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A Solution of Air Cargo Capacity Allocation through an Integrated Wholesale-Option Contract

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Abstract:
In this research, an airline sells cargo capacity to different freight forwarders in substitutable routes. The freight forwarder purchases from some routes exceed these routes capacity, and the substitutable routes sales cannot fill half of its capacity. An integrated wholesale-option contract model, in a cooperative game form, is developed to perform a capacity allocation model and to solve the demand imbalance among these routes. The game is carried out between a single airline and multiple freight forwarders, and their payoffs are the expected profits. It is found that the demand in the underutilized routes is a self-replicating distribution.

Keywords: *Air cargo, Capacity Allocation, Cooperative game, Wholesale price, Option Contract.*

I. INTRODUCTION

The capacity allocation is severely complicated when the airline provides substitutable routes to the same destination. A problem of demand imbalance between two substituting routes then occurs in which freight forwarders order very high quantities of freight space from hot-selling routes, whereas their demand from the substituting routes is much less than the airline capacity in these routes (underutilized routes) [1]. In fact, this problem fairly new in the air cargo industry, and it is likely to get more severe because of the increasing use of wide-bodied aircraft [2]. This problem may expose the airline to suffer losses on both routes. In the underutilized routes, airline may incur flight fixed cost for each empty space in the aircraft belly-hold because of the insufficient demand. Further, a loss of profit in the hot-selling routes may be incurred in terms of penalties as a consequence of the overbooked and offloaded freight. These penalties are incurred in two forms; delay costs for each late unit of freight and stocking cost for each offloaded unit.

To solve this problem, a sequential cooperative game between a single airline and multiple freight forwarders is performed in the form of a flexible contracting model. This model is used to sell the capacities on underutilized and hot-selling routes together as one bundle. Because the airline guarantees that the demand on these routes is always high, the model exploits the power of airline to sell the capacity of hot-selling route in a wholesale contract. With this in mind, the airline suffers from low demand in the underutilized routes. Consequently, airline needs to motivate freight forwarders to buy larger quantities of freight space from the underutilized routes, so the option-contract is a perfect incentive to the freight forwarder. Therefore, we suggest that the airline can use the mixed wholesale-option-contract to reach an agreement with the freight forwarders to calculate a ratio from their request in the hot-selling routes in which it can be added to the underutilized routes.

The contributions of this research can be summarized as follows: to the best of our knowledge, this paper is the first which uses the mixed wholesale and the option contract in one model. Usually, the wholesale and the option-contracts are used in the literature as alternatives, whereas our approach puts each contracting method in a suitable form to establish one flexible contract and reduce the demand-capacity gaps between substitutable routes.

II. LITERATURE REVIEW

When focused on the air cargo industry, the literature in capacity allocation and management includes overbooking control, pricing and contracting. Various research studies in overbooking control were carried out in the air cargo sector. For example, Kasilingam [3]created a cost-based overbooking model with random continuous and discrete capacity and stated that the optimal overbooking level can be predicted with the aid of over-sale costs, spoilage costs, and show-up rates. Similarly, a fuzzy reasoning model used the same parameters to obtain overbooking levels [4].

Airlines need to decide whether to reject the orders of freight forwarder or accept it, therefore the contracting work appears. In a single-leg flight, Amaruchkul, et al. [5] developed a Markov decision model for intaking an accept/reject decision under free-sale capacity selling. The authors did not consider cancellations and no-shows in the model. This may reduce the profit of airline because of the big chance that freight forwarder cannot fulfill the reserved capacity. Also, the Markov decision model can be used to calculate a bid pricing threshold to manage the booking process [6].

