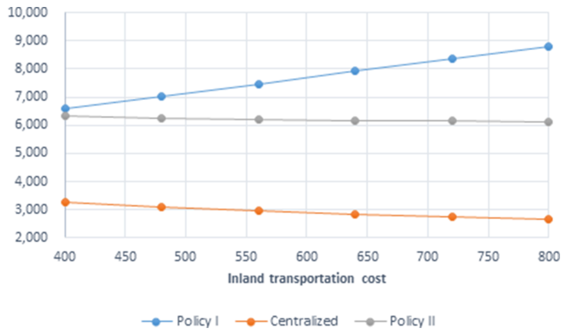

Fig. 5. Optimal expected total costs for a shipping company under Case 3.

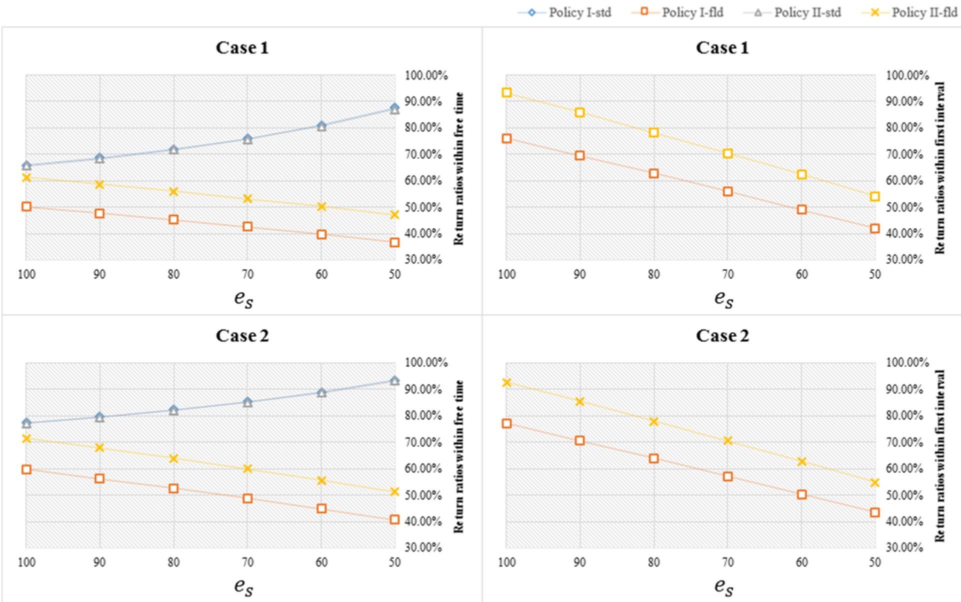

Fig. 6. L_0- and L_1-based return ratios with decreasing e_s under Cases 1 and 2.

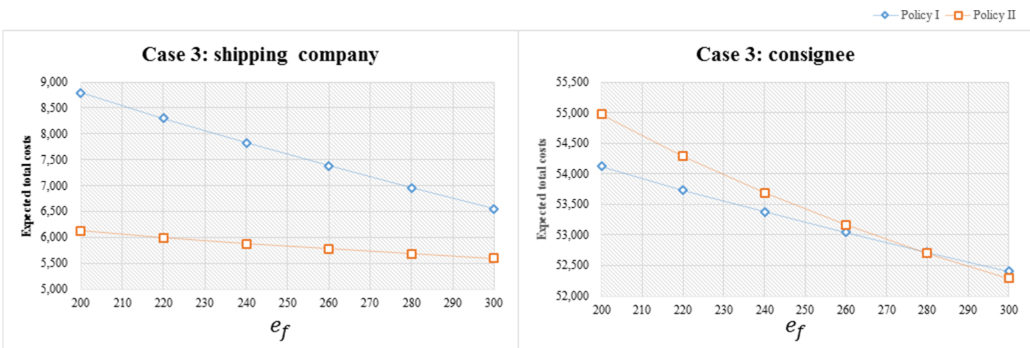

Fig. 7. Optimal expected total costs with increasing e_f under Case 3.

implication shows that a shipping company would be better off by permitting the longer detention interval when a consignee has less returning capability for foldable containers.

In Case 3, it was clearly observed that a shipping company had to bear more expected total costs under Policy I than under Policy II because low return ratios until free time for standard containers caused more additional handling costs for empty containers during the first interval of detention and frequent leasing activities for standard containers. Much like the centralized policy, Policy II guaranteed the same return ratios for both types of containers without a significant increase in the expected total cost of a consignee when compared to Policy I. Therefore, a shipping company could gain better control over container returns and facilitate the circulation of its own containers even under a high level of uncertainty in the return process. On the other hand, the compensation level for leasing foldable containers significantly increases under low and moderate risks when discounting effects escalate under Policy II. This implies that a shipping company strives to receive more foldable containers by penalizing late returns when a consignee is less motivated to return containers promptly.

In general, the management of each party could properly manage their key decision-making under a varying degree of risk in container returns by selecting the proper return policy. One could prefer the centralized policy, due to its lowest expected total costs and its robustness against risk in returns, but this policy also has the lowest return ratio until the free time. In other words, a shipping company would encounter more lost opportunities for the demand of the next cycle, along with insufficient cost savings, by choosing this policy. In this regard, decentralized policies could bring more financial benefits, along with a higher return ratio for both parties; that is, a consignee could make fewer investment efforts in withdrawal rates while a shipping company could reduce lost opportunities by having more empty containers on hand. Cobb (2016) provided a similar philosophy that a sufficient stock of containers could be used for buffer stocks that could help offset used and repairable containers with a stochastic returning process.

The results also proved that foldable containers are very effective in counteracting high risk in container returns because of their space-saving qualities in transportation and storage. Another emerging container type, a combinable container, was introduced by Shintani et al. (2019). They showed that these types of containers could be a useful alternative to deal with the risk of returns; that is,

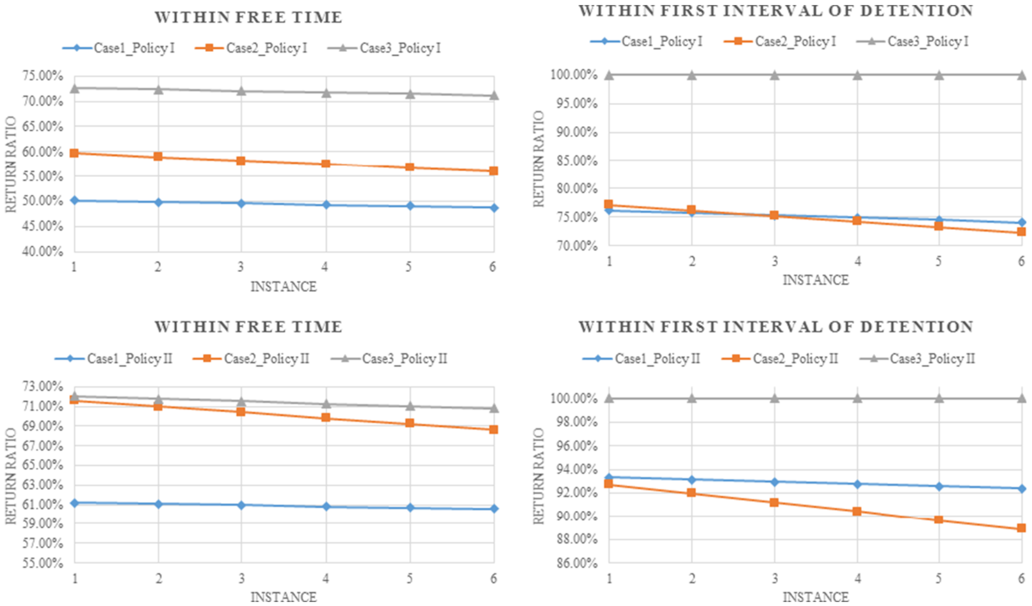

Fig. 8. L_0- and L_1-based return ratios with decreasing pn_{f1} and pn_{f2} for each policy.

they showed potential cost savings in container fleet and empty container repositioning by developing the minimum cost multi-commodity network flow model. However, as mentioned in Section 5.2.6, the proper size of the container fleet is essential according to the degree of the risk.

7. Conclusions

This paper developed a scenario-based model for the LESC-DC to determine optimal devanning time, composed of shipments between a consignee and a port and an empty return, and investigated the effects of proposed policies and container type with regard to the L_0- and L_1-based return ratios. In essence, this paper strives to offer some useful strategies and managerial insights for dealing with issues regarding container return under both decentralized policies and cooperative efforts.

A sensitivity analysis on decentralized versus centralized policies processes with respect to varying key parameters was conducted to determine how adjustments in key parameters affected return behaviors in terms of return ratios within L_0 and L_1 and to determine the optimal usage rate for foldable containers. Cooperation under a centralized policy process results in minimum expected total costs for the entire supply chain. We also demonstrated uncertain situations where the probability of triggering late returns was intensified. In this case, a shipping company behaves more conservatively on the acceptable interval of detention when the consignee increases investment efforts to maximize withdrawal rates so as to minimize detention charges. In addition, because maximum use of foldable containers did not attain minimum costs, suitable container fleet should be taken in account to satisfy the consignee's demands.

Although the centralized policy appeared to be the best implementation for both parties in terms of expected total costs, they would need to sacrifice their own interests to accomplish this cooperation scheme; that is, a shipping company provides a long duration for the first interval of detention charge along with low return ratios, whereas a consignee bears the higher handling cost of laden containers due to low return ratios. Despite the lack of a significant difference in expected total costs between Policies I and II, the return ratios for standard and foldable containers demonstrated substantial deviation throughout all the sensitivity analyses. This suggests that the management should implement each policy carefully to optimize the company's operations based on the degree of risk in container return.

However, we acknowledge the following limitations of this study: (i) we have to propose the coordination mechanism to remove a conflict between the shipping company and the consignee; (ii) it is necessary to analyze investment efforts by considering impacts of labor, technology, space, etc;and (iii) this simplified scenario-based study was conducted using an analytical approach. With regard to the third point, we could consider a more general examination of the problem by developing integer programming models. In the future, this research could be extended by studying the impact of free time as a decision variable with the various types of containers, such as 20ft standard containers and other special types of containers. Another penalty cost, the demurrage charge, could be considered in the analysis of the impact on container flows. This analysis could include the combined free times for demurrage and detention charges, and could take into account more components of withdrawal rates to analyze the impact of investment efforts. Furthermore, this model could be extended by considering detention charges as profit generators in an effort to achieve parity between a shipping company and a consignee in consideration of the ownership of a container; namely, shipper-owned containers (SOCs) and carrier-owned containers (COCs). For SOCs, a consignee is no longer obligated to pay detention and demurrage charges, while COCs play the same role as containers shown in this study.

