AIR CARGO CAPACITY ALLOCATION: SOLUTIONS FOR DEMAND IMBALANCE BETWEEN DIFFERENT ROUTES

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PhD

The Hong Kong Polytechnic University

2020

The Hong Kong Polytechnic University

Department of Industrial and Systems Engineering

Air Cargo Capacity Allocation: Solutions for Demand Imbalance Between Different Routes

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

August 2019

Statement of Authorship

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Abstract

In the air cargo industry, the relationship between market demand and route capacity is complicated. The market demand is commonly uncertain, whereas the capacity of routes is either uncertain or fixed. This causes various gaps between the demand and capacities of routes, i.e., the freight forwarders demand in certain route may either exceed the fixed capacity of airline (hot-selling routes) or the demand is much less than the capacity of other routes, (underutilized routes). This research tackles the imbalance problem between hot-selling and underutilized routes. On this subject, three capacity allocation models are developed to solve the demand imbalance problem.

Due to the continuous growth of the demand of passengers, an extensive use of wide-body aircraft leaves large spaces in the aircraft belly-hold, and thus, some cargo routes become overcapacity. In this vein, underutilized routes are the first topic in this research. This topic is tackled by two objectives. First, filling up the unused space in underutilized routes by proposing the extra-baggage scheme to exploit the increase of passengers. Second, setting the price of the proposed scheme. As the scheme is new, the price is set with reference to the price of the cargo. The multi-item newsvendor model is employed to derive a close-form price formula for the extra-baggage scheme in reference to market price of cargo. The model is formulated with stochastic extra-baggage-deterministic cargo demands. The results revealed that the extra-baggage price is very high because of the cargo penalties. To cancel the effect of the cargo penalties, the deterministic cargo demand is modified to the stochastic form which gives more realistic prices for the extra-baggage. Moreover, the modified model gives the airline the opportunity to switch between two different pricing strategies either market penetration or pure premium strategy. Moreover, a comparison between the existing excess baggage and the proposed extra-baggage service is conducted. It is found that the extra-baggage profit oversteps the excess baggage profit by 25 percent.

However, the above model does not tackle the imbalance problem directly. It does not include the interrelationship between hot-selling and underutilized routes. So, the second model is proposed to combine a hot-selling route with an underutilized route. A Puppet-Cournot game model is developed to estimate the best quantity combination. In this game, the airline controls the game between the two routes. Also, it captures different quantity scenarios in the form of the best response for each route compared to the other. Then, the Puppet-Cournot game is integrated with the quantity discount policy to motivate freight forwarders to increase their orders in the underutilized route. By performing numerical experiments, the results reveal that the quantity discount boosts the profit of the hot-selling route and decreases the profit of the underutilized route. Moreover, it is concluded that the quantity discount model is only applicable when the profit increase in the hot-selling route is greater than the profit decrease in the underutilized route.

Eventually, a sequential cooperative game is performed between the airline and freight forwarders in which they agree that airline assigns an amount in the underutilized routes proportional to the forwarder’s order from the hot-selling routes. In this game, the payoffs are the expected profit from using a mixed-wholesale-option contract between the airline and freight forwarders. The mixed contract takes advantage of airline power in selling the hot-selling routes at the wholesale price and gives advantage to forwarders by opting for option prices of underutilized routes. The model solution shows that the demand in the underutilized routes follows self-replicating distributions. Also, the mixed wholesale-option model is compared with the pure wholesale and pure option-contract models. The results reveal that the mixed model provides the highest allocations in the underutilized routes, leading to a better demand balance among the substitutable routes.

List of Publications

Journal Papers

1. **Shaban, I. A.**, Wang, Z. X., Chan, F. T. S., Chung, S. H., & Qu, T. (2019). An extra-baggage service price setting with reference to cargo prices using multi-item newsvendor model. *Computers & Industrial Engineering, 128,* 877-885.
2. **Shaban, I. A**., Wang, Z. X., Chan, F. T. S., Chung, S. H., Eltoukhy, A. E. E., & Qu, T. (2019). Price setting for extra-baggage service for a combination carrier using the newsvendor setup. *Journal of Air Transport Management, 78,* 1-14.
3. **Shaban, I. A.**, Wang, Z. X., Chan, F. T. S., Chung, S. H., & Qu, T. (2019). A mixed wholesale-option-contract to fix the demand imbalance between substitutable air cargo routes: a cooperative game approach. *International Journal of Production Economics.* (**Submitted**)
4. **Shaban, I.A.,** Chan, F. T. S., Zhang, J. H., Chung, S. H., B. Niu, Qu, T. (2019). A Puppet Cournot-discount model to manage the quantity allocation between two air freight routes. *Computers & Industrial Engineering.* (**Submitted**)

CONFERENCE ARTICLES

1. **Shaban, I. A**., Chan, F. T. S. and Chung, S. H., Airlines Extra-baggage Pricing Policy Using Newsvendor Price-based Model, *The 47th International Conference on Computers & Industrial Engineering*, 11-13 October 2017, Lisbon, Portugal.
2. **Shaban, I. A.,** Chan, F.T.S., Chung, S.H., Qu, T., and Niu, B., Theoretical Formulation and Demand Parameters Optimization for a Proposed Extra-Baggage Service, *The 7^th^ International Conference on Mechanics and Industrial Engineering (ICMIE'18)*, 16 – 18 August 2018, Madrid, Spain.

3. **Shaban, I. A.,** Chan, F.T.S. and Chung, S.H., Qu, T., A Price Setting for an Excess-baggage Service as a Function of Freight Price, *4th International Conference on Science, Engineering &Environment (See-2018)*, 12-14 November 2018, Nagoya, Japan.
4. **Shaban, I. A.,** Chan, F. T. S. and Chung, S. H., and Qu, T., Air Cargo Capacity Allocation: A Comparison Between the Wholesale and Option Contracts, *3rd International Conference on Recent Advancements in Interdisciplinary Research*, 31st August-1st September 2019, Pathum-thani, Thailand. (Accepted)
5. **Shaban, I. A**., Chan, F. T. S. and Chung, S. H., Qu, T. and Niu, B., A Solution of Air Cargo Capacity Allocation Through an Integrated Wholesale-Option Contract, *International Conference on Aviation Management and Information Technology (ICAMIT-19)*, 12th September 2019, Melbourne, Australia. (Accepted)

Acknowledgements

First of all, I would like to express my full gratitude to my supervisors, Prof. Felix T.S. Chan, and Dr. Nick Chung, for their efforts with me in the past three years. They were, and still, a full of guidance and helping power. They taught me, helped me, and motivated me in a full patience. Also, they have never let me down when I needed their help. Prof. Felix, and Dr. Nick guided me in my research work, taught me research method. Their advices provided have polished my research work, publications. To summarize, they push me to a better future, and I believe that Prof. Felix and Dr. Nick are the best example of the successful mentorship. I further would like to thank Dr. T. Qu, for his supervision.

Second, it is the appropriate time to give the full thanks to the co-workers in the ISE department. I am particularly grateful to Dr. Tommy K.L. Choi, and Dr, Carmen Lee, who were my confirmation examiners and they have provided me precious suggestion on my research direction. I also want to thank my best friend Abdelrahman Eltoukky, for his strong support during the three years.

Finally, I love to dedicate this work to the soul of my father who was waiting for this moment. I also love to thank my mother and the entire family. I further praise my lovely wife and my cute daughters Rukaya and Rawda. In fact, without my entire family's encouragement, I would not be able to achieve this far. Not only as a research but also as person.

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List of Abbreviations

APR1	Airline Profit on Route 1
APR2	Airline Profit on Route 2
APRD1	Profit from Route 1 with Quantity Discount
APRD2	Profit from Route 2 with Quantity Discount
CAS	Cost per Available Seat
CPA	Capacity Purchasing Agreement
DP	Dynamic Programming
EBC	Excess Baggage Cost
EBP	Excess Baggage Profit
EBR	Excess Baggage Revenue
FCFS	First Come, First Served
FRFM	Fuzzy Regression Forecasting Model
FSAs	Full-Services Airlines
GDP	Gross Domestic Product
KLM	(Koninklijke Luchtvaart Maatschappij) is the Royal Dutch Airlines, and it is flag airlines of Netherland
LCCs	Low Cost Carriers
LP	Linear Programming
MILP	Mixed Integer Linear Programming
PARM	Perishable-Asset Revenue Management
PCQD	Puppet-Cournot-Quantity Discount model
POA	Price Only Agreement
R/R	Free-sale Method
RM	Revenue Management
RPD	Discount Reverse Point
SEDC	Stochastic Extra-baggage- Deterministic Cargo model
SESC	Stochastic Extra-baggage- Stochastic Cargo model
STOC	Constrained Stochastic Programming

Chapter 1 Introduction

1.1 Research Background

Air cargo transportation is one of the major means of transportation beside sea shipping and road/rail transport. It is substantially involved in shaping the economic development of the world. It connects many cities around the world and facilitates world trade movement (Pearce, 2019). The value of air cargo transportation stems from its safe and fast movement of perishable goods, humanitarian service in carrying live animals, and proper treatment of high value and weather sensitive products (IATA, 2017). These features contribute to a considerable 10.4% increment in air cargo demand growth in 2017 compared to 2010 (ICAO, 2019). Moreover, it is expected that the annual air cargo market demand will rise by 4.2% in the next 20 years, from 2018 to 2037 (Boeing, 2018a). Air cargo market is a major target for many air carriers. These carriers provide different services and share varying proportion from the global demand. In the following sub-sections, air carriers are classified according to service provision.

1.1.1 Air carriers

In terms of service provision, airlines can be divided into three categories: i) all passenger carriers, which provide passenger services by assigning passengers to the upper-deck of the aircraft and allocating passenger bags to its belly-hold; ii) all cargo carriers that provide only cargo carrying service, and thus, they use dedicated freighter aircraft which transport only cargo; and iii) combination airlines, which provide both passenger and cargo services using combi-aircraft. Combination airlines can be either Low-Cost Carriers (LCCs), such as Southwest Airlines in the USA, EasyJet in the UK, and Air Asia in Malaysia, or Full-Service Airlines (FSAs), such as Delta in the USA, Cathay Pacific in Hong Kong, and Lufthansa in Germany. Beside the dedicated freighters and the combi-aircraft, FSAs and LCCs utilize the belly-hold of passenger aircraft to carry cargo. They assign passengers to the aircraft upper-deck and allocate cargo to its belly-hold space, side by side with the checked-baggage of passengers.

1.1.2 Air cargo demand and capacity allocation in combination airlines

Passengers and cargo represent the main demands of combination airlines. Also, passengers' excess baggage can be considered as an indirect demand. This research focuses on the relationship between cargo demand and airline's capacity on different cargo routes. That is, the capacity allocation problems due to demand-capacity gaps between these routes.

Combination airlines commonly use wide-body aircraft to accommodate the dramatic growth of passengers' demand. This leads to an underutilization problem in the belly-hold of the aircraft. Moreover, due to the imbalance in world trade between the different routes, cargo demand is imbalanced as well, i.e. some routes suffer huge shortage (underutilized routes), while some other receive excessive demand (hot-selling routes).

To fill the belly-hold of the aircraft, it is necessary to sort out the possible commodities which can be allocated therein. Combination airlines receive demand from passengers in forms of excess and overweight baggage, and from freight forwarders and big shippers in forms of consolidated goods, spare parts and other products.

On the one hand, airlines gain profit from offering the excess baggage service. For example, on a worldwide scale, the income from over-weight bags, excess baggage, and other ancillary services reached almost 82.2 billion USD (Dailyhive, 2017). On the individual scale, Britons are charged more than 3.5 billion British pounds annually for their excess baggage (DailyMail, 2017), and the sum of US airlines's profit from excess baggage exceeded 4 billion USD in 2016 (Bureau of Transportation Statistics, 2016). Furthermore, the excess baggage facility is required because of last-minute souvenir purchasers, and wrapping service users (Airports International, 2012). In Southern European airports, the majority of wrapping service users come from Africa, Gulf States, Southeast Asia, the Middle East, and Latin America. Additonally, free trade agreements between countries facilitate small-business scale in those countries (Trade and Industry Department, 2017), such as Hong Kong mearchants travelling to South Korea to buy cosmetics (South China Morning Post, 2018). In this case, if these merchants want to gain more profit, they will buy larger amounts of products, and consequently, they will carry heavier baggage to the airport.