In the network scale, Li and Xianyong [7] adopted a single period stochastic programming model for the fixed capacity allocation problem in a multi-leg network. Then, Levina, et al. [8] studied the booking requests acceptance and/or rejection policy by network dynamic programming control, and they proposed a simplified linear programming model and heuristics. Moreover, they identified the contracts in both the guaranteed levels and spot markets. Also, the guaranteed contract was modeled in a series of mixed integer programming models, each representing one spot market case in combination airlines [9]. Barz and Gartner [10] solved the revenue management network problem under fixed capacity, and random cargo weight, volume, and demand. Feng, et al. [1]discussed the demand imbalance among cargo routes and solved the problem using the strategic foreclosure model. Their idea was to categorize freight forwarders according to their size. Strategic foreclosure necessitates that the forwarder who order larger quantity of freight space from the hot-selling routes should buy another quantity in the underutilized routes. Whereas, small forwarders can be allocated only in the underutilized routes. However, the authors ignored the rivals of the airline. If freight forwarders do not accept the airline allocation, they are free to move to any of the airline's rivals. Moreover, when capacity is allocated according to the discrimination policy, the freight forwarders compete for the capacity by overstating their orders to take priority in the hot-selling routes which may lead to an inaccurate allocation in both routes.

In this research, we model the capacity pre-allocation between a single airline and n-freight forwarders in the guaranteed contracts and long-term market. To model this problem, we used a cooperative game between single airline and *n*-freight forwarder.

III. PROBLEM AND MODEL DESCRIPTION

In order to tackle the imbalance between the substitutable hot-selling and the underutilized routes, we propose a negotiation process between the airline and the *n*-freight forwarders. The negotiation process is suggested to be performed through a bargaining game. The bargaining process can be explained as in the following:

Consider an $(n+1)$-player bargaining game, a single airline $\mathfrak{A}$and *n*-freight forwarder $\mathfrak{F}$, for a set of freight forwarders $\mathfrak{F} = \{f : f \in \mathbb{N}\}$. Also, let the airline has two sets of routes; First, the routes with hot-selling demand I,where $\mathrm{I} = \{i : i \in \mathbb{N}\}$. Second, the routes with underutilization $\mathcal{J} = \{j : j \in \mathbb{N}\}$. The airline $\mathfrak{A}$and each freight forwarder $f$negotiate the capacity allocation in the routes I and $\mathcal{J}$, simultaneously. Because the freight forwarders do not arrive at the same time, the negotiation between the airline and each single freight forwarder is carried out sequentially. Hence, Let the capacity of a hot-selling route i be $\mathcal{K}_i$, and the capacity of an underutilized route j be $\mathcal{K}_j$. The sum of the capacities in the hot-selling and the underutilized routes are $\sum_i^{\mathrm{I}} \mathcal{K}_i$, and $\sum_j^{\mathcal{J}} \mathcal{K}_j$, respectively. The market demand for the hot-selling route is represented by a random variable X_i . The demand cumulative distribution function of each route is $F(X_i)$ with $x_i \geq zero$, and the random variable of market demand for the underutilized routes is X_j. The demand cumulative distribution function of each underutilized route is $F(X_j)$ with $x_j \geq zero$. The airline and *n*-freight forwarders negotiate the quantities $\boldsymbol{q}$, i.e. the game is a function of this variable, where the current quantity set is$\boldsymbol{q} = \{\boldsymbol{Q_i}, \boldsymbol{Q_j} \in \mathbb{R}^+ : \sum_{i=1}^{\mathrm{I}} \boldsymbol{Q_i} \geq \sum_i^{\mathrm{I}} \mathcal{K}_i , \sum_{j=1}^{\mathcal{J}} \boldsymbol{Q_j} < \sum_j^{\mathcal{J}} \mathcal{K}_j\}$.

Let the wholesale pricing contract $\mathfrak{w}$ is used to sell the hot-selling routes, because the demand in these routes is almost guaranteed, and the option-contract$\mathcal{O}$is used to sell the underutilized routes, because the demand is very low on these routes. The game between the airline and the freight forwarder is run in consecutive steps. In each step, the airline plays with only one freight forwarder, i.e. the forwarder $\boldsymbol{f_1}$ negotiates the quantity of the freight space $\boldsymbol{Q_i}$in a hot-selling route i at a wholesale unit price w_i, and quantity of the freight space $\boldsymbol{Q_j}$in an underutilized route j at an option-price Ω_j per unit cargo. Next, the freight forwarder executes the actual market demand in the underutilized routes at an exercise price e_j for each cargo unit. We assume that each freight forwarder sells the unit cargo in the hot-selling and underutilized routes at prices p_i and p_j, respectively. Also, it is assumed that the airline incurs a fixed marginal operating cost $\mathsf{C}_i, \mathsf{C}_j$ for each unit in the hot-selling and the underutilized routes, respectively.