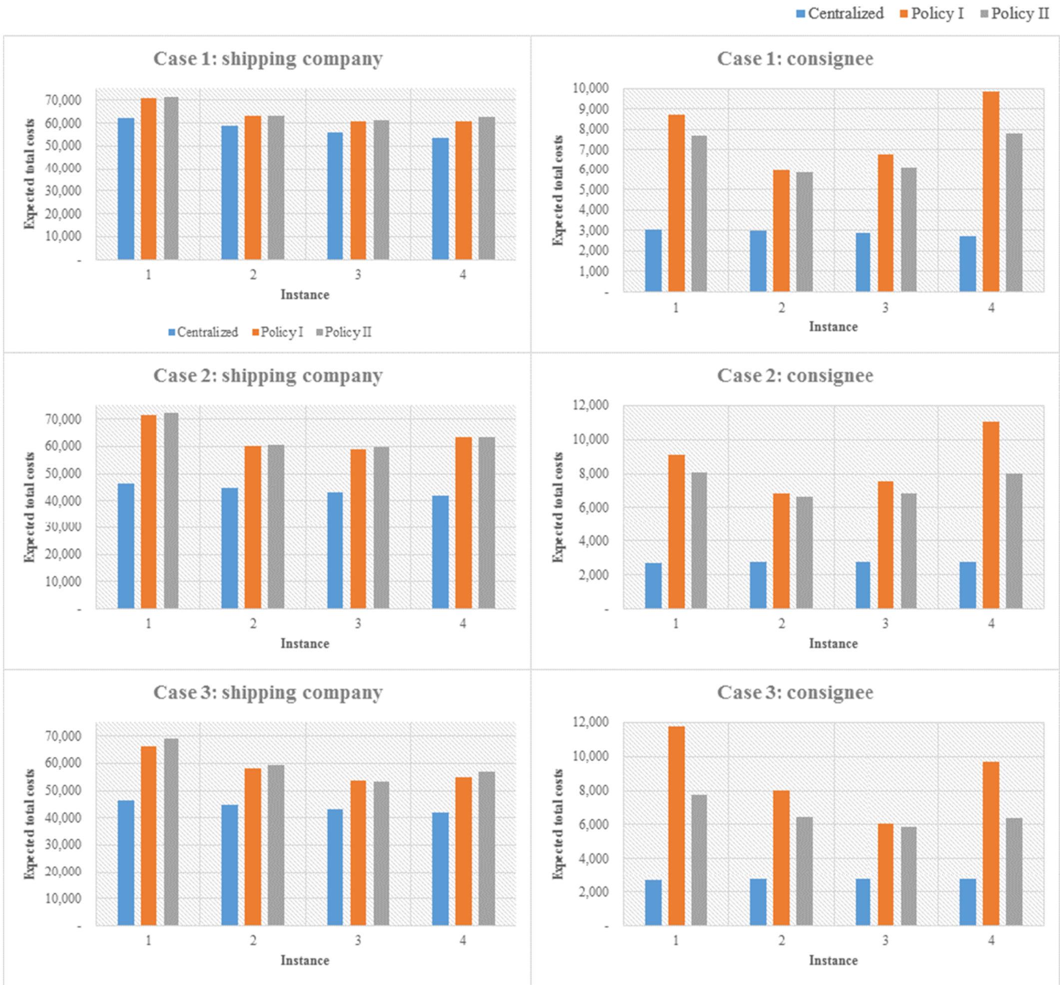

Fig. 9. Optimal expected total costs for both parties under each case.

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Appendix A. Proof of Proposition 1

The optimal solutions for the centralized policy in Eq. (10) is obtained by solving $\frac{\partial E(\Pi_C)}{\partial w_s} = 0$, $\frac{\partial E(\Pi_C)}{\partial w_f} = 0$, and $\frac{\partial E(\Pi_C)}{\partial L_1} = 0$ simultaneously. On simplification, following equations are obtained:

$$\left.\begin{array}{l} L_0[hs_r L_1\{(1 + L_0 - 2L_0^2)p_1 - (L_1 - 1)(1 + 2L_1)(p_2 + p_3)\} \\ - 6\{(hs_s L_0(L_0 - L_1) + L_0 pn_{s1})(p_2 + p_3) + L_1 p_3 x_1\}] \\ + 12 e_s w_s x_3 \end{array}\right\} = 0 \tag{A1}$$

$$\left.\begin{array}{l} L_0[2hf_r L_1 x_6 - 3\{(hf_s L_0(L_0 - L_1) + 4L_0 pn_{f1})(p_2 + p_3) + L_1 p_3 x_2\}] \\ + 24 e_f w_f x_3 \end{array}\right\} = 0 \tag{A2}$$

$$\left.\begin{array}{l} 12hs_s L_0 n_s p_1 + 6(p_2 + p_3)L_1^2(hf_r n_f + hs_r n_s) - 12(LC_f n_f + LC_s n_s)p_3 \\ - 12A_r(p_2 + p_3) - 12A_s - 12p_2(n_f pn_{f1} + n_s pn_{s1}) \\ - 15n_f p_2 t_r - 24n_s p_2 t_r - 12(n_f + n_s)p_3 t_r + 2hf_r L_1^2 p_2 w_f - 8hf_r L_1^3 p_2 w_f \\ + 2hf_r L_1^2 p_3 w_f - 8hf_r L_1^3 p_3 w_f + 12L_0 pn_{f1} w_f(p_2 - p_3) - 12e_f(p_2 + p_3)w_f^2 - 3hf_s L_0 \\ \{n_f p_1 + L_0(1 - p_1)w_f\} + 2(p_2 + p_3)\{hs_r(1 - 4L_1)L_1^2 - 6L_0(hs_s L_0 - pn_{s1}) + 6e_s w_s\}w_s \end{array}\right\} = 0 \tag{A3}$$

Where $x_1 = LC_s - pn_{s1} - t_r$, $x_2 = 4LC_f - 4pn_{f1} - t_r$, $x_3 = L_1 p_1 + L_0(p_2 + p_3)$, $x_5 = pn_{s1} - pn_{s2} + t_r$, and $x_6 = (1 + L_0 - 2L_0^2)p_1 - (L_1 - 1)(1 + 2L_1)(p_2 + p_3)$

Solving Equations (A1) and (A2), one can obtain

$$w_s = \frac{L_0[hs_r L_1\{(L_0-1)(1+2L_0)p_1 + (L_1-1)(1+2L_1)(p_2+p_3)\} + 6\{(hs_s L_0(L_0-L_1) + L_0 pn_{s1})(p_2+p_3) + L_1 p_3 x_1\}]}{12 e_s x_3}$$
$$w_f = \frac{L_0[2hf_r L_1\{(L_0-1)(1+2L_0)p_1 + (L_1-1)(1+2L_1)(p_2+p_3)\} + 3\{(hf_s L_0(L_0-L_1) + 4L_0 pn_{f1})(p_2+p_3) + L_1 p_3 x_2\}]}{24 e_f x_3}$$

Substituting w_s and w_f to Equation (A3), one can obtain sixth order polynomial equation to obtain L_1. We computed Hessian matrix (H^T) to verify the convexity of expected cost function in centralized policy as follows:

$$H^T = \begin{vmatrix} \frac{\partial^2 E(\Pi_c)}{\partial w_s^2} & \frac{\partial^2 E(\Pi_c)}{\partial w_s \partial w_f} & \frac{\partial^2 E(\Pi_c)}{\partial w_s \partial L_1} \\ \frac{\partial^2 E(\Pi_c)}{\partial w_s \partial w_f} & \frac{\partial^2 E(\Pi_c)}{\partial w_f^2} & \frac{\partial^2 E(\Pi_c)}{\partial w_s \partial w_f} \\ \frac{\partial^2 E(\Pi_c)}{\partial w_s \partial L_1} & \frac{\partial^2 E(\Pi_c)}{\partial w_f \partial L_1} & \frac{\partial^2 E(\Pi_c)}{\partial L_1^2} \end{vmatrix} = \begin{vmatrix} \frac{2e_s x_3}{L_0 L_1} & 0 & \frac{\phi_1}{6L_1^2} \\ 0 & \frac{2e_f x_3}{L_0 L_1} & \frac{\phi_2}{12L_1^2} \\ \frac{\phi_1}{6L_1^2} & \frac{\phi_2}{12L_1^2} & \frac{\phi_3}{6L_1^3} \end{vmatrix}$$

where

$$\phi_1 = (1 - p_1)\{hs_r(1 - 4L_1)L_1^2 + 6L_0(hs_s L_0 + pn_{s1}) - 12e_s w_s\}$$

$$\phi_2 = (1 - p_1)\{2hf_r(1 - 4L_1)L_1^2 + 3L_0(hf_s L_0 + 4pn_{f1}) - 24e_f w_f\}$$

$$\begin{aligned}\phi_3 = {} & 12\{(A_r + A_s + e_s w_s^2 + e_f w_f^2)(p_2 + p_3) + LC_s n_s p_3 - hs_s L_0 n_s p_1 + LC_f n_f p_3 + n_f p_2 pn_{f1}\} \\ & + 12n_s p_2 pn_{s1} + 3(5n_f p_2 + 8n_s p_2 + 4n_f p_3 + 4n_s p_3)t_r - 4(p_2 + p_3)(hf_r L_1^3 + 3L_0 pn_{f1} +)w_f \\ & - 3hf_s L_0\{n_f p_1 + L_0(p_2 + p_3)w_f\} - 4(p_2 + p_3)\{hs_r L_1^3 + 3L_0(hs_s L_0 + pn_{s1})\}w_s\end{aligned}$$

The values of principal minors are $H_1^T = \frac{2e_s x_3}{L_0 L_1}$;$H_2^T = \frac{4e_s e_f x_3^2}{L_0^2 L_1^2}$; and $H_3^T = -\frac{x_3}{72L_0^2 L_1^5}\Psi_1$, respectively. Therefore, cost function for a shipping company is convex if $\Psi_1 > 0$, where

$$\begin{aligned}\Psi_1 = {} & e_s L_0(p_2 + p_3)^2\{2hf_r(1 - 4L_1)L_1^2 + 3L_0(hf_s L_0 + 4pn_{f1}) - 24e_f w_f\}^2 + 4e_f L_0(p_2 + \\ & p_3)^2\{hs_r(1 - 4L_1)L_1^2 + 6L_0(hs_s L_0 + pn_{s1}) - 12e_s w_s\}^2 - 48e_s e_f x_3[12\{A_r(p_2 + p_3) + LC_s n_s p_3 + \\ & LC_f n_f p_3 - hs_s L_0 n_s p_1 + A_s + n_f p_2 pn_{f1} + n_s p_2 pn_{s1}\} + 3\{5n_f p_2 + 8n_s p_2 + 4n_f p_3 + 4n_s p_3\}t_r - \\ & 4(p_2 + p_3)\{hf_r L_1^3 + 3L_0 pn_{f1} - 3(e_f w_f^2 + e_s w_s^2)\}w_f - 3hf_s L_0\{n_f p_1 + L_0(p_2 + p_3)w_f\} - 4(p_2 + \\ & p_3)\{hs_r L_1^3 + 3L_0(hs_s L_0 + pn_{s1})\}w_s]\end{aligned}$$

In addition, the handling cost terms of standard containers in Eq. (1) are derived as follows:

$$\begin{aligned}&(n_s - w_s) \times 1 + (n_s - 2w_s) \times 2 + \ldots + (n_s - (L_0 - 1)w_s) \times (L_0 - 1) \\ &\qquad n_s[1 + 2 + \ldots + (L_0 - 1)] - w_s[1^2 + 2^2 + \ldots + (L_0 - 1)^2]\end{aligned}$$

After applying the sums of arithmetic progression and squares of arithmetic progression, one can obtain

$$\frac{n_s L_0(L_0 - 1)}{2} - \frac{w_s L_0(L_0 - 1)(2L_0 + 1)}{6}$$

The handling cost for foldable containers could be derived in the same manner as well as in other scenarios.