On the other hand, multiple freight forwarders negotiate with the airline for purchasing/booking the capacity from the hot-selling routes, where the sum of the orders of freight forwarders exceeds the fixed routes capacity of the airline. Consequently, the airline needs to dole out the existing route capacity to the freight forwarders with the aim of maximizing profit and keeping the freight forwarders satisfied. In doing this, the airlines may need to use common allocation techniques or algorithms, such as the proportional allocation, lexicographic allocation, FCFS (first come, first served) and price discrimination, among others (Cachon & Lariviere, 1999). In these methods, different tools are used to achieve best performance, such as the use of past sales data and turn and earn strategy (Cohen-Vernik & Purohit, 2014; Lu & Lariviere, 2012). Also, it has been reported in the literature that airlines tend to use revenue management techniques to reserve capacity for the freight forwarders (Hellermann, 2006; Moussawi-Haidar, 2014) and manage it (Han et al., 2010) in the single leg and in the network scales (Barz & Gartner, 2016).

1.1.3 Baggage schemes in combination airlines

As mentioned above, combination airlines load checked-baggage of passengers and cargo into the belly-hold of the aircraft. Combination airlines that operate either the LCCs or the FSAs model have different baggage strategies. On the one hand, the LCCs do not offer baggage in the air-ticket and passengers pay for baggage as an ancillary service. For example, on Easy Jet airline, a passenger pays from 11.56 to 43.70 USD[1] to book baggage of weights between 15 and 40 kg, and this rises to 12.50 USD for each excess kilogram over the pre-booked amount. On the other hand, the FSAs offer limited checked-baggage to each passenger on the air-ticket. Additionally, each airline offers different excess baggage schemes for passengers who aspire to additional weight.

Excess baggage service in FSAs have different schemes among airlines. To understand what an excess baggage is, an insight into allowed checked-baggage is given. An airline offers checked-baggage in pieces and/or weight basis. For example, on a single passenger air-ticket, the allowed checked-baggage in some airlines is one-piece of 30 kg weight, and some others provide two pieces with 23 kg per piece. If the allowed checked-baggage is not sufficient, then the airlines offer different excess baggage schemes for passengers who wish to book more weight. Airlines offer excess baggage in two ways: a pre-booking system, where passengers can book a limited amount of excess baggage in advance; and the penalty cost system, in which the passenger pays a high penalty cost for each excess unit of weight at the check-in counter.

1.2 Problem Statements

From the previous section, it can be surmised that FSAs suffer demand imbalance on different cargo routes. This imbalance leads to two different scenarios; freight forwarders order very high

[1] The USD has been transformed from the Pound Sterling at the standard rate in September 3rd, 2018.

quantities of freight space on hot-selling routes , whereas their demand from underutilized routes is much less than the capacity of the airline on these routes (Feng et al., 2015a). However, the existing literature addresses the two situations individually. And this leads to several research gaps which can be summarized as follows.

- The majority of air cargo studies have focused on the situation when demand exceeds the either capacity of routes or the hot-selling routes. Thus, the researchers have addressed this situation using different revenue management techniques, such as overbooking control (Wannakrairot & Phumchusri, 2016), allocation of multiple freight forwarders to the limited route capacity (Amaruchkul & Lorchirachoonkul, 2011), accept/reject policies (Barz & Gartner, 2016), and possible contracting policies (Tao et al., 2017). However, increase in cargo capacity of the airlines is relatively higher than the demand growth (The Economist, 2016). This is due to the extensive use of wide-body aircraft to accommodate growing passenger's demand. Therefore, it is essential to address the challenge posed by the underutilized routes by proposing a viable solution. The gap between the large capacity and the low demand can be ameliorated by reducing cargo prices or filling up the underutilized space by an alternative service. The price reduction may attract more demand, but it may not be enough to fulfill the underutilized space. Moreover, it is not easy to increase the airlines share from the overall cargo demand because rivals' prices are very competitive, such as sea shipping and rail transport, which may make price reduction unfeasible. On the other hand, compensation can be obtained by taking advantage of growing passengers' demand.

  Usually passenger service in the full-service combination airlines includes one to two checked-baggage on the flight ticket. In addition, there are different excess baggage schemes for the passengers who have overweight or excess baggage. The main features of these schemes are that they have no theoretical basis, and they are expensive. These features reflect the difficulty of managing the excess baggage service. There are few studies discussing baggage service of airlines (e.g.(Scotti et al., 2016; Yazdi et al., 2017)), but they do not consider the pricing of the baggage service. Only the study of Wong and co-workers (Wong et al., 2009b) determined the optimal baggage limit which could be used to maximize profit by allocating more cargo on the passenger's flight.

- If there is no theoretical basis to the existing excess baggage, then any proposed service replacing the existing service necessitates the airlines to take some key decisions, which are premised on answering the next two questions: what is the price of this service? And what are the most related services that can be used as benchmark to set the new service price? To answer these two questions, a deep understanding of aircraft belly-hold space planning is required.
- Dealing with the underutilized route and filling the empty space in the belly-hold of an aircraft are necessary steps to enhance these routes demand, they are, however, not the perfect choices to solve the imbalance problem. The proposed extra-baggage service partially solves the imbalance problem when shortage happens only on passengers' flights. This means that the problem may remain in only cargo routes. Most of the related studies on air cargo capacity allocation and management have only dealt with air cargo allocation by doling out each individual route capacity to multiple freight forwarders (Amaruchkul & Lorchirachoonkul, 2011; Feng et al., 2015b). An exception to this methodology is reported by Feng et al. (2015a). The authors addressed the demand imbalance problem during the booking horizon by using the strategic foreclosure

approach. The capacity allocation between the hot-selling and underutilized routes has not been fully considered. Moreover, there is no existing quantity plan to facilitate a better balance between the hot-selling and the underutilized routes.

- Although quantity discount is used in several applications, such as in procurement contracts (Shaban et al., 2019), supply chains (Monahan, 1984), and inventory management (Banerjee, 1986), it has not received much attention in transportation practices. Also, it has not been used in the air cargo research. So, it is of great interest to study the quantity discount to estimate reference quantities which keep the balance between a hot-selling route and an underutilized route.
- On the other hand, capacity allocation gets severely complicated when airline provides substitutable routes to the same destination. In fact, this problem is fairly new in the air cargo industry, and it is likely to get more severe because of the increasing use of wide-body aircraft (Boeing, 2016a). This problem may expose the airline to losses on both routes. In the underutilized routes, the airline may incur flight fixed cost for each empty space in the aircraft belly-hold because of 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.

1.3 Research Objectives

This research aims at developing and investigating capacity allocation models in order to solve the problem of demand imbalance between cargo routes in full-service combination airlines. Additionally, the research study investigates the role of contracting methods in the cargo market. Further project objectives details are outlined as follows:

1. To cope with the underutilized belly-hold problem by proposing an extra-baggage scheme to replace the current excess baggage utilized by airlines.
2. To develop a pricing model for the extra-baggage service to fill the belly-hold of the aircraft operating on the underutilized routes. Also, to create a closed form mathematical model to set the price of the new extra-baggage service with reference to cargo price.
3. To develop a proactive quantity plan by using the Puppet-Cournot game model to estimate the optimum cargo quantities which gives the balance between the hot-selling and the underutilized routes. This is then integrated with a quantity discount to motivate the freight forwarders to accept the airline's pre-planned quantities.
4. To upgrade a quantity balance model to include an airline and multiple freight forwarders. The new model is developed through a sequential cooperative game by means of a flexible contracting model. Further, the effect of integrating the wholesale and the option contracting on the profitability of combination airline is investigated.

1.4 Scope of Research

This research focuses on cargo capacity allocation in combination airlines. Unlike the other airline model, the combination airlines offer both passengers and cargo services. Cargo allocation depends on selling policies. Two different policies are used to sell the route capacity. For the first policy, route capacity is sold on a long-term basis, where the freight forwarders order an amount of capacity from the airline (year or season based). The second is based on dynamic prices and the price changes with the demand curve where the demand is a function of price. The difference between the all-cargo carriers and the combination airlines is that the all-cargo carriers use freighters only, while the combination airlines use the wide-body and/or combi-aircraft. These aircraft cause a great interdependence between the baggage capacity of passengers and the cargo capacity. In this regard, the capacity allocation between the air cargo and the passengers' baggage and the cargo in the aircraft belly-hold is considered.

In addition, capacity allocation in this research considers multiple routes, because of the demand imbalance between the hot-selling and the underutilized routes. Moreover, the allocation process between the hot-selling and the underutilized routes are planned and executed by the aid of game theory.

1.5 Research Contributions

The contributions of this study can be described as follows:

i. This study establishes a theoretical basis for the excess baggage pricing scheme. Currently, this scheme is executed by the airline's top management. Therefore, a theoretical model is required to reduce the ambiguity surrounding the current excess baggage schemes. Furthermore, the proposed theoretical basis treats the extra-baggage scheme as a special kind of cargo. These significant contributions provide a solution for the underutilized belly-hold space with a known pricing pattern, and thus, the extra-baggage price can use standard rates similar to the IATA Tact rates.

ii. The research presents an approach to treat the carrier as the puppeteer who controls the Cournot game in order to adjust the quantities between the hot-selling and the underutilized routes. The value of Puppet-Cournot model stems from the quantity scenarios, which fix the imbalance between the underutilized and the hot-selling routes. Moreover, the Puppet-Cournot model and quantity discount policy has have been integrated. The Puppet-Cournot-Quantity Discount PCDQ model provides an important scientific contribution by designing a proactive capacity allocation plan to avoid demand imbalance.

iii. In addition, the research study has also contributed to knowledge by combining the wholesale and option contract in a cooperative game form between single airline and multiple freight forwarders to establish a flexible contract. This solves the imbalance between the hot-selling and the underutilized routes. Further, the cooperative game is carried out in two phases. These two phases are mainly designed to cope with both risk-neutral and risk-averse freight forwarders, i.e. the freight forwarders are considered as risk neutral in **phase I** and the airline moves to **phase II** when the freight forwarder tends to be risk-averse. In **phase II**, the model uses the buy-back policy to deal with the risk aversion problem. Also, the model considers the airline's rivals by using the two-phase game, i.e. the airline moves to **phase II** when an agreement is not reached in **phase I**, thereby assuring the airline that the freight forwarder will not go to its competitors.

1.6 Research Significances

This research work investigates the capacity allocation of the cargo for combination airlines. The investigation is carried out in the following steps:

I. To demonstrate the potentiality and feasibility of the proposed extra-baggage service, a numerical simulation has been performed. The simulation includes a comparison between the expected profit from the existing excess baggage scheme and the expected profit from the proposed extra-baggage scheme. Both models consider that the baggage are allocated alongside the cargo in the belly-hold of the aircraft. The simulation results show a significant profit improvement for the airlines, when using the proposed extra-baggage scheme. This is apparent as the profit increases by 25% over the current excess baggage scheme. Moreover, the results show a double profit improvement in various seasons. This performance echoes the importance of the extra-baggage service being implemented in real practice.

II. The integrated Puppet-Cournot-Quantity Discount PCQD model provides a proactive quantity plan which can be used as a preliminary stage to the capacity selling strategies between the carrier and the freight forwarders. Furthermore, the quantity discount brings a profit increase to the hot-selling route and a profit decrease in the underutilized route. Also, it prevents the airline from the undetermined quantity discount policy. The Puppet-Cournot-Quantity Discount model suggests the best condition to which the quantity discount can be adopted. Airlines can offer quantity discount, when the profit increase in the hot-selling route is greater than the profit decrease in the underutilized route.

III. The mixed wholesale-option contract model solution shows that the demand in the underutilized routes follows self-replicating distributions. Also, by comparing the mixed wholesale-option model with the pure wholesale and pure option-contract models, the results reveal that the mixed model provides the highest allocations in the underutilized routes, leading to a better demand balance between the hot-selling and the underutilized routes.

1.7 Structure of the Thesis

The rest of this thesis is arranged as follows:

Chapter 2 presents a critical review of the works related to the topics included in this research work. The discussed topics in this literature are the baggage and extra-baggage studies, newsvendor model, and the air cargo revenue management tools, especially the cargo capacity allocation. Moreover, the game theory studies, including the Cournot duopoly and bargaining games, are covered. Also, the possible contract incentives, such as the quantity discount and the buy-back strategy, are critically reviewed. At the end of this chapter, the research gaps are summarized to provide a better description to the research problems and the work done in the research work.

Chapter 3 includes the detailed description of the research problems.