IV. INTEGRATED WHOLESALE-OPTION CONTRACT MODEL

Since the airlines control the aircraft, the airport slot, and it owns the full freight capacity, it is supposed that the airline starts the negotiation from the lower incentive levels to the higher incentive levels. Moreover, since the game is performed sequentially, the airline repeats the same approach with each new freight forwarder, and thus, this brings in the first lemma,

Lemma 1. For identical freight forwarders in a sequential game, the possible capacity allocation for the forwarder $\boldsymbol{f_r}$from the underutilized routes $\mathcal{J}$, is higher than that is allocated to the forwarder $\boldsymbol{f_{r-1}}$, i.e., $\left(\sum_j^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\boldsymbol{r}} > \left(\sum_j^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\boldsymbol{r-1}}$.

Proof We follow the logic that each freight forwarder in $\mathfrak{F}$ comes individually and negotiates the capacity allocation in both hot-selling and underutilized routes simultaneously. By the end of the negotiation, the airline and the freight forwarder reach an agreement which cannot be renegotiated, and thus, the contract is binding between the airline and the freight forwarder $\boldsymbol{f_1}$. This agreement encompasses the sum ofquantities $\left(\sum_i^{\mathrm{I}} \boldsymbol{Q_j}\right)$, and$\left(\sum_j^{\mathcal{J}} \boldsymbol{Q_j}\right)$ from the hot-selling and underutilized routes, respectively.Hence, the capacity of both routes decreases by these amounts, and becomes$\sum_i^{\mathrm{I}} \mathcal{K}_i - \left(\sum_i^{\mathcal{J}} \boldsymbol{Q_i}\right)_{\mathbf{1}}$ and$\sum_j^{\mathcal{J}} \mathcal{K}_j - \left(\sum_j^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\mathbf{1}}$. Similarly, the remainingcapacity after the $\boldsymbol{r^{th}}$ freight forwarder is$\sum_i^{\mathrm{I}} \mathcal{K}_i - \sum_{f=1}^{r}\left(\sum_i^{\mathrm{I}} \boldsymbol{Q_i}\right)_{f}$from the hot-selling routes and $\sum_j^{\mathcal{J}} \mathcal{K}_j - \sum_{f=1}^{r}\left(\sum_j^{\mathcal{J}} \boldsymbol{Q_j}\right)_{f}$from the underutilized routes. By following this logic, the airline's bargaining power increases because of the capacity scarcity, and thus, the relation $\left(\sum_{j}^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\boldsymbol{r}} > \left(\sum_{j}^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\boldsymbol{r-1}}$holds. ∎

Supposing that the freight forwarders cannot cancel any of the quantities purchased, in any hot-selling route i. Therefore, they incur a loss of v_i for each unsold unit out of the purchased quantity in the hot-selling routes, and hence, each freight forwarder is expected to gain a profit of

$$\left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}})\right]\right)_{\mathfrak{w}} = (p_i - w_i)\boldsymbol{Q_{fi}} - (p_i + v_i)\int_0^{\boldsymbol{Q_{fi}}} F(x_i)dx_i \tag{1}$$

upon using the wholesale contract, while each freight forwarder gains an expected profit from the underutilized routes. Moreover, there are no penalties by canceling some of the reserved quantities, when the option contact method is used equation (2):

$$\left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fj}})\right]\right)_{\boldsymbol{O}} = \left(p_j - \Omega_j - e_j\right)\boldsymbol{Q_{fj}} - \left(p_j - e_j\right)\int_0^{\boldsymbol{Q_{fj}}} F(x_j)dx_j \tag{2}$$

Equations (1), (2) give the expected profit of the freight forwarder in $\mathfrak{F}$is estimated by equation (3)

$$E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}}, \boldsymbol{Q_{fj}})\right] = \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}})\right]\right)_{\mathfrak{w}} + \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fj}})\right]\right)_{\boldsymbol{O}} \tag{3}$$

In each step, solving the imbalance between the underutilized and hot-selling routes necessitates the two parties (airline, and freight forwarder) to find a specific condition such that both sides can reach an agreement on the quantities of freight space from the underutilized routes and the hot-selling routes. Therefore, the following proposition describes this condition.