Appendix B. Proof of Proposition 2

The optimal solutions for a consignee's optimization problem are obtained by solving $\frac{\partial E(\Pi_R)}{\partial w_s} = 0$ and $\frac{\partial E(\Pi_R)}{\partial w_f} = 0$ simultaneously. On simplification, Equations (B1) and (B2) are obtained as follows:

$$\left.\begin{aligned}&hs_r L_0 L_1\{1 - L_1(2L_1 - 1)(1 - p_1) + (1 - 2L_0)L_0 p_1\} \\ &- 6L_0\{L_0(1 - p_1)pn_{s1} - p_3 L_1 x_5\} + 12e_s x_3 w_s\end{aligned}\right\} = 0 \tag{B1}$$

$$\left.\begin{aligned}&2hf_r L_0 L_1\{1 - L_1(2L_1 - 1)(1 - p_1) + (1 - 2L_0)L_0 p_1\} \\ &+ 3L_0\{L_1 p_3 x_6 - 4L_0(1 - p_1)pn_{f1}\} + 24e_f w_f x_3\end{aligned}\right\} = 0 \tag{B2}$$

Because the equations are linear in nature, the solutions are obtained as follows:

$$w_s = \frac{L_0[hs_r L_1\{L_1(2L_1-1)(1-p_1) + (2L_0-1)L_0 p_1 - 1\} + 6L_0(1-p_1)pn_{s1} - 6L_1 p_3 x_5]}{12 e_s x_3}$$
$$w_f = \frac{2hf_r L_0 L_1\{L_1(2L_1-1)(1-p_1) + (2L_0-1)L_0 p_1 - 1\} + 3L_0\{4L_0(1-p_1)pn_{f1} - L_1 p_3 x_6\}}{24 e_f x_3}$$

The expected cost function of a consignee is convex because $\frac{\partial^2 E(\Pi_R)}{\partial w_s^2} = \frac{2e_s x_3}{L_0 L_1} > 0$ and $\frac{\partial^2 E(\Pi_R)}{\partial w_s^2} \times \frac{\partial^2 E(\Pi_R)}{\partial w_f^2} - \left(\frac{\partial^2 E(\Pi_R)}{\partial w_s \partial w_f}\right)^2 = \frac{4e_s e_f x_3^2}{L_0^2 L_1^2} > 0$.

Substituting w_s and w_f, the expected cost function of a consignee can be obtained as follows:

$$E(\Pi_S) = \frac{A_1L_1^4 + A_2L_1^3 + A_3L_1^2 + A_4L_1 + A_5}{96e_se_fL_1x_3}$$

where

$$A_1 = 4L_0(1-p_1)\{(e_shf_r(hf_sL_0(1-p_1) - 4p_3(LC_f - pn_{f2})) + 4e_fhs_r(hs_sL_0(1-p_1) - p_3(LC_s - pn_{s2}))\}$$
$$A_2 = 2L_0(1-p_1)\{4e_fhs_r(p_3(LC_s - pn_{s2}) - hs_sL_0(1+2L_0)(1-p_1)) - e_shf_r(hf_sL_0(1+2L_0)(1-p_1) + 4p_3(LC_f - pn_{f2}))\}$$
$$A_3 = e_s\{24e_f(hf_sn_f + 4hs_sn_s)p_1^2 + 2hf_rL_0(hf_s(L_0-1)L_0(1-p_1)(1+2L_0p_1) - 4(L_0(2L_0-1)p_1 - 1)p_3(LC_f - pn_{f2})) - 3L_0p_3 (hf_sL_0(1-p_1) + 4p_3(LC_f - pn_{f2}))(4pn_{f1} - 4pn_{f2} + t_r)\} + 8e_fL_0 \{hs_r(hs_s(L_0-1)L_0(1-p_1)(1+2L_0p_1) + (1 + L_0(2L_0-1)p_1)p_3(LC_s - pn_{s2})) - 6p_3(hs_sL_0(1-p_1) - p_3(LC_s - pn_{s2}))x_4\}$$
$$A_4 = e_s[96A_se_fp_1 + 2hf_rhf_sL_0^3(1-p_1)(1 - L_0(2L_0-1)p_1) + 24e_fp_1 (hf_sL_0n_f(1-2p_1) + 4(hs_sL_0n_s(1-2p_1) + LC_fn_fp_3 + p_3(LC_sn_s - n_fpn_{f2} - n_spn_{s2}))) + 3L_0^2(1-p_1) \{16p_3pn_{f1}(LC_f - pn_{f2}) + hf_sL_0\{4(2 - 2p_1 - p_2)pn_{f1} - p_3(4pn_{f2} - t_r)\}\}] + 8e_fL_0^2(1-p_1) \{hs_rhs_sL_0(1 - L_0(2L_0-1)p_1) + 6(p_3pn_{s1}(pn_{s2} - LC_s) + hs_sL_0((2 - 2p_1 - p_2)pn_{s1} - p_3(pn_{s2} - t_r)))\}$$
$$A_5 = 12L_0(1-p_1)\{8A_se_se_f - e_shf_sL_0^3(1-p_1)pn_{f1} - 4e_fhs_sL_0^3(1-p_1)pn_{s1} + 2e_se_f (4LC_sn_sp_3 - hf_sL_0n_fp_1 - 4hs_sL_0n_sp_1 + 4LC_fn_fp_3 - 4p_3(n_fpn_{f2} + n_spn_{s2}))\}$$

Therefore, the optimal values of L_1 are obtained by solving $\frac{\partial E(\Pi_S)}{\partial L_1} = 0$, i.e. $2A_1p_1L_1^4 + 2A_2L_0(1-p_1)L_1^3 + \{A_3L_0 - (A_4 + A_3L_0)\}L_1^2 - 2A_5p_1L_1 - A_5L_0(1-p_1) = 0$. One can apply Ferrari's method to solve bi-quadratic equation to obtain the optimal values of L_1. Note that $\frac{\partial^2E(\Pi_S)}{\partial L_1^2} = \frac{\Psi_2}{48e_se_fL_1^3x_3^3}$, therefore the expected cost function of the consignee is also convex if.

$$\Psi_2 = A_1p_1^2L_1^6 + 3A_1L_0(1-p_1)p_1L_1^5 + 3A_1L_0^2(1-p_1)^2L_1^4 + \{A_2L_0^2(1-p_1)^2 - p_1(A_3L_0(1-p_1) - A_4p_1)\}L_1^3 + 3A_5p_1^2L_1^2 + 3A_5 L_0(1-p_1)p_1L_1 + A_5L_0^2(1-p_1)^2 > 0.$$

Appendix C. Proof of Proposition 3

Similar to Proposition 2, first we need to find w_s and w_f. After substitution, one finds the cost function of shipping company as a function of L_1, α, and β. Therefore, the optimal values are obtained by solving $\frac{\partial E(\Pi_S')}{\partial \alpha} = 0$, $\frac{\partial E(\Pi_S')}{\partial \beta} = 0$, and $\frac{\partial E(\Pi_S')}{\partial L_1} = 0$. Solving first two equation one can obtain,

$$\alpha = \frac{hs_rL_0L_1^2x_6 + 6[2e_sn_sx_3 + L_0L_1\{(hs_sL_0(L_0 - L_1) - L_0pn_{s1})(p_2 + p_3) + L_1p_3(LC_s + pn_{s1} + t_r)\}]}{12L_0L_1^2p_3pn_{s2}}$$
$$\beta = \frac{2hf_rL_0L_1^2x_6 + 3[8e_fn_fx_3 + L_0L_1\{(hf_sL_0(L_0 - L_1) - 4L_0pn_{f1})(p_2 + p_3) + L_1p_3(4(LC_f + pn_{f1}) + t_r)\}]}{24L_0L_1^2p_3pn_{f2}}$$

By substituting α and β in the equation below, one can obtain L_1

$$A_1'L_1^5 + A_2'L_1^4 + A_3'L_1^3 + A_4'L_1^2 + A_5'L_1 + A_6 = 0$$

where

$$A_1' = 8L_0p_1(p_2 + p_3)\{4e_fhs_r(LC_sp_3 - hs_sL_0(p_2 + p_3) - p_3x_7) + e_shf_r(4p_3(LC_f - x_8) - hf_sL_0(p_2 + p_3))\}$$
$$A_2' = 2L_0(p_2 + p_3)\{4e_fhs_r(hs_sL_0(p_2 + p_3)(p_1 + 2L_0p_1 - 6L_0(p_2 + p_3)) + p_3(6L_0(p_2 + p_3) - p_1)(LC_s - x_7)) + e_shf_r (hf_sL_0(p_2 + p_3)(p_1 + 2L_0p_1 - 6L_0(p_2 + p_3)) + 4p_3(6L_0(p_2 + p_3) - p_1)(LC_f - x_8))\}$$
$$A_3' = 4L_0^2(p_2 + p_3)^2\{4e_fhs_r(hs_sL_0(1 + 2L_0)(p_2 + p_3) + p_3x_7 - LC_sp_3) + e_shf_r(hf_sL_0(1 + 2L_0)(p_2 + p_3) - 4p_3(LC_f - x_8))\}$$
$$A_4' = 96A_se_se_fp_1^2 - 8e_fL_0^2(p_2 + p_3)[hs_r\{hs_sL_0((L_0 - 1)(1 + 2L_0)p_1^2 + L_0p_1(2L_0 - 1)(p_2 + p_3) + (L_0 - 1)(p_2 + p_3)^2 - 2) - ((L_0 - 1)(1 + 2L_0)p_1 - p_2 - p_3)p_3(LC_s - x_7)\} + +6p_3(LC_s - x_7)\{p_1pn_{s1} + p_3(pn_{s1} + t_r - x_7)\} - 6hs_sL_0 \{p_1p_2pn_{s1} + p_3(p_2 + p_3)(pn_{s1} + t_r - x_7) + p_1p_3(2pn_{s1} + t_r - x_7)\}] + e_s [24e_fp_1^2(4p_3(LC_fn_f + LC_sn_s - n_sx_7 - n_fx_8) - hf_sL_0n_fp_1 - 4hs_sL_0n_sp_1) - L_0^2(p_2 + p_3) \{12p_3(LC_f - x_8)(4p_1pn_{f1} + p_3(4pn_{f1} + t_r - 4x_8)) - 3hf_sL_0(4p_1p_2pn_{f1} + p_3(p_2 + p_3)(4pn_{f1} + t_r - 4x_8) + p_1p_3(8pn_{f1} + t_r - 4x_8)) + 2hf_r (hf_sL_0((L_0 - 1)(1 + 2L_0)p_1^2 + (L_0(2L_0 - 1) - 2)p_1(p_2 + p_3) + (L_0 - 1)(p_2 + p_3)^2) - 4\{(L_0 - 1)(1 + 2L_0)p_1 - (1 - p_1)\}p_3(LC_f - x_8))\}]$$