Chapter 4 describes the proposed extra-baggage services and the capacity allocation of the passengers' extra-baggage alongside the received air cargo. Also, the chapter highlights the differences between the existing excess baggage scheme, the proposed extra-baggage scheme, and the model of the extra-baggage combined with cargo under different demand conditions. Numerical analysis for this model has been conducted to investigate the effect of the extra-baggage scheme on the profit of the airline.

Chapter 5 presents the Puppet-Cournot-quantity discount model and the mathematical formulation of the customized model. Similar to Chapter 4, numerical analyses have been carried out to validate the allocation scenarios between the hot-selling and the underutilized routes. Furthermore, the managerial implication of the Puppet-Cournot-Quantity Discount model is thoroughly highlighted.

Chapter 6 is an extension of Chapter 5. This extension includes a cooperative game model between an airline and multiple freight forwarders. The chapter presents the problem description and the mixed wholesale-option contract model in two phases. Also, numerical experiments have been conducted, and the managerial implications of this extension have been outlined.

Chapter 7 summarizes the overall conclusions of the described models in the previous chapters, the existing limitations of this study and possible research directions in the future

Chapter 2 Literature Review

2.1 Introduction

In order to highlight the importance of this research work, some previous related works have been critically reviewed, and the research gaps are discussed.

As previously mentioned, combination airlines face demand imbalance from the cargo routes. The imbalance divides the routes into hot-selling and underutilized routes. This research work deals with this problem in three phases. At first, the underutilized routes are fulfilled, and proactive quantity allocation plan is created in the second phase. The third phase comprises the development of a quantity allocation model that takes care of both the hot-selling and the underutilized routes, and the negotiation between an airline and multiple freight forwarders.

According to these phases, relevant literature topics are reviewed. For instance, for the airlines to utilize the underutilized routes, an extra-baggage scheme is proposed, and thus related baggage studies are reviewed. Moreover, some previous studies related to the research tool used in this research study are reviewed, such as the newsvendor model, the capacity management and allocation tools. Furthermore, two game theory techniques have been developed in this research work. The Puppet-Cournot duopoly game has been developed to create the proactive plan and a cooperative bargaining game has been exploited to run the contracting process between an airline and freight forwarders. Therefore, both game models are reviewed. Moreover, because contracting and negotiation with the freight forwarders may not go smoothly, incentives are necessary to reach an agreement. Therefore, contract incentives, such as quantity discount and the buy-back policies, are discussed in this literature review. Finally, the research gaps in these topics are outlined at the end of this chapter, which are linked to the problem statements and the contributions of the research work.

2.2 Baggage Studies

Unlike full-service combination airlines (FSAs), Low-Cost Carriers (LCCs) unbundle the cost of baggage from the price of the air-ticket. LCCs charge passengers for any checked-in bag based on weight, while the cost of an air-ticket for full-service combination airlines include the baggage. Most of the research focused on LCCs unbundling schemes and factors that affected these schemes. For instance, Vinod and Moore (2009) demonstrated the impact of branding strategy of airlines and the of unbundling their ancillary services on pricing and revenue management. The authors considered a situation where some airlines segmented their market into different flight classes, and they provided services for different passengers, i.e. excessive baggage bundling as an ancillary service with varied prices. Similarly, Garrow et al. (2012) studied the trend of US airlines to segregate their airfares into different revenue resources and ancillary services. They reported that the checked baggage was one of the most beneficial resources in the service discrimination trend. However, the study focused only on US low-cost carriers, which did not sufficiently represent global conditions. Henrickson and Scott (2012) also investigated the effect of segregating fees for checked bag on air ticket prices following the dramatic increase in jet fuel prices between 1995 and 2009. They concluded that separating the baggage fees from the air tickets allowed the airlines to decrease their airfares, which increased their competitiveness and resulted in increased profit. Furthermore, Zou et al. (2017) showed that baggage fees have a potential influence on increasing the airfare and the traffic.

Results from some studies indicated that baggage fees were influenced by fuel prices. Barone et al. (2011) studied the effect of changes in jet fuel prices on baggage limits and prices and used ordinary least squares (OLS) to develop a market model. The model was aimed at estimating stock returns of airlines when changing baggage fees. The results revealed that the checked bag fees of airlines did not affect their competing stock prices, which was correlated with abnormal stock returns. Scotti and Dresner (2015) adopted a three-stage least squares (3SLS) regression method to investigate the significance of baggage fees on passenger demand on some US routes. Their results showed that high baggage fees negatively affected air passenger demand, which was in consonance with the investigation by Yazdi et al. (2017).

Other than fuel prices, operational performance of an airline directly influenced baggage fees. Although an airline reduced baggage mishandling by increasing its fees, passengers did not complain about the increased baggage rates (Scotti et al., 2016). Moreover, baggage has been identified as one of the main reasons for flight delays, so baggage fees policy could be an important factor to improve the on-time performance of flight (Yazdi et al., 2017). Therefore, the delay penalty costs could be minimized.

Wong et al. (2009a) formulated a constrained model for cargo and regular checked-baggage of passengers in a price dependent newsvendor form. They recommended that allocating more cargo in the belly-hold space could be achieved by decreasing the space occupied by passengers' baggage. Although this recommendation may increase the profit of airlines, it constitutes a burden on passengers who bring over-weight baggage to the airport. These may not be very useful in the current large aircraft capacities and low freight demand. This is coincident with the increase of the unused cargo capacity on different routes, because of the frequent use of wide-body aircraft (Brandt & Nickel, 2018).

2.3 Newsvendor Model

The newsvendor model, pioneered by economist Edgeworth. Edgeworth (1888) is one of the most common models used in inventory management. The aim of the newsvendor model is to estimate the stock quantity which maximizes the expected profit of a firm. Whitin (1955) created the first newsvendor-based price model, by assuming that demand was a linear function of price (Mills, 1959). Furthermore, Thowsen (1975) introduced the ability of the newsvendor in dynamic pricing. Moreover, Khouja (1999) stated that the newsvendor could help in many different applications, such as:

a. Multiple and varied objectives and utility functions.
b. Diversity in supplier pricing strategies.
c. Different discounting configurations and pricing policies for newsvendors.
d. Different information statements of demand.
e. Constrained multi-item problems.
f. Substitutive multi-item problems.
g. Systems in multiple echelons.
h. Models for multiple locations.
i. Newsvendor can be extended to the multiple periods in different selling periods.

Multiple items newsvendor was studied in different research. Lau and Hing-Ling Lau (1996) developed the newsvendor model to solve more than one product. The model included the capacity constraints and resource constraints. Erlebacher (2000) refined the multi-item newsvendor with single resource problem in closed form, and also developed a heuristic to find a faster solution to the problem of the constrained model.

The newsvendor model was also used for setting prices, as reported in the work by Bodily and Weatherford (1995). The authors adopted the newsvendor form to apply a general pricing scheme with multiple prices for a perishable asset. The model showed a good performance on pricing schemes of airlines in terms of maximizing profit. Nevertheless, the work only solved the limited capacity problem with a very simple PARM (perishable-asset revenue management) approach. Moreover, they categorized the prices into limited categories. Each category is limited and cannot be re-opened. This may lead to shortage costs because of the no-shows and the cancellations.

Typically, demand in the newsvendor model is formulated as a function of price in two forms; additive and multiplicative forms (Petruzzi & Dada, 1999). In these forms, Ye and Sun (2016) set prices of firms using the additive form newsvendor model to enhance the pricing strategies for strategic customers and in maintaining the firms' profit at maximum levels. Similarly, using an additive demand function, Ahn et al. (2007) formulated a mathematical programming model to integrate production and pricing decisions, but the decisions were built based on a deterministic demand, which was not in touch with reality. In a step towards making the model more realistic, Arcelus et al. (2012) applied the two forms of the price dependent demand (multiplicative and additive demand functions). They formulated the demand in a stochastic form. To solve the proposed problem, the authors integrated the problem into three optimization forms: maximizing the expected profit, obtaining the maximum of minimum guaranteed profit, and the greatest probability of expected profit.

Hellermann (2006) discussed the newsvendor model as a useful tool to estimate the required space between the airline and the forwarders. However, he discussed the very traditional model and the model was formulated purely on cargo. On the other hand, Wong et al. (2009a) adopted the multi-variable newsvendor model to determine the passenger baggage limits and keep enough space in the aircraft belly-hold to add more cargo. However, this model did not include the excess weight of passengers' baggage.

In this vein, it is revealed that the air cargo and the baggage of passengers can combined by employing the newsvendor model, and therefore the model in Chapter 4 is formulated by the multi-item newsvendor model.

2.4 Air Cargo Revenue Management

Revenue management was first introduced to manage seat inventory by limiting the seat number to differentiate the airfare into different classes (Belobaba, 1987). However, Smith et al. (1992) stated that the American Airlines commissioned this study in the 1960s, but in separate small problems, such as overbooking, traffic control, and discount allocation. Revenue Management (RM) or Yield Management was defined by Kimes (1997) as a way to allocate the available demand to the limited capacity of the airline in order to maximize its profit. Also, he defined it as a method which supports the decision of the airline to sell the right capacities to the right consumer at the appropriate time. In revenue management, price changes because each customer has different levels of willingness to pay for a certain product, so price discrimination is used to decide the prices for each level of these consumers. For example, airlines offer different fare classes to their passengers (Cleophas et al., 2011). Weatherford and Bodily (1992) developed a revenue management model which combined the perishable asset pricing to the overbooking problem. This model was known as *Perishable-Asset Revenue Management* (PARM). The research discussed the different common objectives which were used in revenue management problems to maximize the firm's overall profit, to obtain the maximum use of its fixed capacity, and to get the maximum revenue for the sold products or services. In addition, PARM was used to maximize the customer's good-will to pay for the product or the service, to minimize the net present value of the service of the production process, and finally, to obtain the maximum price from the customer.

However, revenue management term is most likely paired with transportation and/or airline industry, to maximize the revenues of the firm. deB. Harris and Pinder (1995) identified the common features of the services and operations to apply the revenue management as:

a) *Perishability:* The revenue is equal to zero after the service operations start. For example, the remaining space in the freighter aircraft lost its revenue after departure.
b) *Fixed capacity*: Smith et al. (1992) stated that Revenue Management (RM) was most suitable to apply in short-run limited capacity.
c) *Costly capacity change*: regarding the previous feature, the expansion of a firm's capacity requires a high cost, and it increase the cost of operations. On the other hand, the marginal sales are not guaranteed.
d) *Demand segmentation ability*: Revenue management is suitable when the market demand has different characteristics, thus the firm can categorize these markets and use price differentiation strategies to set a suitable price for each market.
e) *Capacity reservation and advance sales*: As the firm has a fixed capacity, revenue management helps the firm to put an acceptance and/or rejection criterion on their sales and reservation through updating the long and medium-term forecasting.
f) *Demand uncertainty*: The demand uncertainty represents a problem in the capacity management process; however, the advantage of RM is the applicability to demand fluctuations.

g) *Predictable demands of a given historical data*: To exploit the full utilization of revenue management, it requires set data records and service history. These data are necessary to forecast the market demand and determine the different market segments.

Revenue management techniques provide a system with controlled capacity and right prices. In these systems, the problem is usually segmented into multiple problems. On the other hand, air cargo revenue management is the maximization of airline profitability by means of integrating the forecasting of the devoted passenger's combi- aircraft and dedicated freighters, planning and allocating of the network capacity, controlling overbooking levels, accept-reject policies, capacity contracting, and pricing (Feng et al., 2015b).

2.4.1 Demand forecasting

As demand is a major factor in this research work, relevant studies should be surveyed. Short-term forecasts are usually the focus of revenue management. Usually, airlines forecast their demand with a timeline of 6 to 12 months (Slager & Kapteijns, 2004). It is slightly difficult to predict the airline’s demand in the medium or long-term because of different aircraft sizes, routes, and schedules. However, demand fluctuation can be adapted by adding more aircraft to the existing fleet (Berge & Hopperstad, 1993). As revenue management falls between uncertain demand and fixed capacity, it is necessary to consider the limited capacity. Suryani et al. (2012) created an approach to the forecasting of the air cargo market demand with the expanded terminal capacity by using system dynamic simulation model. Totamane et al. (2014) adopted Potluck game to predict air cargo demand. Their model had a significant contribution in improving load factor by 9%-12%. Nevertheless, the model was not strong enough to test the predictors, such as fleet type, cargo volume, and airplane size. Moreover, Chou et al. (2011) used the current international cargo market to forecast the market demand of the freight volume, and they developed a Fuzzy

Regression Forecasting Model (FRFM) to achieve this objective. The FRFM model represented an integration between the conventional linear regression model and the concurrent forecasting model. The integration was developed in order to reduce the forecasting errors. The model was implemented using data from Taiwanese airlines. The implementation collected the data for the air freight market in Taiwan and the number of Taiwanese exports from the air cargo. To check the model accuracy, the research used Taiwanese export volume and GDP.