Proposition 1 The freight forwarder optimum quantity from the hot-selling can be obtained for the following the ***balance ratio***

$$\boldsymbol{\alpha_f}^* = \frac{\boldsymbol{F}(\overline{\boldsymbol{Q}}_{\boldsymbol{fi}})(p_i + v_i) + \boldsymbol{F}(\overline{\boldsymbol{Q}}_{\boldsymbol{fj}})(p_j - e_j) - (p_i - w_i)}{(p_j - \Omega_j - e_j)} \tag{4}$$

Further, the accompanying quantity from the underutilized route is satisfactory to the freight forwarder.

Proof Equations (1), (2) are derived from the following two equations which are used to solve the wholesale and the option contracts for the freight forwarder side, respectively:

$$\max_{\boldsymbol{Q_{fi}} \geq \boldsymbol{0}} \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}})\right]\right)_{\mathfrak{w}} = E\left[p_i \min\{\boldsymbol{Q_{fi}}, x_i\} - w_i\boldsymbol{Q_{fi}} - v_i\{\boldsymbol{Q_{fi}} - x_i\}^+\right] \tag{5}$$

, and

$$\max_{\boldsymbol{Q_{fi}} \geq \boldsymbol{0}} \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}})\right]\right)_{\mathfrak{w}} = E\left[(p_j - e_j)\min\{\boldsymbol{Q_{fj}}, \boldsymbol{x_j}\} - \Omega_j\boldsymbol{Q_{fj}}\right] \tag{6}$$

Further, the overall expected profit can be obtained in Equation (7

$$E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}}, \boldsymbol{Q_{fj}})\right] = (p_i - w_i)\boldsymbol{Q_i} - (p_i + v_i)\int_0^{Q_i} F(x_i)dx_i + (p_j - \Omega_j - e_j)\boldsymbol{Q_j} - (p_j - e_j)\int_0^{\boldsymbol{Q_j}} F(x_j)dx_j \tag{7}$$

We assume that the airline and each freight forwarder are able to reach an agreement under the condition that the airline gives the freight forwarder an amount in the underutilized routes proportional to the quantity of the hot-selling routes. Equation **Error! Reference source not found.** defines the relation

$$\therefore \boldsymbol{Q_j} \propto \boldsymbol{Q_i} \qquad \therefore\ \boldsymbol{Q_j} = \boldsymbol{\alpha_i Q_i} \tag{8}$$

such that $0 \leq \alpha_i \leq 1$

By substituting **Error! Reference source not found.** in (7, the overall expected profit becomes a function of hot-selling quantity $\boldsymbol{Q_i}$. Additionally, it is easy to prove that equation (7 is concave [11]. Consequently, the freight forwarder's maximum expected profit is obtainable when the partial derivative of equation (7 w.r.t the hot-selling quantity equals zero, and so, we obtain the value $\boldsymbol{\alpha_{\mathfrak{f}}}^*$,and the forwarder will be satisfied. ■

In fact, the solution in **Proposition 1** captures reality. In real life, the individual customers send their parcels, packages and freight to freight forwarders to carry them from the country of origin to a certain destination. Regardless of the cargo route followed, the customers need their freight to arrive at the desired destination. Therefore, route identification is one of the freight forwarder's jobs, however, the airline is the party who owns the assets of cargo routes. In this regard, the final decision on routes assignment is achievable by negotiation between the freight forwarders and the airline.

The airline side incurs shortage cost s_j for each unit in the underutilized routes. Consequently, by adopting the option contract, the airline can earn an expected profit of;

$$\left(E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}j}\right)\right]\right)_{\mathcal{O}} = \left(\Omega_j + e_j - C_j\right)\boldsymbol{Q}_{\mathfrak{A}j} - \left(e_j + s_j\right)\int_0^{\boldsymbol{Q}_{\mathfrak{A}j}} F(x_j)dx_j \quad (8)$$

, and the expected profit from the hot-selling routes when using the wholesale contract is;

$$(E[\Pi_{\mathfrak{A}}(\boldsymbol{Q}_{\mathfrak{A}i})])_{\mathfrak{w}} = (w_i - C_i)\boldsymbol{Q}_{\mathfrak{A}i} - w_i\int_0^{\boldsymbol{Q}_{\mathfrak{A}i}} F(x_i)dx_i \quad (9)$$

Equation (8), (9) brings out corollary 2, which gives the airline possible profit from the hot-selling and the underutilized routes.