$$A_5' = \\ 24L_0p_1(p_2+p_3)[8A_se_se_f - 4e_fhs_sL_0^3(p_2+p_3)pn_{s1} - e_s \\ \{hf_sL_0^3(p_2+p_3)pn_{f1} + 2e_f(hf_sL_0n_fp_1 + 4hs_sL_0n_sp_1 - 4p_3(LC_fn_f + LC_sn_s - n_sx_7 - n_fx_8))\}]$$

$$A_6' = \\ 12L_0^2(p_2+p_3)^2[8A_se_se_f - 4e_fhs_sL_0^3(p_2+p_3)pn_{s1} - e_s \\ \{hf_sL_0^3(p_2+p_3)pn_{f1} + 2e_f(hf_sL_0n_fp_1 + 4hs_sL_0n_sp_1 - 4p_3(LC_fn_f + LC_sn_s - n_sx_7 - n_fx_8))\}]$$

where $x_7 = pn_{s2}\alpha$ and $x_8 = pn_{f2}\beta$.

Therefore, we compute Hessian matrix (H^T) to verify convexity as follows:

$$H^T = \begin{vmatrix} \frac{\partial^2E(\Pi_{S'})}{\partial\alpha^2} & \frac{\partial^2E(\Pi_{S'})}{\partial\alpha\partial\beta} & \frac{\partial^2E(\Pi_{S'})}{\partial\alpha\partial L_1} \\ \frac{\partial^2E(\Pi_{S'})}{\partial\alpha\partial\beta} & \frac{\partial^2E(\Pi_{S'})}{\partial\beta^2} & \frac{\partial^2E(\Pi_{S'})}{\partial\beta\partial L_1} \\ \frac{\partial^2E(\Pi_{S'})}{\partial\alpha\partial L_1} & \frac{\partial^2E(\Pi_{S'})}{\partial\beta\partial L_1} & \frac{\partial^2E(\Pi_{S'})}{\partial L_1^2} \end{vmatrix} = \begin{vmatrix} \frac{L_0L_1p_3^2pn_{s2}^2}{e_sx_3} & 0 & \frac{p_3pn_{s2}\phi_4}{12e_sL_1^2x_3^2} \\ 0 & \frac{L_0L_1p_3^2pn_{f2}^2}{e_fx_3} & \frac{p_3pn_{f2}\phi_5}{24e_2L_1^2x_3^2} \\ \frac{p_3pn_{s2}\phi_4}{12e_sL_1^2x_3^2} & \frac{p_3pn_{f2}\phi_5}{24e_2L_1^2x_3^2} & \frac{p_3^4pn_{s2}^2pn_{f2}^2\phi_6}{24e_2L_1^3} \end{vmatrix}$$

The values of principal minors are $H_1^T = \frac{L_0L_1p_3^2pn_{s2}^2}{e_sx_3} > 0$;$H_2^T = \frac{L_0^2L_1^2p_3^4pn_{f2}^2pn_{s2}^2}{e_se_fx_3^2} > 0$; and $H_3^T = \frac{L_0p_3^4pn_{f2}^2pn_{s2}^2}{576e_s^2e_f^2L_1^3x_3^6}\Psi_3$, respectively. Therefore, cost function for a shipping company is convex if $\Psi_3 > 0$, where

$$\phi_4 = 12e_sn_sx_3^2 + L_0L_1^2(1-p_1)[hs_r\{p_1\{2L_0^3 - L_0^2 - L_0 + L_1^2(4L_1-1)\} + L_0x_{10}(1-p_1)\} + 6L_0\{hs_sL_0 - p_1pn_{s1} - p_3(LC_s + pn_{s1} + t_r - 2x_7)\}]$$

$$\phi_5 = \\ 2hf_rL_0L_1^2(1-p_1)\{L_0(6L_1^2 - 2L_1 - 1) + (L_0-L_1)^2(2L_0 + 4L_1 - 1)p_1\}pn_{f2} + 3[hf_sL_0^3L_1^2(1-p_1)pn_{f2} + 8e_fL_1^2n_sp_1^2pn_{s2} + 16e_fL_0L_1n_s \\ p_1(1-p_1)pn_{s2} + L_0^2(1-p_1)\{8e_fn_s(1-p_1)pn_{s2} - L_1^2pn_{f2}(4p_1pn_{f1} + p_3(4LC_f + 4pn_{f1} + t_r - 8x_8))\}]$$

$$\phi_6 = 96A_se_se_fx_3^3 - 8e_fL_0(1-p_1)\{x_{18}(x_7 - LC_s) - hs_rhs_sx_{17}L_1^3\} + 6L_0[L_1^3p_1p_3(LC_s - x_7)\{p_1pn_{s1} + p_3(pn_{s1} + t_r - x_7)\} \\ + hs_sL_0\{3x_{19}pn_{s1} + 3x_{20}pn_{s1} + x_{21}pn_{s1} + L_1^3p_1(p_3x_7 - p_3(1-p_1)(pn_{s1} + t_r) - p_1\{p_2pn_{s1} + p_3(2pn_{s1} + t_r)\})\}] \\ - e_s[24e_fx_3^3\{hf_sL_0n_fp_1 + 4hs_sL_0n_sp_1 + 4p_3(n_sx_7 + n_fx_8 - LC_fn_f - LC_sn_s)\} + L_0(1-p_1)\} - 2hf_rL_1^3hf_sx_{17} - 4x_{18}(LC_f - x_8)\} \\ + 3L_0\{4L_1^3p_1p_3(LC_f - x_8)\{4p_1pn_{f1} + p_3(4pn_{f1} + t_r - 4x_8)\} + hf_sL_0\{12x_{19}pn_{f1} + 12x_{20}pn_{f1} + 4x_{21}pn_{f1} + L_1^3p_1 \\ (4p_3x_8 - 4(p_3(1-p_1) + p_1(p_2 + 2p_3))pn_{f1} - p_3t_r)\}\}]$$

$$\Psi_3 = [2e_shf_rx_3x_{10} \\ + 4e_f[hs_rx_9x_{10} - 6\{hs_sx_{11} + 4e_sn_sx_{12} + 2e_sL_1^2n_sp_1^2 + L_0^2(1-p_1)\{2e_sn_s(1-p_1) + L_1^2(LC_sp_3 - (1-p_2)pn_{s1} + p_3(t_r - 2x_7))\}\}]^2 \\ - 3\{hf_sx_{11} + 16e_fn_fx_{12} + 8e_fL_1^2n_fp_1^2 - L_0^2(1-p_1)\{8e_fn_f(1-p_1) + L_1^2(4LC_fp_3 - 4(1-p_2)pn_{f1} + p_3(t_r - 8x_8))\}\}]^2 \\ - 12L_0L_1^2x_9[96A_se_se_fx_3^3 - 8e_fL_0(1-p_1)\{hs_rL_1^3(hs_sx_{13})\} - x_{14}(LC_s - x_7) + 6L_0 \\ \{L_1^3p_1p_3(LC_s - x_7)\{pn_{s1} - p_2pn_{s1} - p_3(t_r - x_7)\} + hs_sL_0\{L_1^3p_1((1 - p_1^2 - p_2)pn_{s1} - p_3(t_r - x_7)) - 3x_{16}pn_{s1} - L_0^3(1-p_1)^3pn_{s1} - 3x_{15}p_1pn_{s1}\}\}] \\ + e_s[24e_fx_3^3\{hf_sL_0n_fp_1 - 4LC_sn_s + 4LC_fn_fp_3 + 4n_s\{hs_sL_0p_1 + x_7 + (p_1+p_2)(LC_s - x_7)\} - 4n_fp_3x_8\} - 2hf_rL_0L_1^3(1-p_1)hf_sx_{13}] - 3L_0^2(1-p_1) \\ [4L_1^3p_1p_3(LC_f - x_8)\{4(1-p_2)pn_{f1} - p_3(t_r - 4x_8)\} + hf_sL_0\{L_1^3p_1\{4p_3pn_{f1} - p_3(t_r - 4x_8)\} - 12x_{16}pn_{f1} - 4L_0^3(1-p_1)^3pn_{f1} - 12x_{15}p_1pn_{f1}\}] - 4 \\ x_{14}(LC_f - x_8)$$

where $x_9 = L_0(1-p_1) + L_1p_1$, $x_{10} = (L_0 - L_1)^2(2L_0 - 1 + 4L_1)p_1 - L_0L_1^2(1-p_1)(L_0(6L_1^2 - 1 - 2L_1)$, $x_{11} = L_0^3L_1^2(1-p_1)$, .