By the aid of recorded history and current air cargo booking data, cancelation rates, number of no-shows, and amounts of offloads and spoilage, etc., airline can forecast the short-term market demand. This market demand is a combination of Gamma and normal distribution as mentioned by Swan (2002). Thus, the proposed model in Chapter 4 utilizes the normally distributed demand assumption.

2.4.2 Capacity allocation

Air cargo capacity plan and allocation represent a great dilemma during the whole supply chain process (Feng et al., 2015b). This is because any cargo has two uncontrollable dimensions which are its weight and volume.

As simpler start, researchers studied allocation problem with single-leg flight to solve revenue management problem in forms of capacity allocation, such as (Amaruchkul et al., 2007). But because of the widespread use of Hub-and-Spoke network, the research shifted from single-leg studies to network studies. Capacity allocation usually depends on the aircraft capacity, so it is necessary to assign the aircraft in the planning process of the network. This planning process over the network is usually performed in three separate steps, which are represented by fleet selection, aircraft rotation, and cargo routing processes. Derigs et al. (2009) integrated these three processes into one model to solve the network planning problem. The authors formulated two different models to carry out these operations in order to maximize the network profit. The objective was achieved by estimating the best combination of the three processes. They also used the shortest path algorithms and the column generation techniques to solve the subproblems in each model.

The airline capacity allocation is the step which comes after the network planning process, but this problem is a complex problem. Because of this complexity, little research tackled this area, and most of this research focused on Dynamic Programming (DP) to formulate their problems. For example, in terms of passengers, Huang and Liang (2011) formulated the seat control model in network scale instead of single-leg scale by dynamic programming. Meissner and Strauss (2012) improved an approximate dynamic programming approach with network effects in revenue management. The authors added choices of customers to appraise the Markov decision process. This was simultaneously separated across the levels of inventory resource. Also, Huang and Lu (2015) adopted multi-dimensional dynamic programming to formulate the air cargo network problem. Afterwards, they replaced this model with two linear programming model to reduce the computational cost. In addition, the authors included the dynamic factor to avoid the lack of accuracy of the LP models.

In the same aspect, Hosseinalifam et al. (2016) set a threshold value for the firm resource to stand for bid prices, which can be used as accept/ reject policy. Whereas, Huang and Chang (2010) used the dynamic programming platform but with stochastic weight and volume of the cargo. On the other hand, the dynamic programming was used to solve the discrete Markov chain model, besides two heuristics which studied the allocation process in large-scale (Amaruchkul & Lorchirachoonkul, 2011). Moreover, Modarres and Sharifyazdi (2009) formulated a capacity allocation model in a mathematical form. The authors put three basic assumptions to the model, which are:

a. The model is only viable with the limited and perishable capacity. So short-term analysis is not easy to modify.
b. Uncertain demand conditions.
c. The customer is segmented into different classes, so the price can be discriminated among the different classes.

They also solved the model analytically by proving that the stochastic allocation model was a unimodal function, not concave, so the optimal capacity allocation by using the unimodal function properties was obtained. The limitation of this model was that it ignored the overbooking problem and assumed that all the customers would show up. Wang (2016a) developed a stochastic integer programming model or constrained stochastic programming STOC model with network effects to optimize the capacity allocation in air cargo industry. The author used a discrete random variable to represent the demand uncertainty. They developed an algorithm to sequentially solve the augmented MILP (Mixed Integer Linear Programming) in multiple iterations, and from the optimal solution, a lower bound and upper bound were developed on the optimal STOC value. The results showed that the upper and lower bounds were improving from iteration to other. They extended this work to be a constrained stochastic programming model (Wang, 2016b). *Table 2-1* contains a literature summary for capacity planning and allocation.

These models introduced the problems of booking limits, but before considering the overbooking levels, combination airlines should use the network plan and the forecasted demand in each route to offer the existed capacity in terms of long, medium, and short-term contracts. Moreover, they have to decide the hot-sale contract clauses in advance. The next section reports the literature on this issue.

Table 2-1 Capacity planning and allocation literature summary

Title	Model	Solution	Environment
(Li & Xianyong, 2006)	Stochastic programming model	Chance-constrained programming	Uncertain demand
(Wong et al., 2009a)	Multi-item Newsvendor	Closed-form solution (multiple scenarios)	Stochastic demands
(Xiao & Yang, 2010)	Continuous-time control	Closed-form solution (numerical examples)	Stochastic demand
(Amaruchkul & Lorchirachoonkul, 2011)	Discrete Markov chain	Dynamic programming, two heuristics	Stochastic demand
(Hoffmann, 2012)	Mathematical dynamic programming	Heuristics	Stochastic demand
(Feng et al., 2015a)	Nonlinear programming model	Closed form solution	Cost structure data
(Wada et al., 2017)	Risk-neutral and risk-averse formulations,	Sample Average Approximation	Stochastic demand
(Moussawi-Haidar, 2014)	Closed form expression form, and discrete-time dynamic capacity control	Dynamic programming, and several heuristics	Time variable and stochastic capacity
(Zhao et al., 2017)	Duopoly game	Nash equilibrium in closed form, (numerical experiment)	Uncertain demand (joint distribution)

2.4.3 Capacity contracting

When airline offers some spaces for advance sales, forwarders respond in different ways based on their capacity. Forwarders with different capacity requirement go to the airline to negotiate and sign contracts for long and medium-term. For example, a forwarder who wants to purchase a fixed capacity on a certain route and within a certain period in a year, is expected to follow the Capacity Purchasing Agreements (CPA). Usually, CPAs have a lifespan of either six or twelve months (Hellermann, 2006). Hellermann's model discussed the capacity option of movement from long-term to the spot market contract between three players, the shipper, the intermediary (freight forwarder) and the airline as the asset provider. The researcher Hellermann (2006) used the Stackelberg game to solve the relationship between the airline, which offers the main capacity in the long-term, and the intermediary. He concluded that the hot market price premium policy was more profitable than using the reservation spot prices. Although he proposed a model to combine the long-term and the short-term contracts, he ignored the time effect on air cargo changes.

Slager and Kapteijns (2004) introduced different capacity selling methods between carriers and forwarders of shippers in KLM[2]. Two different ways were discussed; guaranteed capacity contracts and free sales (or R/R sales). The customer (forwarder) and the carrier agree to reserve an amount of cargo space on a particular flight a day per week. This contract continues over IATA schedule period, while other forwarders (customers) reserve space in advance. So, they use either the free sale (or R/R method). Free sale has three different options. In the first option, the forwarder pays directly from an existing price list; this price list is not fixed over the different seasons. The second option is the Price Only Agreement (POA), where the forwarder books on a hot-sale season.

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[2] KLM (***K**oninklijke **L**uchtvaart **M**aatschappij*) is the Royal Dutch Airlines, and it is the flagship airlines of the Netherlands

The agreement ends by the end of the season. The third option allows the customer to pay for one shipment with a specific price.

Gupta (2008) proposed two different capacity contracting schemes. In the first scheme, the carrier may deal with the freight rate exogenously, and the forwarder can, in advance, reserve capacity with fixed fees. The second scheme is the same as the first, but with zero reservation fees. The two schemes give the carrier a power to control the contract parameters. Furthermore, the forwarder needs to play complex games to opt for a suitable carrier and reservation options which decrease the opportunity costs. On the other hand, by investigating the different air cargo contracting methods, Hellermann et al. (2013) concluded that the airlines can use both option-contracts and the pre-commited contracts, but the contracting method depends on the contracting situation and the negotiation skills of the freight forwarder.

Amaruchkul et al. (2011) studied the capacity contract issues between airlines and forwarders, such as the significant parameters in the negotiation process. These parameters include operational cost of air cargo, market demand, each single freight forwarder request and reservation quantity, and marginal profits. Moreover, they proposed a refund option for the unsold capacity. The refund option used a similar fixed reservation scheme with a wholesale price. The airline sells the cargo capacity to freight forwarders at wholesale price, then it refunds freight forwarders for the unsold quantities at a rate less than the wholesale price. In this regard, airlines should consider this scenario by selling cargo quantity more than the route capacity. However, this may lead to profit reduction if the sold quantities exceed the capacity during the flight departure. Therefore, airlines should solve this problem by precisely estimating the overbooking levels.

2.4.4 Overbooking control

Revenue Management enjoys service perishability and fixed capacity. Moreover, it permits advance booking, which allows customers to book before they even pay or receive the products. For passengers, airline opens the booking process to a certain flight at least six months in advance. For cargo case, the shipper and/or forwarder can book the capacity within twelve to six months before a specific flight (Amaruchkul et al., 2011). These features, in RM, gives rise to complicated decisions. Some questions, therefore, arise from these scenarios. For example, how much is this fixed capacity? And if the airline offers certain capacity to its customers, what if some of these customers fail to show before the departure of the flight? Moreover, if the customer cancels the order, what will the airline do?

Due to the above concerns, airlines result to overbooking. Overbooking is a precautionary action that an airline takes by selling more cargo space to avoid the empty spaces which may result from cancelation or no-show (Kasilingam, 1997b). So, considering overbooking levels has a great benefit to the airline not only on the congested flights but also, in the un-congested flights. If the airline imposed correct overbooking levels, these all overbooked spaces will compensate cancellation and no-show spaces. Hence, it will convert to a revenue. But, most likely this not happen and the airline has to find an alternative plan to offer a good service to its customer, and therefore, these procedures reduce the airline's revenue (Suzuki, 2006). Some research works studied the overbooking problem, but unfortunately, only few studies focused on air cargo overbooking. For instance, Kasilingam (1997a) developed a rigorous model to estimate the overbooking considering uncertain capacity by using different probability distributions in both discrete and continues random variable (Kasilingam, 1997b). Also, Wang and Kao (2008b) adopted a fuzzy knowledge algorithm to estimate the optimum air cargo overbooking levels under uncertain capacity environment. In a different manner, Popescu et al. (2006) suggested that overbooking can be predicted by estimating the show-up-rates. The show-up-rate means only the show-up rates of the cargo weights, regardless of the cargo second dimension (volume). After data fitting and the behavioural analysis, they found that it might be more suitable to use non-parametric estimators rather than using a different parametric distribution, such as (normal, gamma, and Weibull). So, they started with the histogram as the most common non-parametric estimator. Wavelet methods, as used, minimized the noise which existed in the estimator bins. Nevertheless, the authors used a discrete distribution for these rates, and they did not take into account that the cancelation rate had different records.

On the aspect of air cargo features, weight and volume dimensions take key roles in the complexity of applying revenue management tools. Luo et al. (2009) formulated two dimensions overbooking models. The authors changed the overbooking limits in the one-dimensional overbooking models to a curve line in the two-dimensional overbooking model. Also, Wannakrairot and Phumchusri (2016) extended Popescu's model from one dimension show-up-rate to two dimensions by adding the density of booking request. The objective of these authors was to minimize the total costs. The difference between this research (Wannakrairot & Phumchusri, 2016) and Popescu's research was not only in the model dimensionality, but also this model considered the show-up-rate, and the booking density follows a known probability distribution. In addition, they studied the effect of spoilage and offload costs in their research. On the other hand, the two dimensions overbooking model-based maximum profit approach was carried out by (Moussawi-Haidar & Cakanyildirim, 2012).

The above research was formulated through an aggregated model and analysis. The authors claimed that the overbooking could be estimated by a box bounded by two threshold points.

Moreover, it did not rely on booking request distribution. The limitation of this model was the fixed density assumption, which might not agree with the offloading process. Finally, it might not be necessary that the overbooking levels count on the likelihood of the show-up-rates, but this might also result in uncertain demand for larger size cargo, and therefore reflected in prices. Airline alliances may be a good scenario to avoid the offload costs in many cases, however, this solution poses different concerns.

Chen and Hao (2013) discussed the benefits of co-option alliances to the different participants and how it affected overbooking decision. The authors developed an overbooking model to control the overbooking for the different airlines involved in the co-option alliance. The model was implemented in the travel market of China. Additionally, Wang and Fung (2014) studied the alliance overbooking problem from a different perspective. They formulated a model to avoid the overbooking risks which might happen in the allied airlines. See *Table 2-2,* a summary of overbooking models in the literature.