Corollary 2 The airline's overall expected profit is the total of two sums; first, the sold quantities of the freight space $\sum_i^I \boldsymbol{Q_i}$ in the hot-selling route by wholesale contract. Second, the sold quantities $\sum_j^J \boldsymbol{Q_j}$ from the underutilized routes by option contract.

$$E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}i}, \boldsymbol{Q}_{\mathfrak{A}j}\right)\right] = (E[\Pi_{\mathfrak{A}}(\boldsymbol{Q}_{\mathfrak{A}i})])_{\mathfrak{w}} + \left(E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}j}\right)\right]\right)_{\mathcal{O}} \quad (10)$$

From the airline side, it aims to maximize the overall expected profit by balancing capacity among the hot-selling and underutilized routes. This leads to the following proposition,

Proposition 2 The optimum quantity of the airline from the hot-selling can be obtained from the following formula:

$$\boldsymbol{\alpha_{\mathfrak{A}}}^* = \frac{w_i \boldsymbol{F}(\overline{\boldsymbol{Q}}_{\mathfrak{A}i}) + \boldsymbol{F}\left(\overline{\boldsymbol{Q}}_{\mathfrak{A}j}\right)\left(e_j + s_j\right) - (w_i - C_i)}{\left(\Omega_j + e_j - C_j\right)} \quad (11)$$

, and consequently, the underutilized quantity is also estimated.

Intuitively, the decision of $\boldsymbol{\alpha - ratio}$ brings the airline into conflict with the freight forwarder,however, this conflict occurs at different levels. For example, the small freight forwarders prefer to get higher freight space quantities in the hot-selling routes, and therefore, they would prefer $\boldsymbol{\alpha - ratio}$small**,** whereas the airline prefers to use its power to give them a larger $\boldsymbol{\alpha - ratio}$**.** The large freight forwarders and airline very easily agree to the proper ratio. This logic is shown in **Figure 1**, and it is compatible with the model of Feng, et al. [1].

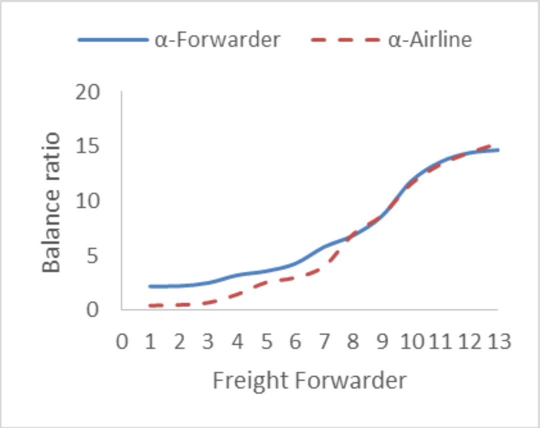

Figure 1 The airline and freight forwarders balance ratios. (The freight forwarders are arranged

ascendingly according to the orders from the hot-selling routes).

The proof of **Proposition 2** is similar to **Proposition 1**. Moreover, **Proposition 1**, and **Proposition 2** bring out a new proposition which describes the relationship between the two types of routes.

Proposition 3 Assuming that both freight forwarders and the airline are risk neural, the optimum quantity allocation to the underutilized route is the inverse of a relocated and scaled cumulative distribution of the quantities in the hot-selling routes, and thus, the cargo quantities which allocated to the underutilized routes follow the self-replicating distributions such as normal, gamma and exponential distribution.

$$F\left(\boldsymbol{Q}_j{}^*\right) = \{A\, F(\boldsymbol{Q}_i{}^*) + B\}^+ \tag{12}$$

, where

$$A = \frac{(p_i + v_i)(\Omega_j + e_j - C_j) - w_i(p_j - \Omega_j - e_j)}{(e_j + s_j)(p_j - \Omega_j - e_j) - (p_j - e_j)(\Omega_j + e_j - C_j)}$$

, and

$$B = \left[\frac{(w_i - C_i)(p_j - \Omega_j - e_j) - (p_i - w_i)(\Omega_j + e_j - C_j)}{(e_j + s_j)(p_j - \Omega_j - e_j) - (p_j - e_j)(\Omega_j + e_j - C_j)}\right]$$