$x_{12} = L_0L_1(1-p_1)p_1$,

$x_{13} = L_0(L_0(1 + 6L_1^2(1-p_1)^2)p_1 + 2L_1^3(1-p_1)p_1^2 - L_0^2(1 + 6L_1(1-p_1)^3 - 2p_1) + 2L_0^3((3-p_1)(1-p_1)p_1 - 1)$,

$x_{14} = L_0^2(1 - 6L_1) + L_0(2L_0(6L_1 - 1) - 1 - 6L_1^2)p_1 + 2(L_0 - L_1)^3p_1^2)p_3$, $x_{15} = L_0^2L_1(1-p_1)^2$, $x_{16} = L_0L_1^2(1-p_1)p_1^2$,

$$x_{17} = \\ L_0(2L_1^3p_1^2(1-p_1) + L_0p_1(p_1^2 + 2p_1(1-p_1) + (1 + 6L_1^2)(1-p_1)^2) - 2L_0^3(p_1^3 + p_1^2(1-p_1) + (1-p_1)^3) \\ + L_0^2(p_1^3 + p_1^2(1-p_1) - p_1(1-p_1)^2 + (6L_1 - 1)(1-p_1)^3,$$

$x_{18} = p_3(2p_1^2(L_1^3 - L_0^3) + L_0p_1\{p_1 + (1 + 6L_1^2)(1-p_1)\} + L_0^2(p_1^2 + (6L_1 - 1)(1-p_1)^2)$, $x_{19} = L_0L_1^2p_1^2(1-p_1)$,

$x_{20} = L_0^2L_1p_1(1-p_1)^2$, $x_{21} = L_0^3(1-p_1)^3$

Appendix D. Results from sensitivity analyses

Tables D1–D13.

Table D1
Impacts of p_1, p_2, and p_3 on optimal solutions and expected total costs.

Centralized

Instance	Parameters									L_0-based return ratio		L_1-based return ratio	
	p_1	p_2	p_3	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
1	0.7	0.2	0.1	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%
2	0.6	0.2	0.2	36.46	5.48	6.03	56,342	2,935	59,276	27.42%	27.42%	100.00%	100.00%
3	0.5	0.3	0.2	36.06	5.55	6.10	52,872	2,886	55,758	27.73%	27.73%	100.00%	100.00%
4	0.4	0.3	0.3	35.78	5.59	6.15	49,407	2,831	52,237	27.95%	27.95%	100.00%	100.00%
5	0.3	0.3	0.4	35.57	5.62	6.19	45,943	2,772	48,715	28.12%	28.12%	100.00%	100.00%
6	0.2	0.3	0.5	35.41	5.65	6.21	42,482	2,711	45,193	28.24%	28.24%	100.00%	100.00%
7	0.1	0.4	0.5	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%

Policy I

Instance	Parameters									L_0-based return ratio		L_1-based return ratio	
	p_1	p_2	p_3	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
1	0.7	0.2	0.1	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%
2	0.6	0.2	0.2	16.00	12.50	13.26	61,298	5,585	66,883	62.48%	60.27%	100.00%	96.45%
3	0.5	0.3	0.2	15.15	13.20	13.94	60,120	5,835	65,956	66.01%	63.38%	100.00%	96.02%
4	0.4	0.3	0.3	14.88	10.03	14.78	58,345	6,224	64,569	50.17%	67.20%	74.66%	100.00%
5	0.3	0.3	0.4	14.49	6.01	15.18	56,707	7,213	63,919	30.05%	69.01%	43.54%	100.00%
6	0.2	0.3	0.5	14.17	1.70	15.53	54,838	8,613	63,452	8.50%	70.58%	12.05%	100.00%
7	0.1	0.4	0.5	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%

Policy II

Instance	Parameters											L_0-based return ratio		L_1-based return ratio	
	p_1	p_2	p_3	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
1	0.7	0.2	0.1	15.25	13.12	13.47	0.50	9.60	64,338	5,739	70,077	65.59%	61.22%	100.00%	93.32%
2	0.6	0.2	0.2	16.09	12.43	13.67	0.50	1.51	61,211	5,479	66,690	62.15%	62.15%	100.00%	100.00%
3	0.5	0.3	0.2	15.22	13.14	14.45	0.50	1.64	60,017	5,715	65,732	65.69%	65.69%	100.00%	100.00%
4	0.4	0.3	0.3	14.97	13.36	14.69	5.08	0.70	58,273	5,778	64,051	66.79%	66.79%	100.00%	100.00%
5	0.3	0.3	0.4	14.60	13.70	15.07	8.15	0.70	56,940	5,888	62,829	68.50%	68.50%	100.00%	100.00%
6	0.2	0.3	0.5	14.29	13.99	15.39	10.02	0.70	55,691	5,983	61,674	69.97%	69.97%	100.00%	100.00%
7	0.1	0.4	0.5	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%

Table D2
Sensitivity analysis on L_0 for Cases 1 and 2.

Case 1: low risk

Centralized

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	44.10	4.54	4.99	95,991	2,738	98,729	11.34%	11.34%	100.00%	100.00%
6	42.67	4.69	5.16	83,498	2,782	86,280	14.06%	14.06%	100.00%	100.00%
7	41.32	4.84	5.32	74,788	2,824	77,613	16.94%	16.94%	100.00%	100.00%
8	39.97	5.00	5.50	68,421	2,869	71,290	20.02%	20.02%	100.00%	100.00%
9	38.57	5.19	5.70	63,593	2,918	66,511	23.33%	23.33%	100.00%	100.00%
10	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%

Policy I

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	21.76	9.19	7.31	99,042	4,778	103,820	22.98%	16.62%	100.00%	72.32%
6	20.33	9.84	7.98	86,750	4,992	91,743	29.52%	21.77%	100.00%	73.77%
7	19.01	10.52	8.67	78,260	5,213	83,474	36.83%	27.58%	100.00%	74.89%
8	17.74	11.28	9.39	72,143	5,455	77,598	45.11%	34.14%	100.00%	75.67%
9	16.47	12.14	10.17	67,611	5,729	73,340	54.65%	41.58%	100.00%	76.09%
10	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%

Policy II

L_0	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	21.80	9.17	8.74	0.50	9.60	99,201	4,533	103,734	100.00%	86.62%	100.00%	86.62%
6	20.37	9.82	9.65	0.50	9.60	86,898	4,743	91,641	100.00%	89.41%	100.00%	89.41%
7	19.06	10.49	10.56	0.50	9.60	78,399	4,958	83,357	100.00%	91.51%	100.00%	91.51%
8	17.79	11.25	11.49	0.50	9.60	72,278	5,189	77,467	100.00%	92.88%	100.00%	92.88%
9	16.52	12.11	12.45	0.50	9.60	67,748	5,446	73,193	100.00%	93.49%	100.00%	93.49%
10	15.25	13.12	13.47	0.50	9.60	64,338	5,739	70,077	100.00%	93.32%	100.00%	93.32%

Case 2: moderate risk

Centralized

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	37.27	5.37	5.90	61,587	2,646	64,232	13.42%	13.42%	100.00%	100.00%
6	36.90	5.42	5.96	56,186	2,675	58,862	16.26%	16.26%	100.00%	100.00%
7	36.56	5.47	6.02	52,418	2,702	55,120	19.15%	19.15%	100.00%	100.00%
8	36.23	5.52	6.07	49,662	2,726	52,388	22.08%	22.08%	100.00%	100.00%
9	35.91	5.57	6.13	47,572	2,749	50,322	25.07%	25.07%	100.00%	100.00%
10	35.57	5.62	6.19	45,943	2,772	48,715	28.12%	28.12%	100.00%	100.00%

Policy I

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	14.84	13.48	10.85	74,415	6,276	80,691	33.69%	24.66%	100.00%	73.19%
6	14.36	13.93	11.39	69,549	6,438	75,988	41.78%	31.06%	100.00%	74.35%
7	13.96	14.33	11.87	66,257	6,571	72,828	50.15%	37.76%	100.00%	75.30%
8	13.59	14.71	12.31	63,949	6,681	70,630	58.85%	44.76%	100.00%	76.07%
9	13.25	15.09	12.73	62,297	6,775	69,072	67.90%	52.07%	100.00%	76.68%
10	12.92	15.47	13.13	61,108	6,854	67,963	77.37%	59.70%	100.00%	77.16%

(*continued on next page*)

Table D2 (*continued*)

Case 1: low risk

Policy II

L_0	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	14.87	13.46	12.91	0.50	9.60	74,611	5,933	80,544	33.66%	29.34%	100.00%	87.20%
6	14.39	13.90	13.62	0.50	9.60	69,728	6,100	75,828	41.70%	37.14%	100.00%	89.07%
7	13.99	14.31	14.24	0.50	9.60	66,423	6,235	72,658	50.10%	45.32%	100.00%	90.49%
8	13.62	14.68	14.78	0.50	9.60	64,104	6,347	70,451	58.70%	53.74%	100.00%	91.54%
9	13.28	15.05	15.28	0.50	9.60	62,445	6,440	68,885	67.75%	62.52%	100.00%	92.27%
10	12.95	15.44	15.75	0.50	9.60	61,251	6,516	67,767	77.18%	71.57%	100.00%	92.73%

Table D3
Sensitivity analysis on L_0 for Case 3.

Case 3: high risk

Centralized

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	35.82	5.58	6.14	44,300	2,530	46,830	13.96%	13.96%	100.00%	100.00%
6	35.71	5.60	6.16	42,486	2,558	45,043	16.80%	16.80%	100.00%	100.00%
7	35.60	5.62	6.18	41,216	2,583	43,799	19.66%	19.66%	100.00%	100.00%
8	35.50	5.63	6.20	40,285	2,607	42,891	22.54%	22.54%	100.00%	100.00%
9	35.39	5.65	6.22	39,576	2,628	42,204	25.43%	25.43%	100.00%	100.00%
10	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%

Policy I

L_0	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	14.56	3.06	15.11	58,516	8,126	66,642	7.65%	34.34%	22.29%	100.00%
6	14.35	2.62	15.33	56,933	8,338	65,271	7.87%	41.80%	18.82%	100.00%
7	14.18	2.31	15.51	55,853	8,498	64,351	8.09%	49.35%	16.39%	100.00%
8	14.04	2.09	15.67	55,088	8,622	63,710	8.37%	57.00%	14.69%	100.00%
9	13.90	1.95	15.83	54,531	8,720	63,251	8.76%	64.74%	13.53%	100.00%
10	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%

Policy II

L_0	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
5	14.67	13.63	15.00	9.25	0.70	59,128	5,893	65,021	34.08%	34.08%	100.00%	100.00%
6	14.46	13.83	15.21	9.50	0.70	57,618	5,983	63,602	41.48%	41.48%	100.00%	100.00%
7	14.30	13.99	15.39	9.69	0.70	56,596	6,048	62,644	48.97%	48.97%	100.00%	100.00%
8	14.15	14.14	15.55	9.84	0.70	55,876	6,092	61,967	56.55%	56.55%	100.00%	100.00%
9	14.01	14.27	15.70	9.96	0.70	55,355	6,116	61,472	64.23%	64.23%	100.00%	100.00%
10	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%

Table D4
Sensitivity analysis on t_r for Cases 1 and 2.