By the end of this section, it is concluded that deciding the correct overbooking level is one of the most effective processes in the air cargo industry. Thus, considering this level, the carrier ought to set a suitable policy to decide either to accept or reject the forwarders' requests and when they negotiate any new capacity contracts. The next section discusses the related studies which discussed accept-or-reject policies.

2.4.5 Accept-reject policy

The decision of the airline to accept or reject follows the overbooking situations. As aforementioned, the forwarders come individually to the airlines, and they order different quantities. The airline should decide whether to accept or reject freight forwarder's request. The studies on this topic aim also to accept the orders which maximize the profit of the airline.

Table 2-2 Overbooking literature summary

Title	Model	Solution	Factors
(Kasilingam, 1997b)	Closed form mathematical formulation	Closed form solution	Continuous and discrete probability distributions, stochastic capacity
(Popescu et al., 2006)	Predicting show-up rates.	Quantitative analysis	Discrete and normal distribution
(Becker, 2008)	Shipping information records (SIR)	Questionnaire (behavioural analysis)	Forecasting numbers of shows-up records
(Wang & Kao, 2008a)	Fuzzy knowledge system	Fuzzy reasoning	Show-up rate, over-sale cost and spoilage cost
(Luo et al., 2009)	Curve (Cab) and Rectangle (Rab) model	Closed form solution and heuristics	Minimize offloading and spoilage costs
(Moussawi-Haidar & Cakanyildirim, 2012)	Aggregate mathematical programming	Closed form solution	Beta-distribution for show up rate
(Singhaseni et al., 2013)	Mathematical programming model	Computational analysis for five scenarios	Adopt the passenger overbooking methodology
(Wannakrairot & Phumchusri, 2016)	Regression analysis	Computational analysis of different factors, naïve method	Random variables (request level, show-up rate, and booking request density)

Regarding this issue, Amaruchkul et al. (2007) proposed an accept-or-reject policy for single segment flight by using Markov model. The authors developed six heuristics to the Markov model and argued that the new accept-reject policy gives better results compared to the first-come first-served (FCFS) policy.

The extension of this work was also done by (Amaruchkul & Lorchirachoonkul, 2011), which included multiple flights instead of a single leg. Moreover, they formulated the model by dynamic programming and solved it by proposing two heuristics. How was the performance of the model? Put that information here.

Han et al. (2010) improved the two previous models by allocating the flight capacity in single-leg-flight. The model added more consideration of profit rate for each cargo type. The authors adopted the Markov decision process model to control the booking process under the uncertainties of cargo weight, volume, profit rate and type. Also, the same problem can be solved by dynamic programming model, and Amaruchkul et al., (2007) stated that the exact solution of this Markov problem is difficult to be obtained, so they developed six heuristics to cope with this issue. The solutions compared the proposed heuristics with the first-come first-served (FCFS) strategy. Moreover, a de-couple heuristic can be improved by adopting the joint approximation algorithm to solve this dynamic programming model (Huang & Chang, 2010).

2.5 Game Theory

In this section, the game theory techniques, which are relevant to the topics in this research work, are discussed. Not many studies in air cargo field used the game theory techniques, although airlines play multiple games with different players. For example, the airlines play with the airport in slot sales and auctions (Sheng et al., 2015). Also, they engage in cooperative and revenue sharing games (Saraswati & Hanaoka, 2014; Zhang et al., 2010). Moreover, leader-follower (Stackelberg) games are adopted (D'Alfonso & Nastasi, 2012). For the same objectives, the airlines compete with one another to get the highest allocation or revenue share (Xiao et al., 2016).

The games between airlines extend to different modes, such as competing for hub-domination in the network service (Fageda et al., 2011; Hansen, 1990). Furthermore, they compete for passengers in either single period models (Borenstein & Rose, 1994) or dynamic models (Andrew & Lyn, 2013). Grauberger and Kimms (2016) introduced the Nash equilibrium of a competition game between multiple airlines to simultaneously estimate the optimum booking quantities and prices in network scale. Furthermore, the airlines may compete to select their partner in making a profitable alliance (Adler & Smilowitz, 2007). The airlines' strategic alliance groups also play among themselves to reach agreements for the revenue share proportions (Çetiner & Kimms, 2013; Hu et al., 2012).

In addition, combination airlines have a direct relationship with freight forwarders. Therefore, they play different games, including leader-follower games and bargaining games. Hellermann (2006) used the Stackelberg game to model the long-term and spot market contract between single airline and single freight forwarder. He concluded that the premium pricing policy gives more benefits than the reservation prices. Also, Gupta (2008) adopted the Stackelberg game to design a flexible capacity contract. Tao et al. (2017) used the Stackelberg game to update Hellermann's model (Hellermann, 2006) by including multiple forwarders, thereby solving the capacity booking and pricing through an option-contract form. Amaruchkul et al. (2011) aimed to estimate the maximum profit for the airline and the forwarder together. On this subject, they adopted the principal-agent game in which the airline was the principal and the freight forwarder was the agent. Although the game was run between the airline and the freight forwarder, the airline leads the game by setting the final allocation and pricing decisions.

2.5.1 Cournot duopoly model

Augustin Cournot was the first to estimate optimal production quantities between two independent firms who compete for perfectly substitutable products, i.e. the "Cournot duopoly" (Cournot, 1838). The Cournot duopoly model has undergone many changes and development. For example, Edgeworth (1925) claimed that a duopolist can increase his revenue by simply reducing the product price, provided that other duopolist's price is fixed. This claim has been tackled by Sonnenschein (1968), who stated that the Cournot model had two different interpretations which was not clear to Edgeworth. Dowrick (1986) integrated the Cournot and leader-follower Stackelberg models to discuss asymmetric duopolies. However, for a duopolist, the comparison between the Cournot model and hierarchical Stackelberg model showed that Stackelberg profit is greater than the Cournot profit (Anderson & Engers, 1992). Vives (1984) studied the effect of information on Cournot model, and claimed that the Cournot-based information model could never give an optimal market outcome. Ewerhart (2014) studied the Cournot duopoly game for a biconcave demand.

From the above studies, it is revealed that the Cournot duopoly game model can be used to optimize the quantity share between hot-selling and underutilized routes and maximizes the profit of the two routes. In this research the is price a linear function of the quantity. Moreover, the two routes compete the best allocation which gives the airline a preliminary quantity allocation before opining the booking for the two routes.

2.5.2 Wholesale and option contracts

In the literature, both wholesale and option-contracts have been widely used in the supply chain. For example, Cachon and Lariviere (1999) and Wei et al. (2013) used the wholesale price to dole out capacity to multiple retailers. Furthermore, the wholesale contract was adopted for revenue sharing in the supply chain (Chakraborty et al., 2015; El Ouardighi, 2014) . Similarly, the option-contract was widely adopted in capacity allocation and revenue sharing (Cai et al., 2016; Vafa Arani et al., 2016). Also, it has been used to support the buying decision for the balance between the loss-aversion preference and maximization of retailers' profits (Xu et al., 2019). Further, it is observed that the wholesale and option-contracts are applied as alternatives (Davis & Leider, 2018; Keyvanloo et al., 2015). For example, Burnetas and Ritchken (2005) showed the effect of using an option-contract on wholesale prices and Zhao et al. (2010) introduced wholesale drawbacks in supply chains and suggested the adoption of the option-contract instead.

Also, wholesale and option-contracts were implemented in the air cargo industry. For instance, Gupta (2008) and Levin et al. (2012) used wholesale pricing in the allotment contract between airline and freight forwarders. Whereas, Hellermann (2006) and Hellermann et al. (2013) used the option-contract in the Stackelberg game to allocate cargo capacities for a single freight forwarder in a single airline, Tao et al. (2017) adopted the option-contract to set the cargo prices and to estimate the optimum quantity reservation. Both contracting methods were used to address similar challenges.

2.6 Contract Incentives

It is crucial to find a method to attract freight forwarders to increase their purchase on the underutilized routes. A quantity discount strategy is an effective method to sell more quantity by decreasing the total of buyers' costs (Crowther, 1964). Yin and Kim (2012) developed an analytical model to apply an all-unit quantity discount in shipping transportation lines. They employed quantity discount to characterize the tariff in a container line. Qiu and Lee (2019) used the Stackelberg (leader-follower) game to set a single quantity discount break point in the dry port system. They adopted Monahan (1984) settings to estimate the optimal single break-point under an all-quantity discount policy.

Also, buy-back policy is commonly used in the real practice as an incentive to buyers or retailers when negotiating with suppliers and manufacturers (Nagarajan & Sosic, 2008). The buy-back policy states that the supplier returns the production cost to the retailers for every unsold product (Pasternack, 2008). Lin et al. (2017) applied the buy-back policy in air cargo industry. They formulated pricing model through Hellermann's model combined with Black Scholes model. Also, the results showed that the airline and the freight forwarders revenues increased when applying the buy-back policy.

2.7 Research Gaps

From the information provided above in the literature review section, the existing research gaps can be summarized as follows:

1- Since combination airlines provide two services (passenger and cargo), it is expected that those previous studies should examine and investigate the two services together. However, most of those studies dealt with each service independently (Amaruchkul & Lorchirachoonkul, 2011; Becker, 2008). Even when some studies tried to combine cargo and passengers in one model, such as (Wong et al., 2009a), they studied the possible weight limits for the checked-baggage of passengers to allocate more cargo in their passengers' flight. This means that they focused on the problem when the cargo capacity is less than the market demand. Moreover, there are no studies considering the passengers' demand growth to solve the underutilized routes problem. The excess baggage is proposed in this research work to contribute to the solution of this problem. However, the studies which paid attention to the passengers' baggage were performed on LCCs, while passengers' bags in the full-service combination carriers did not receive much attention (e.g. (Scotti et al., 2016; Zou et al., 2017)). Furthermore, there is no published work to manage the excess baggage schemes of the full-service combination airlines (FSAs).

2- The separation between passengers and cargo planning in the combination airlines leads to an aggressive cargo demand imbalance. This problem was studied by (Feng et al., 2015a), but they segmented freight forwarders according to the ordering size. Therefore, large freight forwarders have greater chance to get more cargo space in the hot-selling routes, and the small forwarders are allocated to underutilized routes. This does not give the small freight forwarders a fair allocation. In this regard, a proactive plan is required to suit a variety of sizes for freight forwarders. Therefore, this research work proposes quantity discount policy to ameliorate this problem. Although the robustness of this approach has been established in other industries, it is yet to be applied to the air cargo industry. The advantage of the policy also lies in its ability to distinguish the different categories of freight forwarders and attract them to buy more amount in the underutilized routes.

3- Although there are many cargo capacity allocation studies, most of them focused only on allocating the cargo capacity to freight forwarders to avoid the overbooking problem (Barz & Gartner, 2016; Becker, 2008). This implies that these studies dealt with only hot-selling routes. For example, Amaruchkul and Lorchirachoonkul (2011) used the discrete Markov chain to dole out the capacity to multiple freight forwarder in a hot-selling route. Furthermore, the capacity allocation is usually carried out through a contracting process between the airline and freight forwarders. Most of the contracting studies consider the airline as a leader and the freight forwarders as follower, and thus they used the Stackelberg, leader-follower game (Tao et al., 2017). In addition, as the research stream focused on the hot-selling route problems, they applied only one contracting strategy, either option contracting (Hellermann et al., 2013; Tao et al., 2017) or wholesale price contracts (Gupta & Wang, 2007). Since the demand imbalance between hot-selling and underutilized routes increases, it is necessary to take advantage of each contracting method for these routes.

4- The wholesale and option contracts were implemented in the air cargo industry. For Example, Gupta (2008) and Levina et al. (2011) used the wholesale pricing in the allotment contract between the airline and the freight forwarders. Whereas Hellermann (2006) and Hellermann et al. (2013) used the option contract in the Stackelberg game to allocate the cargo capacities for a single freight forwarder in a single airline, Tao et al. (2017) adopted the option-contract to set the cargo prices and to estimate the optimum quantity reservation. Both contracting methods were used to solve similar situations. All these works were used only to solve the capacity allocation by assuming either uncertain route capacity or limited capacity, and thus, they tried to balance the capacity and demand for a single route. However, they have not combined the wholesale and the option contracts in the air cargo industry. This combination takes advantage of each contracting method in one model, and thus, it solves the demand imbalance problem.