Proof In real practice, the freight forwarders go to the airline individually to reserve the quantity of freight space in the different routes through negotiation process. Usually, the forwarder requests higher quantities of freight space in the hot-selling routes, unlike their orders in the underutilized routes which are very small. In this regard, the airline negotiates to solve the underutilization problem in the underutilized routes. It is assumed that the airline and the freight forwarder agree that the freight forwarder receives a quantity in the underutilized routes proportional to the requested quantity in the hot-selling route. This proportion is derived in **Proposition 1** for the freight forwarder, and in **Proposition 2** for the airline. Therefore, the baragining equilibrium can be achieved when $\boldsymbol{\alpha_{\mathfrak{a}i}{}^* = \alpha_{\mathfrak{f}i}{}^*}$. Therefore, the freight forwarder and the airline agree on the quantites allocated to underuilized routes which resulting from equation (12).Furtheromre, when the X_j is the random variable with parameters ($\mu_i = \bar{X}_i$,$\sigma_i{}^2 = s_i{}^2$), then $X_j = AX_i + B$ is a random variable with parameters ($\mu_j = A\bar{X}_i + B$, $\sigma_j{}^2 = A^2 s_i{}^2$), this hold only when the demand follows self-replicated probabilty distribtutions. ■

The statement in **Proposition 3** proves the model flexibility and validity to the real market, where it is flexible enough to the freight forwarder to get an allocation in the hot-selling only, if and only if, the freight forwarder orders a quantity of,

$$\boldsymbol{Q}_i{}^{**} = \boldsymbol{F}^{-1}\left\{\frac{(\boldsymbol{w}_i - C_i)(\boldsymbol{p}_j - \boldsymbol{\Omega}_j - \boldsymbol{e}_j) - (\boldsymbol{p}_i - \boldsymbol{w}_i)(\boldsymbol{\Omega}_j + \boldsymbol{e}_j - C_j)}{(\boldsymbol{p}_i + \boldsymbol{v}_i)(\boldsymbol{\Omega}_j + \boldsymbol{e}_j - C_j) - \boldsymbol{w}_i(\boldsymbol{p}_j - \boldsymbol{\Omega}_j - \boldsymbol{e}_j)}\right\}^+ \tag{13}$$

, and the capacity is large enough, and in this case, the freight forwarder is considered as the airline's strategic partner. Moreover, **Proposition 3** and **Lemma 1** affirm that the allocated cargo in the underutilized routes increases by the increase of the freight forwarder order in the hot-selling routes, and this is showing in **Figure2**. However, it is not strictly increasing because the model also considers the high demand to the forwarder and considers the negotiation power. Thus, adding to **Lemma 1**, the airline should give-up the negotiation power from the decreased capacity to the potential freight forwarders.

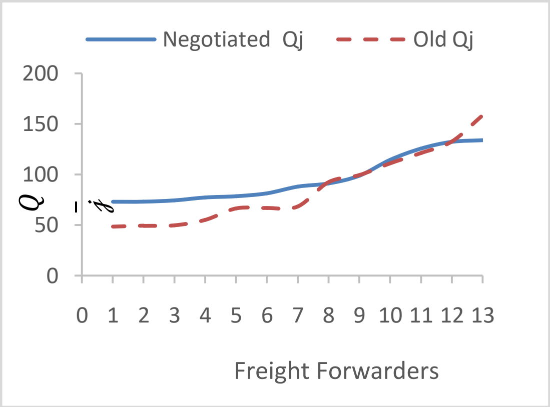

Figure 2 Allocation from negotiated allocation vs. the old allocation

V. CONCLUSIONS

In this article, the demand imbalance between the substitutable cargo routes is solved through an analytic model. The model integrates the wholesale contract and the option contract in a sequential cooperative game model. The airline plays the game with each freight forwarder. The solution assumes that the airline can negotiate with the freight forwarder to reduce its demand in the hot-selling route and add the reduced quantity to the underutilized route. We found that the underutilized routes demand can be represented by a self-replicated distribution. This research is a preliminary work. Our future plan is to extend the model to include the risk-averse freight forwarders.

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