Case 1: low risk

Centralized

							L_0-based return ratio		L_1-based return ratio	
t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
400	31.16	6.42	7.06	38,166	3,349	41,515	32.09%	32.09%	100.00%	100.00%
480	32.38	6.18	6.79	42,545	3,260	45,805	30.88%	30.88%	100.00%	100.00%
560	33.59	5.95	6.55	46,897	3,179	50,076	29.77%	29.77%	100.00%	100.00%
640	34.78	5.75	6.33	51,225	3,105	54,330	28.75%	28.75%	100.00%	100.00%
720	35.95	5.56	6.12	55,531	3,037	58,568	27.82%	27.82%	100.00%	100.00%
800	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%

Policy I

							L_0-based return ratio		L_1-based return ratio	
t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
400	14.21	14.08	10.45	40,464	6,500	46,964	70.39%	47.52%	100.00%	67.51%
480	14.40	13.89	10.56	45,263	6,407	51,670	69.44%	48.01%	100.00%	69.14%
560	14.60	13.70	10.67	50,035	6,315	56,350	68.51%	48.51%	100.00%	70.81%
640	14.79	13.52	10.79	54,780	6,225	61,004	67.59%	49.03%	100.00%	72.54%
720	14.99	13.34	10.90	59,499	6,135	65,634	66.69%	49.57%	100.00%	74.32%
800	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%

Policy II

									L_0-based return ratio		L_1-based return ratio	
t_r	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
400	14.26	14.03	12.86	0.50	9.60	40,763	6,054	46,818	70.15%	58.44%	100.00%	83.31%
480	14.45	13.84	12.97	0.50	9.60	45,532	5,989	51,521	69.21%	58.96%	100.00%	85.20%
560	14.65	13.66	13.09	0.50	9.60	50,273	5,925	56,197	68.28%	59.50%	100.00%	87.15%
640	14.84	13.47	13.21	0.50	9.60	54,987	5,862	60,849	67.37%	60.06%	100.00%	89.15%
720	15.04	13.29	13.34	0.50	9.60	59,675	5,800	65,475	66.47%	60.63%	100.00%	91.21%
800	15.25	13.12	13.47	0.50	9.60	64,338	5,739	70,077	65.59%	61.22%	100.00%	93.32%

Case 2: moderate risk

Centralized

							L_0-based return ratio		L_1-based return ratio	
t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
400	28.69	6.97	7.67	31,411	3,315	34,726	34.86%	34.86%	100.00%	100.00%
480	30.15	6.63	7.30	34,451	3,179	37,631	33.17%	33.17%	100.00%	100.00%
560	31.56	6.34	6.97	37,416	3,060	40,476	31.68%	31.68%	100.00%	100.00%
640	32.94	6.07	6.68	40,315	2,953	43,268	30.36%	30.36%	100.00%	100.00%
720	34.27	5.84	6.42	43,155	2,858	46,013	29.18%	29.18%	100.00%	100.00%
800	35.57	5.62	6.19	46,823	2,880	49,703	28.12%	28.12%	100.00%	100.00%

Policy I

							L_0-based return ratio		L_1-based return ratio	
t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
400	12.39	16.14	12.31	39,297	7,224	46,521	80.71%	55.95%	100.00%	69.33%
480	12.50	16.01	12.47	43,755	7,150	50,905	80.03%	56.67%	100.00%	70.81%
560	12.60	15.87	12.63	48,165	7,075	55,241	79.35%	57.40%	100.00%	72.34%
640	12.71	15.74	12.79	52,527	7,001	59,528	78.69%	58.15%	100.00%	73.91%
720	12.82	15.60	12.96	56,841	6,928	63,769	78.02%	58.92%	100.00%	75.51%
800	12.92	15.47	13.13	61,108	6,854	67,963	77.37%	59.70%	100.00%	77.16%

(*continued on next page*)

Table D4 (*continued*)

Case 1: low risk

Policy II

t_r	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
400	12.42	16.11	14.85	0.50	9.60	39,606	6,750	46,356	80.54%	67.51%	100.00%	83.82%
480	12.52	15.97	15.03	0.50	9.60	44,032	6,702	50,734	79.86%	68.30%	100.00%	85.52%
560	12.63	15.84	15.20	0.50	9.60	48,408	6,655	55,063	79.19%	69.10%	100.00%	87.26%
640	12.74	15.70	15.38	0.50	9.60	52,737	6,608	59,345	78.52%	69.91%	100.00%	89.04%
720	12.84	15.57	15.56	0.50	9.60	57,017	6,562	63,579	77.86%	70.75%	100.00%	90.86%
800	12.95	15.44	15.75	0.50	9.60	61,251	6,516	67,767	77.21%	71.59%	100.00%	92.73%

Table D5
Sensitivity analysis on t_r for Case 3.

Case 3: high risk

Centralized

t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
400	28.18	7.10	7.81	28,054	3,249	31,303	35.49%	35.49%	100.00%	100.00%
480	29.70	6.73	7.41	30,425	3,098	33,523	33.67%	33.67%	100.00%	100.00%
560	31.16	6.42	7.06	32,695	2,965	35,660	32.09%	32.09%	100.00%	100.00%
640	32.58	6.14	6.75	34,878	2,847	37,725	30.69%	30.69%	100.00%	100.00%
720	33.95	5.89	6.48	36,983	2,742	39,726	29.45%	29.45%	100.00%	100.00%
800	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%

Policy I

t_r	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
400	13.41	13.47	16.41	35,717	6,614	42,331	67.37%	74.59%	90.32%	100.00%
480	13.48	11.19	16.32	39,622	7,044	46,666	55.94%	74.18%	75.41%	100.00%
560	13.55	8.89	16.23	43,416	7,477	50,893	44.43%	73.79%	60.21%	100.00%
640	13.63	6.56	16.15	47,098	7,913	55,011	32.81%	73.39%	44.71%	100.00%
720	13.70	4.22	16.06	50,666	8,353	59,019	21.10%	72.99%	28.90%	100.00%
800	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%

Policy II

t_r	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
400	13.52	14.73	16.23	1.64	0.70	35,532	6,317	41,849	73.67%	73.78%	99.57%	99.72%
480	13.59	14.72	16.19	3.33	0.70	39,469	6,239	45,709	73.59%	73.59%	100.00%	100.00%
560	13.66	14.64	16.10	5.01	0.70	43,399	6,210	49,609	73.19%	73.19%	100.00%	100.00%
640	13.74	14.56	16.02	6.70	0.70	47,293	6,181	53,474	72.80%	72.80%	100.00%	100.00%
720	13.81	14.48	15.93	8.38	0.70	51,151	6,152	57,303	72.41%	72.41%	100.00%	100.00%
800	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%

Table D6
Sensitivity analysis on e_s for Cases 1 and 2.

Case 1: low risk

Centralized

							L_0-based return ratio		L_1-based return ratio	
e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
100	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%
90	36.97	5.41	5.95	59,788	2,980	62,769	27.05%	27.05%	100.00%	100.00%
80	36.84	5.43	5.97	59,759	2,987	62,746	27.14%	27.14%	100.00%	100.00%
70	36.71	5.45	5.99	59,729	2,994	62,723	27.24%	27.24%	100.00%	100.00%
60	36.59	5.47	6.01	59,698	3,001	62,699	27.33%	27.33%	100.00%	100.00%
50	36.46	5.49	6.03	59,668	3,008	62,676	27.43%	27.43%	100.00%	100.00%

Policy I

							L_0-based return ratio		L_1-based return ratio	
e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
100	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%
90	14.58	13.72	10.49	64,525	6,339	70,864	68.61%	47.68%	100.00%	69.49%
80	13.90	14.38	9.93	64,910	6,680	71,590	71.92%	45.15%	100.00%	62.77%
70	13.17	15.19	9.35	65,369	7,084	72,453	75.95%	42.51%	100.00%	55.97%
60	12.35	16.20	8.74	65,940	7,579	73,520	80.98%	39.73%	100.00%	49.06%
50	11.42	17.51	8.09	66,689	8,211	74,900	87.55%	36.79%	100.00%	42.02%

Policy II

										L_0-based return ratio		L_1-based return ratio	
e_s	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$		n_s	n_f	n_s	n_f
100	15.25	13.12	13.47	0.50	9.60	64,338	5,739	70,077		65.59%	61.22%	100.00%	93.32%
90	14.63	13.67	12.91	0.50	9.60	64,768	5,931	70,699		68.36%	58.68%	100.00%	85.83%
80	13.96	14.33	12.33	0.50	9.60	65,260	6,158	71,418		71.65%	56.03%	100.00%	78.19%
70	13.22	15.13	11.71	0.50	9.60	65,841	6,433	72,274		75.63%	53.24%	100.00%	70.40%
60	12.41	16.12	11.06	0.50	9.60	66,554	6,776	73,329		80.61%	50.29%	100.00%	62.39%
50	11.48	17.42	10.37	0.50	9.60	67,473	7,221	74,694		87.10%	47.14%	100.00%	54.11%

Case 2: moderate risk

Centralized

							L_0-based return ratio		L_1-based return ratio	
e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
100	35.57	5.62	6.19	45,943	2,772	48,715	28.12%	28.12%	100.00%	100.00%
90	35.52	5.63	6.19	45,925	2,775	48,700	28.15%	28.15%	100.00%	100.00%
80	35.48	5.64	6.20	45,906	2,778	48,684	28.19%	28.19%	100.00%	100.00%
70	35.43	5.64	6.21	45,887	2,781	48,668	28.22%	28.22%	100.00%	100.00%
60	35.39	5.65	6.22	45,868	2,784	48,652	28.26%	28.26%	100.00%	100.00%
50	35.34	5.66	6.23	45,849	2,787	48,636	28.30%	28.30%	100.00%	100.00%

Policy I

							L_0-based return ratio		L_1-based return ratio	
e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
100	12.92	15.47	13.13	61,108	6,854	67,963	77.37%	59.70%	100.00%	77.16%
90	12.56	15.93	12.36	61,901	7,123	69,023	79.63%	56.19%	100.00%	70.57%
80	12.16	16.45	11.56	62,792	7,424	70,216	82.24%	52.56%	100.00%	63.92%
70	11.72	17.06	10.73	63,816	7,767	71,584	85.29%	48.79%	100.00%	57.21%
60	11.24	17.79	9.87	65,027	8,168	73,195	88.96%	44.85%	100.00%	50.41%
50	10.69	18.70	8.95	66,512	8,650	75,162	93.50%	40.69%	100.00%	43.52%

(continued on next page)

Table D6 (*continued*)

Case 1: low risk

Policy II

e_s	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
100	12.95	15.44	15.75	0.50	9.60	61,251	6,516	67,767	77.21%	71.59%	100.00%	92.73%
90	12.59	15.89	14.93	0.50	9.60	62,151	6,673	68,824	79.46%	67.87%	100.00%	85.42%
80	12.19	16.41	14.08	0.50	9.60	63,157	6,854	70,011	82.04%	64.00%	100.00%	78.01%
70	11.75	17.01	13.19	0.50	9.60	64,305	7,066	71,372	85.07%	59.96%	100.00%	70.48%
60	11.27	17.74	12.26	0.50	9.60	65,653	7,320	72,973	88.71%	55.71%	100.00%	62.79%
50	10.73	18.64	11.26	0.50	9.60	67,292	7,632	74,925	93.22%	51.19%	100.00%	54.91%

Table D7
Sensitivity analysis on e_s for Case 3.