Chapter 3 Problem Description

After the planning period, carriers usually experience contradictory demand-capacity gaps on different routes. Cargo demand may exceed the capacity of some routes (hot-selling routes), whereas demand may not be sufficient to fill even half of the capacity of other routes (underutilized routes). The Civil Administration of China states that hot-selling routes represent 24.5 percent of all operating routes, and the underutilized routes represent 33.6 percent of all operating routes (Feng et al., 2015a). The common example of this problem is the excessive freight on the noon passenger flight from Cairo to Dubai, while there is little freight demand in the overnight flight for the same origin-destination. The reasons for this imbalance problem include the difference in trade movement between the cities, shown clearly between Asia-North America and Middle East-Europe lanes (IATA, 2018a). Moreover, increased utilization of wide-body aircraft leaves more empty space in the belly-hold (Boeing, 2018b). This occurs because of the difference between the passengers and freight traffic, which affects the plan of the airline and the capacity of routes.

The increase in air cargo demand causes two opposite effects on airlines. First, extra-profits when the capacity accommodates this demand. Second, profit-drop because of the opportunity costs and the penalty costs. The opportunity costs result from the empty space during flight departure because of order cancellations and no-shows. The penalty costs result from delayed, destroyed, and offloaded cargos because of inaccurate overbooking calculations (Feng et al., 2015b).

As a result, the relationship between cargo demand and airline capacity has received a great deal of research attention in the past few decades (Amaruchkul & Lorchirachoonkul, 2011; Gupta, 2008; Han et al., 2010; Hellermann et al., 2013). Many methodologies have been used to characterize this relationship, and deal with the different demand-capacity gaps. For instance, air cargo overbooking, capacity allocation and management, accept-reject policy, and contracting. However, very few studies tackled the demand imbalance between the hot-selling and the underutilized routes (Feng et al., 2015a).

In order to tackle the imbalance between the substitutable hot-selling and the underutilized routes in combination airlines, it is necessary to take advantage of passenger service, develop a preplan for the quantities which keep the demand balanced, and improve capacity allocation of the airline when negotiating with freight forwarders. In this regard, passenger-cargo relationship and cargo planning horizon should be described.

With regard to passengers, it is expected that passenger demand will grow from 3.8 billion passengers to almost double by 2035 (IATA, 2016). Thus, combination airlines have a great challenge in satisfying the rapid growth of passenger demand. This challenge is felt in the limited capacity of airports (Evans & Schäfer, 2014) and in constrained staff and fleet capacity (Kölker et al., 2016). One of the potential solutions to demand upsurge is to replace narrow-body aircraft with wide-body aircraft. Although wide-body aircraft accommodate a larger number of passengers, they have a larger belly-hold capacity compared to the narrow-body aircraft (Boeing, 2016b). This coincides with reports which reveal that the cargo demand is not sufficient to cover the cargo capacity of airlines (Air Cargo News, 2016; The Economist, 2016). Consequently, the large space in wide-body aircraft leads to an underutilization problem in the belly-hold of the aircraft. Moreover, in different seasons, the problem of underutilization of the belly-hold of aircraft occurs and in some other seasons, over-capacity problem arises (Feng et al., 2015a). Furthermore, the world freighter usage is expected to increase from 1770 to 3010 freighters, i.e. 70% increase in the period 2016 - 2033, and the aircraft belly-hold utilization does not exceed 50%, as shown in *Figure 3-1* (IATA, 2017). Low load factor negatively influences the business performance of airlines, while an increase in the load factor enhances overall saving (Totamane et al., 2014). To exploit the growth of passengers, an extra-baggage scheme is proposed and discussed in **Chapter 4.**

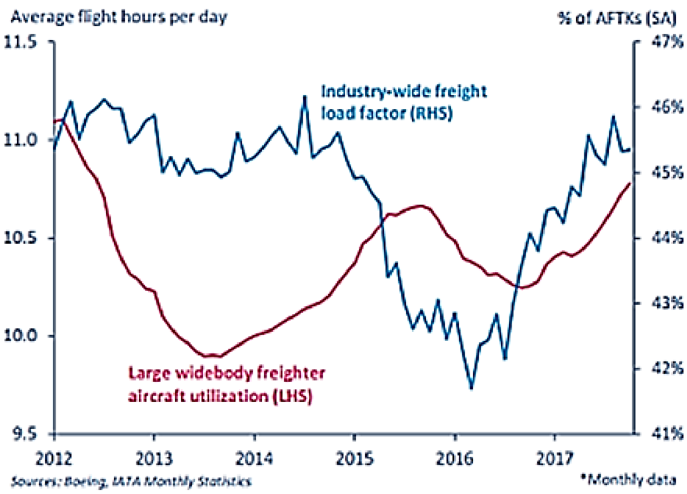

Figure 3-1 Wide-body freighter aircraft utilization and the relative load factor (Source: IATA Cargo Strategy)

Twelve months before flight departure, airlines offer their routes' capacity for sale and/or reservation. During this period, large, medium and small freight forwarders go sequentially to the airline to buy or book a space on different routes (Slager & Kapteijns, 2004). Airlines sell their capacity by long-term contract in the first six months from the commencement of the booking horizon (shown in *Figure 3-2*), and then they sell the remaining capacity in medium-term contracts until a few days before the flight departure. During these few days, the airline sells this remaining space in free-sale and dynamic pricing. Along the booking horizon, multiple substitutable routes are offered for booking. Capacity and demand differ among these substitutable cargo routes. The imbalance problem occurs because of the demand-capacity gap on the different cargo routes. These gaps usually happen in some seasons. Freight forwarders prefer to reserve larger space on some routes, resulting in a positive gap between demand and route capacity (hot-selling routes). On the other hand, freight forwarders reserve very few quantities of freight space in the substituting routes, leading to a negative-gap between the demand and the route capacity (underutilized routes).

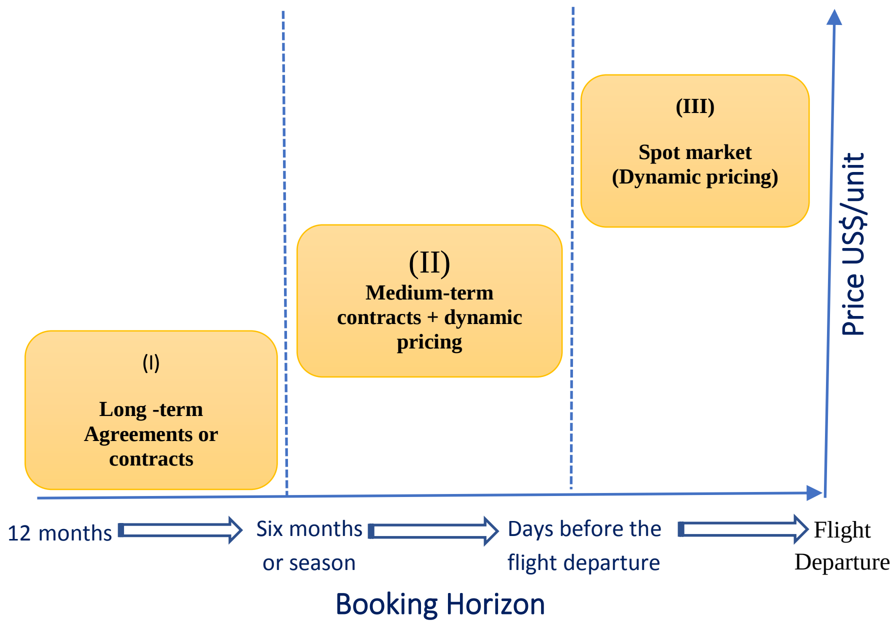

Figure 3-2 Different capacity reservation periods and type of contracts

To solve the demand imbalance between the hot-selling and the underutilized routes, a proactive cargo plan is proposed in **Chapter 5**, and modelling results of mixed wholesale-option contract in forms of cooperative games are presented in **Chapter 6**. The flow chart of the research project is illustrated in *Figure 3-3*

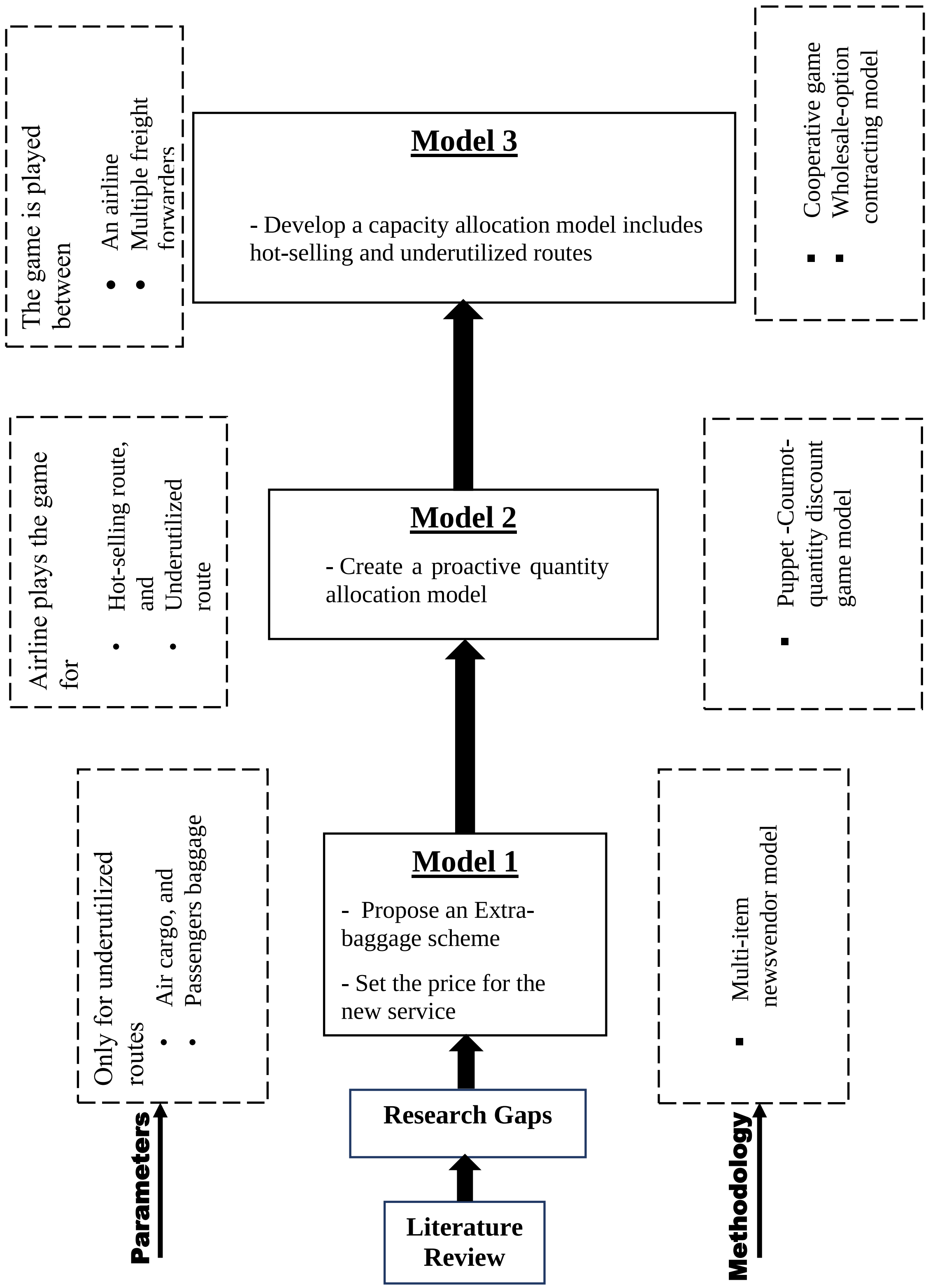

Figure 3-3 The flow chart of the research project

Chapter 4 Combined Extra-baggage and Cargo Model

4.1 Introduction

The first step in solving the demand-capacity imbalance between different routes is dealt with in this chapter[3]. The air cargo routes in this research project are either hot-selling routes (market demand is more than the capacity of the airline), or underutilized routes, where the airline receives a demand much less than its capacity. Most of the revenue and capacity management studies, such as Amaruchkul et al. (2007) and Han et al. (2010), have focused on demand on the hot-selling routes, while the underutilized routes begin to increase because of the significant growth in the passengers' demand and the need for using wide-bodied aircraft, which also increases the airlines cargo capacity (IATA, 2016).

On this subject, a solution for filling up the unused space in the underutilized routes is required. The advantage of the increase in the demand of passengers is taken to supplement the unused space in the belly-hold space by the means of extra-baggage. The extra-baggage scheme is proposed to replace the current excess-baggage scheme in the full-service combination airlines. The extra-baggage scheme is considered as a special cargo service. As extra-baggage deals with passengers and takes cargo features. The difference between the current excess-baggage, extra-baggage and the cargo services are described in this chapter. Also, the price of the extra-baggage as a function

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[3] The work in this chapter has been published in following papers:

1. **Shaban, I. A.**, Wang, Z. X., Chan, F. T. S., Chung, S. H., & Qu, T. (2019). An extra-baggage service price setting with reference to cargo prices using multi-item newsvendor model. *Computers & Industrial Engineering, 128*, 877-885.
2. **Shaban, I. A**., Wang, Z. X., Chan, F. T. S., Chung, S. H., Eltoukhy, A. E. E., & Qu, T. (2019). Price setting for extra-baggage service for a combination carrier using the newsvendor setup. *Journal of Air Transport Management, 78*, 1-14.

of the cargo price is modelled through the multi-item newsvendor model. The stochastic extra-baggage and deterministic cargo demand environment are first modelled. Then, the model is formulated under a stochastic extra-baggage and stochastic cargo demand environment.

Eventually, the proposed extra-baggage and the excess-baggage services are compared. Moreover, the chapter ends with the managerial implications of the proposed extra-baggage scheme.

4.2 The Excess-baggage Service in Combination Airlines.

The FSAs airlines provide two excess-baggage options: First, a passenger books one or two additional pieces in advance. Second, the passenger pays for each excess unit weight over the allowed checked-baggage at the check-in counter. For more elaboration, in the current situation, airlines proffer from one to two pieces (between 23 and 35kg each), for each passenger on his/her tickets. Therefore, they also offer excess-baggage schemes for passengers who may have more baggage over the allowed weight. The weight and the price of these excess-baggage schemes vary from one airline to another. Not only excess-baggage schemes differ in terms of pricing and weight allowed, the schemes also differ within the airlines. Moreover, pricing policies of the excess-baggage are frequently changed, for instance, excess-baggage schemes weights and prices differ with the fare class and vary with the different geographical zones. Furthermore, the excess-baggage price may change before and after a certain date.

In Lufthansa, the excess-baggage price before 18 April 2018 differed from the price after 18 April 2018 (Lufthansa, 2018). This difference was not only on the excess-baggage prices but also in the route classification system. Before April 2018, the pricing was based on two price zones: prices within Europe routes, and prices between the intercontinental routes.After 18 April, on the other hand, the intercontinental routes were split into five new routes. These routes include North Africa, Eastern Mediterranean countries, and Central Asia routes, short intercontinental routes, medium intercontinental routes, long intercontinental routes, and routes from/to Japan. Consequently, the prices on some routes increased and decreased on others. The rise in the price of some routes reached 78 USD over the old rates 200 USD, e.g. the maximum bag price in the intercontinental routes was 200 USD, and it became 230 USD in the medium intercontinental and 278 USD in the long intercontinental routes.

The common factor among all the schemes is the high prices which represent a huge burden on passengers. This burden reaches its peak when passengers go to the airport with over-weight baggage without an advance booking. In this situation, the passenger either pays a very high price for each unit over-weight or dispose of the excess weight, if he/she is not willing to pay. In most airlines, the excess-baggage scheme is also limited to one or two pieces over the allowed regular baggage. For example, Lufthansa does not accept a single bag which weighs more than 32kg, and they forward this baggage to the cargo sector (Lufthansa, 2017).

4.3 A Proposed Extra-baggage Scheme and the Cargo Service

To achieve the first objective in which the large belly-hold space in the passengers' aircraft can be utilized, an excess-baggage scheme under the name "Extra-baggage scheme" is proposed. The proposed scheme is supposed to replace the current excess-baggage scheme. *Figure 4-1* illustrates a schematic diagram of the difference between the current excess-baggage and the proposed extra-baggage scheme.

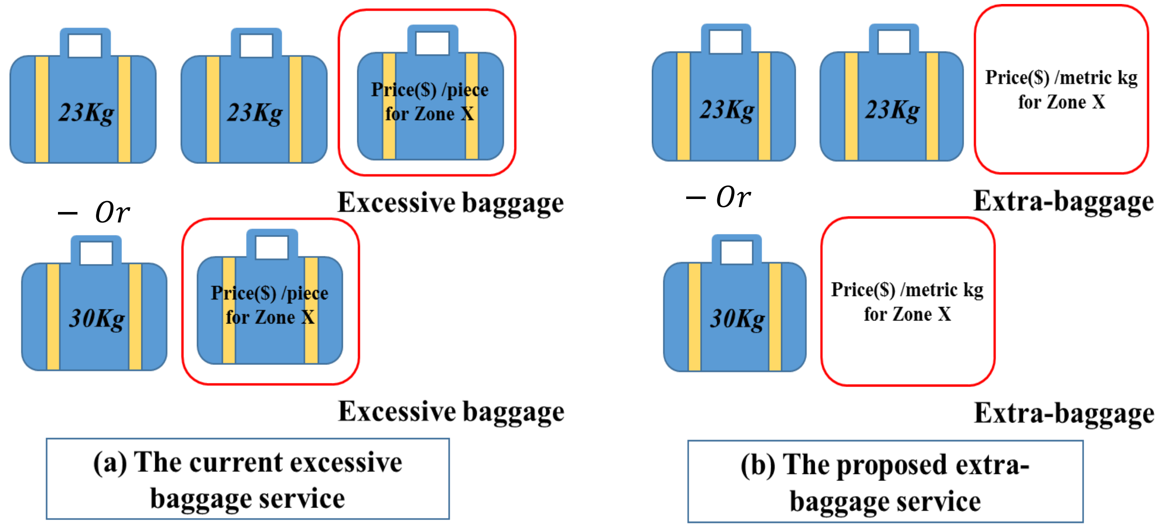


Figure 4-1 A schematic diagram compares the current excessive bags scheme and the proposed extra-baggage scheme.

The extra-baggage scheme can be considered as a special cargo service, where the extra-baggage and the cargo services have some common features, especially when they serve the same market. *Figure 4-2* shows the main common features and the basic differences between the extra-baggage and cargo services.

The extra-baggage operations start from the passenger who brings his/her belongings to the airport when traveling to a new destination. The airline can offer two payment options for the extra-baggage. First, the passenger books extra-weight during the air ticket booking or through the airline's website, and the extra-baggage will be added to the tickets.

Second, he/she pays directly for any extra-weight over the allowed baggage in the airline check-in office, and the rate for the second case should be equal to the first one plus penalty costs for each kilogram, and hence the airline can avoid an inconvenient situation as in the current excess bag scheme. Passengers check up with their allowed bags and extra-baggage in the airport at the airline check-in office, similar to the regular check-in process.

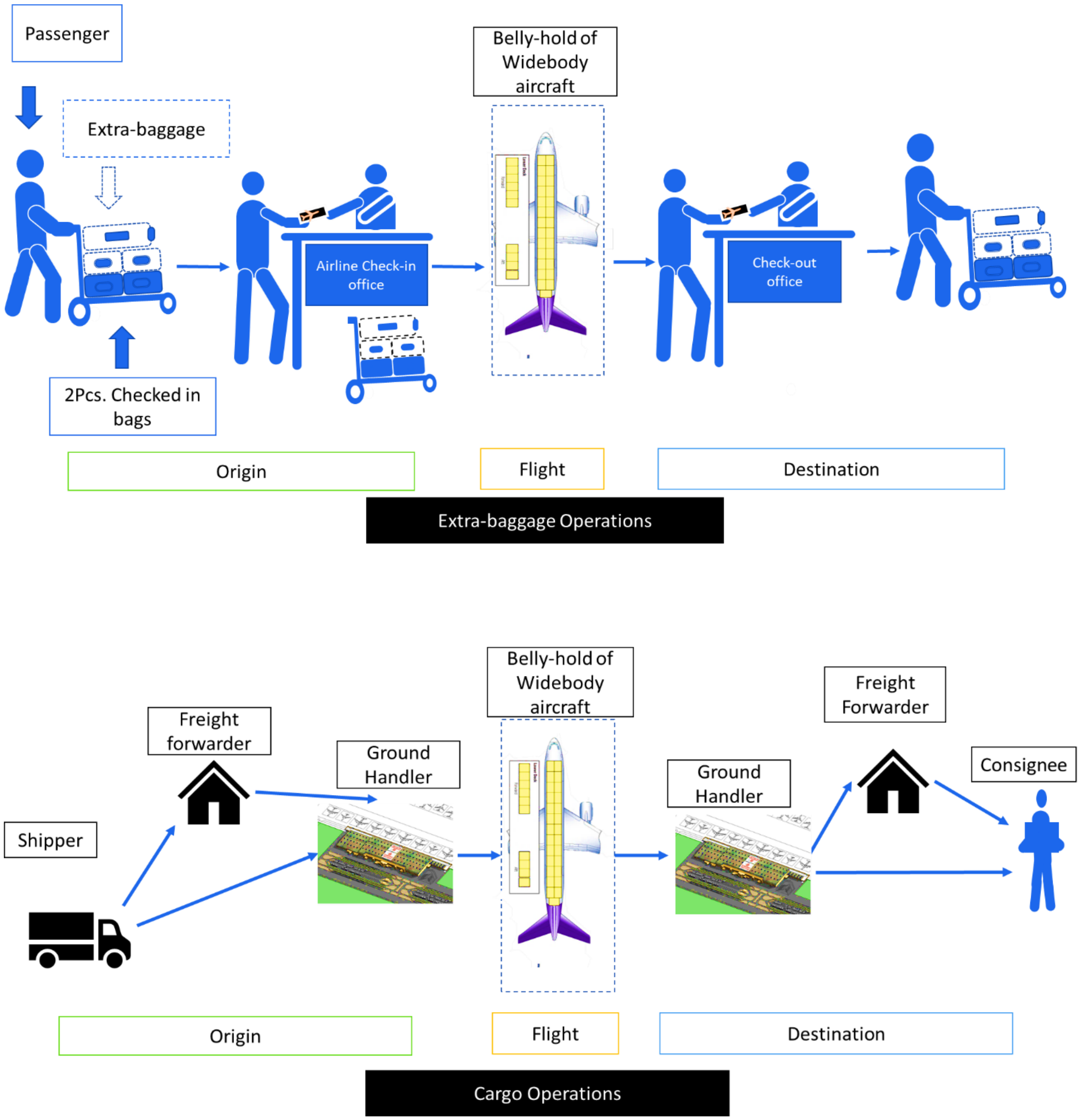


Figure 4-2 The basic operations of extra-baggage and the cargo services

The extra-baggage and the allowed baggage for the passenger are loaded together into the wide-bodied aircraft belly-hold. Then the passenger picks all of his/her baggage (allowed, and extra-baggage) when arriving at the destination.

On the other hand, the cargo operations are more complicated than the extra-baggage, where the cargo operations start from the shippers who either buy a space directly from the airline, usually for large shippers, or the shippers send their goods to a freight forwarder that reserves space in the aircraft. The freight forwarder works as a mediator between the shippers and the airline. The freight forwarder consolidates the freight from different shippers and sends it to the combination airline (The combination airline carries both passengers and cargo). The freight forwarder at the destination receives the freight from the airline and sends it to the consignee. Also, the consignee may be the person who receives the freight directly from the airline.

The shipper can be a passenger, where the passenger who has many belongings sends them to a freight forwarder, the freight forwarder in turns takes the freight to the destination. Therefore, the extra-baggage switches to cargo and becomes the whole cargo operations. The cargo rate is based on freight weight and volume, and it is measured in FTK (freight ton kilometres). Thus, the extra-baggage can be considered as a special cargo, the passenger brings the belongings to his flight, and the airline offers a rate without any negotiation, the same as for air tickets.

4.4 The Extra-baggage Optimal Price

In the above section, the extra-baggage scheme was introduced, and the relationship between the extra-baggage and the cargo was also discussed. In this section, the theoretical formulation of the extra-baggage price is developed. The formulation is undertaken in two steps; in the first step, because the extra-baggage is a new scheme, its demand unpredictable, so the extra-baggage demand is formulated in a stochastic form, while the cargo service demand is formulated in a deterministic environment. Formulating the cargo under deterministic demand assumes that air cargo is a stable industry relative to the new extra-baggage, thus it can be predicted. In the second step, the model is then enhanced by formulating both extra-baggage and the cargo under stochastic demand.