Case 3: high risk

Centralized

e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
100	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%
90	35.25	5.67	6.24	39,008	2,650	41,658	28.37%	28.37%	100.00%	100.00%
80	35.22	5.68	6.25	38,994	2,652	41,647	28.39%	28.39%	100.00%	100.00%
70	35.19	5.68	6.25	38,981	2,654	41,635	28.42%	28.42%	100.00%	100.00%
60	35.16	5.69	6.26	38,967	2,656	41,624	28.44%	28.44%	100.00%	100.00%
50	35.13	5.69	6.26	38,954	2,658	41,612	28.46%	28.46%	100.00%	100.00%

Policy I

e_s	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
100	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%
90	13.77	2.06	15.97	54,118	8,753	62,871	10.32%	72.60%	14.22%	100.00%
80	13.77	2.32	15.97	54,114	8,700	62,814	11.61%	72.60%	16.00%	100.00%
70	13.77	2.65	15.97	54,110	8,631	62,741	13.27%	72.60%	18.28%	100.00%
60	13.77	3.10	15.97	54,103	8,539	62,643	15.49%	72.60%	21.33%	100.00%
50	13.77	3.72	15.97	54,095	8,410	62,505	18.58%	72.60%	25.59%	100.00%

Policy II

e_s	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
100	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%
90	13.89	14.40	15.84	8.99	0.70	54,818	6,124	60,942	72.02%	72.02%	100.00%	100.00%
80	13.89	14.40	15.84	7.91	0.70	54,663	6,124	60,787	72.02%	72.02%	100.00%	100.00%
70	13.89	14.40	15.84	6.83	0.70	54,508	6,124	60,631	72.02%	72.02%	100.00%	100.00%
60	13.89	14.40	15.84	5.75	0.70	54,353	6,124	60,476	72.02%	72.02%	100.00%	100.00%
50	13.89	14.40	15.84	4.68	0.70	54,197	6,124	60,321	72.02%	72.02%	100.00%	100.00%

Table D8
Sensitivity analysis on e_f for Cases 1 and 2.

Case 1: low risk

Centralized

e_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%
220	37.39	5.35	5.88	59,888	2,958	62,846	26.75%	26.75%	100.00%	100.00%
240	37.68	5.31	5.84	59,957	2,943	62,900	26.54%	26.54%	100.00%	100.00%
260	37.96	5.27	5.79	60,024	2,928	62,952	26.34%	26.34%	100.00%	100.00%
280	38.24	5.23	5.75	60,090	2,914	63,004	26.15%	26.15%	100.00%	100.00%
300	38.52	5.19	5.71	60,155	2,901	63,055	25.96%	25.96%	100.00%	100.00%

Policy I

e_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%
220	15.19	13.16	10.02	64,390	6,131	70,521	65.81%	45.56%	100.00%	69.23%
240	15.19	13.16	9.19	64,555	6,201	70,757	65.81%	41.76%	100.00%	63.46%
260	15.19	13.16	8.48	64,695	6,261	70,956	65.81%	38.55%	100.00%	58.58%
280	15.19	13.16	7.88	64,815	6,312	71,127	65.81%	35.80%	100.00%	54.39%
300	15.19	13.16	7.35	64,919	6,356	71,275	65.81%	33.41%	100.00%	50.77%

Policy II

e_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	15.25	13.12	13.47	0.50	9.60	64,338	5,739	70,077	65.59%	61.22%	100.00%	93.32%
220	15.25	13.12	12.24	0.50	9.60	64,634	5,736	70,370	65.59%	55.65%	100.00%	84.84%
240	15.25	13.12	11.22	0.50	9.60	64,880	5,735	70,615	65.59%	51.01%	100.00%	77.77%
260	15.25	13.12	10.36	0.50	9.60	65,089	5,733	70,822	65.59%	47.09%	100.00%	71.79%
280	15.25	13.12	9.62	0.50	9.60	65,268	5,732	70,999	65.59%	43.73%	100.00%	66.66%
300	15.25	13.12	8.98	0.50	9.60	65,423	5,731	71,153	65.59%	40.81%	100.00%	62.22%

Case 2: moderate risk

Centralized

e_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	35.57	5.62	6.19	45,943	2,772	48,715	28.12%	28.12%	100.00%	100.00%
220	35.68	5.61	6.17	45,988	2,765	48,753	28.03%	28.03%	100.00%	100.00%
240	35.78	5.59	6.15	46,033	2,758	48,791	27.95%	27.95%	100.00%	100.00%
260	35.89	5.57	6.13	46,077	2,751	48,828	27.86%	27.86%	100.00%	100.00%
280	36.00	5.56	6.11	46,120	2,745	48,865	27.78%	27.78%	100.00%	100.00%
300	36.10	5.54	6.09	46,164	2,738	48,902	27.70%	27.70%	100.00%	100.00%

Policy I

e_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	12.92	15.47	13.13	61,108	6,854	67,963	77.37%	59.70%	100.00%	77.16%
220	12.92	15.47	11.94	61,372	6,954	68,326	77.37%	54.27%	100.00%	70.15%
240	12.92	15.47	10.95	61,592	7,037	68,629	77.37%	49.75%	100.00%	64.30%
260	12.92	15.47	10.10	61,778	7,107	68,885	77.37%	45.92%	100.00%	59.36%
280	12.92	15.47	9.38	61,938	7,167	69,104	77.37%	42.64%	100.00%	55.12%
300	12.92	15.47	8.76	62,076	7,219	69,295	77.37%	39.80%	100.00%	51.44%

(*continued on next page*)

Table D8 (*continued*)

Case 1: low risk

Policy II

e_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	12.95	15.44	15.75	0.50	9.60	61,251	6,516	67,767	77.21%	71.59%	100.00%	92.73%
220	12.95	15.44	14.32	0.50	9.60	61,630	6,512	68,142	77.21%	65.09%	100.00%	84.30%
240	12.95	15.44	13.13	0.50	9.60	61,946	6,508	68,455	77.21%	59.66%	100.00%	77.27%
260	12.95	15.44	12.12	0.50	9.60	62,214	6,506	68,719	77.21%	55.07%	100.00%	71.33%
280	12.95	15.44	11.25	0.50	9.60	62,443	6,503	68,946	77.21%	51.14%	100.00%	66.23%
300	12.95	15.44	10.50	0.50	9.60	62,641	6,501	69,142	77.21%	47.73%	100.00%	61.82%

Table D9
Sensitivity analysis on e_f for Case 3.

Case 3: high risk

Centralized

e_f							L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%
220	35.35	5.66	6.22	39,054	2,643	41,697	28.29%	28.29%	100.00%	100.00%
240	35.42	5.65	6.21	39,086	2,639	41,725	28.23%	28.23%	100.00%	100.00%
260	35.49	5.64	6.20	39,118	2,634	41,752	28.18%	28.18%	100.00%	100.00%
280	35.56	5.62	6.19	39,150	2,629	41,779	28.12%	28.12%	100.00%	100.00%
300	35.63	5.61	6.17	39,181	2,625	41,806	28.07%	28.07%	100.00%	100.00%

Policy I

e_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%
220	14.12	3.22	15.58	53,734	8,301	62,034	16.09%	70.83%	22.71%	100.00%
240	14.44	4.57	15.24	53,377	7,832	61,208	22.85%	69.26%	32.99%	100.00%
260	14.74	5.91	14.93	53,041	7,385	60,426	29.56%	67.84%	43.57%	100.00%
280	15.02	7.24	14.64	52,719	6,958	59,678	36.22%	66.56%	54.42%	100.00%
300	15.29	8.57	14.38	52,407	6,548	58,955	42.84%	65.38%	65.52%	100.00%

Policy II

e_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
200	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%
220	14.23	14.06	15.46	8.61	0.70	54,288	5,995	60,283	70.29%	70.29%	100.00%	100.00%
240	14.54	13.75	15.13	7.27	0.70	53,692	5,880	59,572	68.75%	68.75%	100.00%	100.00%
260	14.84	13.47	14.82	6.00	0.70	53,168	5,776	58,944	67.37%	67.37%	100.00%	100.00%
280	15.13	13.22	14.54	4.81	0.70	52,703	5,681	58,384	66.11%	66.11%	100.00%	100.00%
300	15.39	12.99	14.29	3.68	0.70	52,287	5,594	57,881	64.96%	64.96%	100.00%	100.00%

Table D10
Sensitivity analysis on pn_{f1} and pn_{f2} for Cases 1 and 2.

Case 1: low risk

Centralized

								L_0-based return ratio		L_1-based return ratio	
pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
70	100	37.09	5.39	5.93	59,818	2,974	62,792	26.96%	26.96%	100.00%	100.00%
60	88	37.07	5.39	5.93	59,804	2,975	62,779	26.97%	26.97%	100.00%	100.00%
50	76	37.05	5.40	5.94	59,790	2,976	62,766	26.99%	26.99%	100.00%	100.00%
40	64	37.03	5.40	5.94	59,776	2,977	62,753	27.01%	27.01%	100.00%	100.00%
30	52	37.01	5.40	5.94	59,761	2,978	62,740	27.02%	27.02%	100.00%	100.00%
20	40	36.99	5.41	5.95	59,747	2,979	62,727	27.04%	27.04%	100.00%	100.00%

Policy I

								L_0-based return ratio		L_1-based return ratio	
pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
70	100	15.19	13.16	11.03	64,192	6,047	70,238	65.81%	50.11%	100.00%	76.15%
60	88	15.19	13.16	10.96	64,169	6,056	70,225	65.81%	49.84%	100.00%	75.73%
50	76	15.19	13.16	10.90	64,147	6,065	70,212	65.81%	49.56%	100.00%	75.31%
40	64	15.19	13.16	10.84	64,124	6,075	70,199	65.81%	49.29%	100.00%	74.89%
30	52	15.19	13.16	10.78	64,101	6,085	70,186	65.81%	49.01%	100.00%	74.47%
20	40	15.19	13.16	10.72	64,078	6,095	70,173	65.81%	48.74%	100.00%	74.06%

Policy II

										L_0-based return ratio		L_1-based return ratio	
pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
70	100	15.25	13.12	13.47	0.5	9.60	64,338	5,739	70,077	65.59%	61.22%	100.00%	93.32%
60	88	15.25	13.12	13.44	0.5	10.91	64,322	5,739	70,061	65.59%	61.09%	100.00%	93.14%
50	76	15.25	13.12	13.41	0.5	12.63	64,307	5,739	70,045	65.59%	60.97%	100.00%	92.95%
40	64	15.25	13.12	13.39	0.5	15.00	64,291	5,739	70,029	65.59%	60.85%	100.00%	92.76%
30	52	15.25	13.12	13.36	0.5	18.46	64,275	5,739	70,013	65.59%	60.73%	100.00%	92.58%
20	40	15.25	13.12	13.33	0.5	24.00	64,259	5,738	69,997	65.59%	60.60%	100.00%	92.39%

Case 2: moderate risk

Centralized

								L_0-based return ratio		L_1-based return ratio	
pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
70	100	35.57	5.62	6.19	45,943	2,772	48,715	28.12%	28.12%	100.00%	100.00%
60	88	35.55	5.63	6.19	45,911	2,773	48,684	28.13%	28.13%	100.00%	100.00%
50	76	35.52	5.63	6.19	45,878	2,775	48,653	28.15%	28.15%	100.00%	100.00%
40	64	35.50	5.63	6.20	45,846	2,776	48,622	28.17%	28.17%	100.00%	100.00%
30	52	35.48	5.64	6.20	45,813	2,778	48,591	28.19%	28.19%	100.00%	100.00%
20	40	35.45	5.64	6.21	45,780	2,779	48,560	28.21%	28.21%	100.00%	100.00%

Policy I

								L_0-based return ratio		L_1-based return ratio	
pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
70	100	12.92	15.47	13.13	61,108	6,854	67,963	77.37%	59.70%	100.00%	77.16%
60	88	12.92	15.47	12.97	61,059	6,873	67,932	77.37%	58.94%	100.00%	76.18%
50	76	12.92	15.47	12.80	61,009	6,892	67,901	77.37%	58.18%	100.00%	75.20%
40	64	12.92	15.47	12.63	60,958	6,912	67,869	77.37%	57.43%	100.00%	74.22%
30	52	12.92	15.47	12.47	60,906	6,932	67,837	77.37%	56.67%	100.00%	73.24%
20	40	12.92	15.47	12.30	60,853	6,952	67,805	77.37%	55.91%	100.00%	72.26%

(*continued on next page*)

Table D10 (*continued*)

Case 1: low risk

Policy II

pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
70	100	12.95	15.44	15.75	0.50	9.60	61,251	6,516	67,767	77.21%	71.59%	100.00%	92.73%
60	88	12.95	15.44	15.62	0.50	10.91	61,218	6,515	67,734	77.21%	71.00%	100.00%	91.96%
50	76	12.95	15.44	15.49	0.50	12.63	61,185	6,515	67,700	77.21%	70.40%	100.00%	91.19%
40	64	12.95	15.44	15.36	0.50	15.00	61,151	6,515	67,666	77.21%	69.81%	100.00%	90.41%
30	52	12.95	15.44	15.23	0.50	18.46	61,117	6,514	67,631	77.21%	69.21%	100.00%	89.64%
20	40	12.95	15.44	15.10	0.50	24.00	61,081	6,514	67,595	77.21%	68.62%	100.00%	88.87%

Table D11
Sensitivity analysis on pn_{f1} and pn_{f2} for Case 3.

Case 3: high risk

Centralized

pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
70	100	35.28	5.67	6.24	39,021	2,648	41,670	28.34%	28.34%	100.00%	100.00%
60	88	35.26	5.67	6.24	38,980	2,650	41,629	28.36%	28.36%	100.00%	100.00%
50	76	35.23	5.68	6.24	38,938	2,651	41,589	28.38%	28.38%	100.00%	100.00%
40	64	35.21	5.68	6.25	38,896	2,653	41,549	28.40%	28.40%	100.00%	100.00%
30	52	35.19	5.68	6.25	38,854	2,655	41,509	28.42%	28.42%	100.00%	100.00%
20	40	35.17	5.69	6.26	38,812	2,656	41,468	28.44%	28.44%	100.00%	100.00%

Policy I

pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
70	100	13.77	1.86	15.97	54,121	8,796	62,917	9.29%	72.60%	12.80%	100.00%
60	88	13.83	2.07	15.91	53,958	8,716	62,675	10.36%	72.31%	14.33%	100.00%
50	76	13.88	2.29	15.84	53,796	8,637	62,433	11.44%	72.02%	15.89%	100.00%
40	64	13.94	2.51	15.78	53,635	8,557	62,192	12.53%	71.74%	17.46%	100.00%
30	52	14.00	2.72	15.72	53,475	8,478	61,953	13.62%	71.45%	19.06%	100.00%
20	40	14.05	2.94	15.66	53,316	8,398	61,714	14.72%	71.17%	20.68%	100.00%

Policy II

pn_{f1}	pn_{f2}	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	L_0-based return ratio n_s	L_0-based return ratio n_f	L_1-based return ratio n_s	L_1-based return ratio n_f
70	100	13.89	14.40	15.84	10.06	0.70	54,974	6,124	61,097	72.02%	72.02%	100.00%	100.00%
60	88	13.93	14.35	15.79	9.86	0.68	54,782	6,105	60,887	71.77%	71.77%	100.00%	100.00%
50	76	13.98	14.30	15.74	9.65	0.66	54,593	6,087	60,680	71.52%	71.52%	100.00%	100.00%
40	64	14.03	14.26	15.68	9.45	0.63	54,405	6,069	60,474	71.28%	71.28%	100.00%	100.00%
30	52	14.08	14.21	15.63	9.25	0.58	54,219	6,051	60,270	71.04%	71.04%	100.00%	100.00%
20	40	14.12	14.16	15.58	9.05	0.50	54,035	6,033	60,068	70.80%	70.80%	100.00%	100.00%

Table D12
Sensitivity analysis on different container fleet for Cases 1 and 2.

Case 1: low risk

Centralized

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	40.31	7.94	1.98	62,009	3,022	65,032	24.81%	24.81%	100.00%	100.00%
240	160	37.97	6.32	4.21	58,872	2,983	61,855	26.34%	26.34%	100.00%	100.00%
160	240	37.00	4.32	6.49	55,972	2,885	58,857	27.03%	27.03%	100.00%	100.00%
80	320	37.28	2.15	8.58	53,352	2,721	56,073	26.82%	26.82%	100.00%	100.00%

Policy I

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.59	7.96	7.55	70,654	8,703	79,357	24.87%	94.41%	26.34%	100.00%
240	160	14.88	12.75	10.75	63,228	6,013	69,241	53.11%	67.20%	79.04%	100.00%
160	240	13.90	11.51	9.93	60,888	6,759	67,647	71.92%	41.38%	100.00%	57.54%
80	320	10.35	7.73	7.40	60,672	9,881	70,553	96.66%	23.12%	100.00%	23.92%

Policy II

										L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.65	10.25	7.51	12.00	0.70	71,501	7,692	79,193	32.04%	93.90%	34.12%	100.00%
240	160	14.93	15.26	10.71	12.00	0.70	63,275	5,860	69,135	63.58%	66.96%	94.94%	100.00%
160	240	13.96	11.46	11.46	0.50	9.60	61,367	6,113	67,480	71.65%	47.77%	100.00%	66.67%
80	320	10.41	7.69	9.61	0.50	9.60	62,520	7,816	70,336	96.09%	30.04%	100.00%	31.26%

Case 2: moderate risk

Centralized

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	39.02	8.20	2.05	46,318	2,696	49,014	25.63%	25.63%	100.00%	100.00%
240	160	36.78	6.53	4.35	44,742	2,731	47,473	27.19%	27.19%	100.00%	100.00%
160	240	35.09	4.56	6.84	43,248	2,744	45,992	28.49%	28.49%	100.00%	100.00%
80	320	34.02	2.35	9.41	41,897	2,724	44,621	29.39%	29.39%	100.00%	100.00%

Policy I

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.05	7.93	7.96	71,484	9,116	80,600	24.78%	99.50%	24.90%	100.00%
240	160	12.68	14.71	12.62	60,339	6,809	67,147	61.29%	78.86%	77.72%	100.00%
160	240	12.16	13.16	11.56	59,056	7,536	66,591	82.24%	48.18%	100.00%	58.59%
80	320	10.06	7.95	7.98	63,271	11,035	74,306	99.40%	24.93%	100.00%	25.08%

Policy II

										L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.08	10.21	7.93	12.00	0.70	72,355	8,041	80,396	31.91%	99.17%	32.18%	100.00%
240	160	12.71	17.38	12.59	12.00	0.70	60,383	6,630	67,013	72.43%	78.68%	92.06%	100.00%
160	240	12.19	9.60	14.08	0.50	9.60	59,570	6,825	66,394	60.00%	58.67%	73.13%	71.51%
80	320	10.10	7.92	10.19	0.50	9.60	63,409	8,030	71,439	99.05%	31.85%	100.00%	32.15%

Table D13
Sensitivity analysis on different container fleet for Case 3.

Case 3: high risk

Centralized

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	39.02	8.20	2.05	46,318	2,696	49,014	25.63%	25.63%	100.00%	100.00%
240	160	36.78	6.53	4.35	44,742	2,731	47,473	27.19%	27.19%	100.00%	100.00%
160	240	35.09	4.56	6.84	43,248	2,744	45,992	28.49%	28.49%	100.00%	100.00%
80	320	34.02	2.35	9.41	41,897	2,724	44,621	29.39%	29.39%	100.00%	100.00%

Policy I

								L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.44	0.73	7.67	66,052	11,741	77,793	2.27%	95.83%	2.37%	100.00%
240	160	13.01	6.43	12.30	58,299	8,003	66,302	26.81%	76.88%	34.87%	100.00%
160	240	14.50	11.03	15.76	53,642	6,083	59,725	68.95%	65.65%	100.00%	95.21%
80	320	12.92	6.19	12.11	54,860	9,682	64,542	77.40%	37.85%	100.00%	48.91%

Policy II

										L_0-based return ratio		L_1-based return ratio	
n_s	n_f	L_1^*	w_s^*	w_f^*	α^*	β^*	$E(\Pi_R^*)$	$E(\Pi_S^*)$	$E(\Pi^*)$	n_s	n_f	n_s	n_f
320	80	10.54	7.75	7.59	12.00	0.70	69,211	7,730	76,941	24.22%	94.88%	25.53%	100.00%
240	160	13.10	14.59	12.22	12.00	0.70	59,141	6,446	65,587	60.78%	76.36%	79.59%	100.00%
160	240	14.60	10.96	16.44	0.50	1.47	53,457	5,849	59,306	68.52%	68.52%	100.00%	100.00%
80	320	13.03	6.14	20.05	0.50	9.60	56,830	6,390	63,220	76.74%	62.67%	100.00%	81.66%

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