4.4.1 Stochastic extra-baggage-deterministic cargo SEDC model

Consider a combination airline offers cargo service j at a price p_j, and it plans to add a new extra-baggage service i to its services list. The airline plans to set the price p_i for the new extra-baggage service with reference to the cargo price p_j. Also, it aims to determine the space to offer in the new service x_i, in order to maximize the overall expected profit. Both services have price-dependent demand functions. We assume that the demand environment of the cargo j is deterministic, the extra-baggage i demand is random, and noise does not depend on its price. In the literature, the randomness of the price demand function is modelled in two forms, typically additive and multiplicative. Mills (1959) defined the additive form as $D(p,\varepsilon) = y(p) + \varepsilon$, and Karlin and Carr (1962) defined the multiplicative form as $D(p,\varepsilon) = y(p)\varepsilon$, where $y(p)$ is the function which depicts the decreasing relationship between the demand and the price, and ε is the random variable which may be defined in the range $[A, B]$. In economics literature, $y(p)$ is represented in linear form $y(p_i) = a - bp$, when the demand function is additive, and in iso-elastic form $y(p_i) = ap_i{}^{-b}$ when the demand function is multiplicative (Kocabıyıkoğlu & Popescu, 2011). To interpret the relationship between $D(p,\varepsilon)$ and $y(p)$, the second term is the deterministic demand curve, and this term changes in stochastic demand in the first term, by adding or multiplying the scaling factor ε which represents the random market size.

In this model, it is supposed that the cargo market is more stable so as to make it predictable, thus its demand may be represented in deterministic form $y(p_j)$, while the extra-baggage market size is still difficult to predict, so it is better to be represented in the stochastic form $D(p_i, \varepsilon_i)$. As abovementioned, both additive and multiplicative approaches are used in the literature. However, the extra-baggage is proposed as a solution for the overcapacity problem, which is unstable on different routes, while the demand in some routes exceeds its capacity, especially in seasonal periods. Therefore, the extra-baggage demand is preferably formulated in iso-elastic form, and hence, the multiplicative model is adopted to formulate the extra-baggage service, in the multiplicative demand case, $D(p_i, \varepsilon_i) = y(p_i)\varepsilon_i$, where $y(p_i)$ can be replaced by $y(p_i) = a{p_i}^{-b}$. In the single period problem, the airline offers quantity x_j of the cargo service j at unit operational cost c_j, and x_i of the extra-baggage i at unit operational cost c_i. The operational cost of both cargo and extra-baggage can be written as in equation (4-1):

$$C = c_i x_i + c_j x_j \tag{4-1}$$

If the offered quantity of the cargo during the period exceeds the forecasted demand, then the quantity difference stands for the leftover $x_j - y(p_j)$ at unit overbooking cost h_j; similarly, the leftover in the extra-baggage i is $x_i - D(p_i, \varepsilon_i)$ at unit overbooking cost h_i; where $h_i \geq c_i$, and $h_j \geq c_j$. On the other hand, if the forecasted demand exceeds the offered quantities x_i, x_j then the airline will incur unit shortage "opportunity" costs, s_i, s_j respectively. The total flight revenue is $p_i D(p_i, \varepsilon_i) + p_j y(p_j)$. The profit function can be expressed in terms of quantity and price, as in equation (4-2);

$$\Pi(x_i, x_j, p_i, p_j)$$
$$= \begin{cases} p_i D(p_i, \varepsilon_i) + p_j y(p_j) - c_i x_j - c_j x_j - h_i\big(x_i - D(p_i, \varepsilon_i)\big) \\ \qquad - h_j\big(x_j - y(p_j)\big); & D(p_i, \varepsilon_i) + y(p_j) \leq x_i + x_j \\ p_i x_i + p_j x_j - c_i x_i - c_j x_j - s_i\big(D(p_i, \varepsilon_i) - x_i\big) \\ \qquad - s_j\big(y(p_j) - x_j\big); & D(p_i, \varepsilon_i) + y(p_j) > x_i + x_j \end{cases} \tag{4-2}$$

Also, assuming that the total demand of the extra-baggage i and cargo j equals the aircraft belly-hold capacity $\emptyset$, as in equation (4-3),

$$D(p_i, \varepsilon_i) + y\left(p_j\right) = \emptyset \tag{4-3}$$

The proper form of the demand of extra-baggage i in this profit equation is $D(p_i, \varepsilon_i) = y(p_i)\varepsilon_i$, and $y\left(p_j\right) = \emptyset - y(p_i)\varepsilon_i$, identifying the q value for each service by $q_i = x_i/y(p_i)$, and $q_j = x_j/(\emptyset - y(p_i)\varepsilon_i)$.

$$\Pi\left(q_i, q_j, p_i, p_j\right)$$
$$= \begin{cases} p_i y(p_i)\varepsilon_i + p_j(\emptyset - y(p_i)\varepsilon_i) - c_i q_i y(p_i) - c_j q_j(\emptyset - y(p_i)\varepsilon_i) \\ -h_i y(p_i)(q_i - \varepsilon_i) - h_j(q_i - 1)(\emptyset - y(p_i)\varepsilon_i); & \varepsilon_i \leq q_i \\ p_i y(p_i) q_i + p_j q_j(\emptyset - y(p_i)\varepsilon_i) - c_i q_i y(p_i) - c_j(\emptyset - y(p_i)\varepsilon_i) - \\ s_i y(p_i)(\varepsilon_i - q_i) - s_j(\emptyset - y(p_i)\varepsilon_i)(1 - q_i); & \varepsilon_i > q_i \end{cases} \tag{4-4}$$

These variable transformations solve the problem of the relationship between the sum of the demand and the total quantity because interpretation of the new transformation is only related to the random variable of extra-baggage ε_i , and thus, the value q_i. The study aims to set the price and the offered quantity of the extra-baggage with reference to the existing cargo service when they have some common features. In this case, the shortage in product i occurs when ε_i exceeds the q_i value, and the airline experiences leftover if ε_i is less than the q_i value. Regarding the leftover and shortage in cargo j, they can be determined based on the likelihood of the shortage and the leftover of the extra-baggage i. Therefore, the corresponding optimal capacity offering and pricing policy is to offer $x_i^* = y(p_i^*)q_i^*$ units in the aircraft belly-hold for the extra-baggage and sell it at unit price p_i^* which is function of air cargo j price p_j, where q_i^* and p_i^*, maximize the expected profit.

$$E[\Pi(q_i, p_i, q_j, p_j)]$$

$$= (p_i - c_i - p_j + c_j q_j) y(p_j) \mu_i + (p_j - c_j q_j) \emptyset$$

$$- (c_i + h_i) y(p_i) \int_A^{q_i} (q_i - \varepsilon_i) f(\varepsilon_i) d\varepsilon_i - h_c \emptyset (q_j$$

$$- 1) \int_A^{q_i} f(\varepsilon_i) \, d\varepsilon_i + h_j (q_j - 1) y(p_i) \int_A^{q_i} \varepsilon_i \, f(\varepsilon_i) d\varepsilon_i \tag{4-5}$$

$$- (p_i + s_i - c_i) y(p_i) \int_{q_i}^{B} (\varepsilon_i - q_i) \, f(\varepsilon_i) d\varepsilon_i$$

$$- (p_j + s_j)(1 - q_j) \int_{q_i}^{B} f(\varepsilon_i) \, d\varepsilon_i$$

$$+ (p_j - s_j)(1 - q_j) y(p_i) \int_{q_i}^{B} \varepsilon_i \, f(\varepsilon_i) d\varepsilon_i$$

Defining $\Lambda(q_i) = \int_A^{q_I} (q_i - \varepsilon_i) f(\varepsilon_i) d\varepsilon_i$; and $\Theta(q_i) = \int_{q_i}^{B} (\varepsilon_i - q_i) \, f(\varepsilon_i) d\varepsilon_i$; $\varpi(q_j) =$ $\int_A^{q_i} \varepsilon_i \, f(\varepsilon_i) d\varepsilon_i$, and $\xi(q_j) = \int_{q_i}^{B} \varepsilon_i \, f(\varepsilon_i) d\varepsilon_i$, equation (4-5) can be written as equation (4-6)

$$E[\Pi(q_i, p_i)] = \psi(p_i, p_j) - L(q_i, q_j, p_i, p_j) \tag{4-6}$$

where,

$$\psi(p_i, p_j) = (p_i - c_i - p_j + c_j q_j) y(p_i) \mu_i + (p_j - c_j q_j) \emptyset \tag{4-7}$$

And

$$L(q_i, q_j, p_i, p_j)$$

$$= (c_i + h_i)y(p_i)\,\Lambda(q_i) + h_j\emptyset(q_j - 1)\int_A^{q_i} f(\varepsilon_i)\,d\varepsilon_i$$

$$- h_j(q_j - 1)y(p_i)\,\varpi(q_j) + (p_i + s_i - c_i)y(p_i)\Theta(q_i) \qquad (4\text{-}8)$$

$$+ (p_j + s_j)(1 - q_j)\int_{q_I}^{B} f(\varepsilon_i)\,d\varepsilon_i$$

$$- (p_j - s_j)(1 - q_j)y(p_i)\xi(q_j)$$

Mills (1959) defined the interpretation of the riskless profit function, in equation (4-7), as a deterministic profit value when replacing the uncertainty value of the product value ε_i by the mean value μ_i. In this model, the profit function holds extra-baggage and cargo and thus, the profit is a function of the two items prices. Lemma 4-1 can be derived from equation (4-7).

Lemma 4-1 *For extra-baggage service with stochastic demand and cargo service with deterministic demand, the riskless profit of a flight which carries both extra-baggage and cargo can be estimated by*

$$\psi(p_i, p_j) = (p_i - c_i)y(p_i)\mu_i + (p_j - c_j)y(p_j)$$

Proof Equation (4-7) is derived from the transformed objective function (4-5), and the equation can be divided into two terms; the first is related to the extra-baggage service i and the second to the cargo service j.

$\psi(p_i, p_j) = \{(p_i - c_i)y(p_i)\mu_i\} + \{(c_j q_j - p_j)y(p_i)\mu_i + (p_j - c_j)\emptyset\}$, and as previously mentioned, when changing the stochastic demand to deterministic form the ε is replaced by μ and therefore, we can move to the rule, $y(p_i)\mu_i = (\emptyset - y(p_j))$. ■

Lemma 4-1 proves that the model keeps the basic meaning of the profit function which is defined by the difference between the total revenue and the total costs. This also ensures model robustness and simplicity.

Equation (4-8) is the loss function according to the definition of (Silver Edward & Peterson, 1985), which evaluates the leftover cost $(c_i + h_i)$ for each of $\Lambda(q_i)y(p_i)$ of extra-baggage i, the expected leftover when too large value of q_i is selected; in addition to $h_j\emptyset$ for each likelihood of the leftover in extra-baggage minus the mean value of h_j in the range $[A, q_i]$; if the value of q_j is chosen more than one, and the shortage costs for product i is $(p_i + s_i - c_i)$ for each $\Theta(q_i)y(p_i)$ expected shortages when too small value q_i is selected. The shortage costs of the cargo service are $\left(p_j + s_j\right)$ for the likelihood extra-baggage quantity minus $\left(p_j - s_j\right)$for expected extra-baggage quantity; if the value of q_j is chosen less than one. The expected profit is depicted in (4-6), and the riskless profit occurs in certain selected demands with no uncertainty, and the uncertainty factor in the model is added to the expected penalties.

The objective of the model is to maximize the expected profit in (4-7):

$$\underset{q_i, p_i}{\text{Maximize}}\ E[(\Pi(q_i, p_i)]. \tag{4-9}$$

The first and the second partial derivatives of $E[(\Pi(q_i, p_i)]$ are taken with respect to q_i and p_i

$$\frac{\partial E[(\Pi(q_i, p_i)]}{\partial q_i} = -(c_i + h_i)y(p_i)F(q_i) + (p_i + s_i - c_i)y(p_i)[1 - F(q_i)] \tag{4-10}$$

$$\frac{\partial^2 E[(\Pi(q_i, p_i)]}{\partial {q_i}^2} = -[(c_i + h_i) + (p_i + s_i - c_i)]y(p_i)f(q_i) \tag{4-11}$$

Equations (4-10) and (4-11) prove that the expected profit function is concave in product i quantity when equation (4-10) is equal to zero. Similarly, the overall expected profit is concave in both extra-baggage i and cargo j, equation (4-12)

$$\frac{\partial E[\Pi(q_i, p_i)]}{\partial p_i{}^*} = 0 \tag{4-12}$$

Lemma 4-2 follows equation (4-12):

Lemma 4-2 *For fixed extra-baggage and cargo quantities, the optimal price of extra-baggage i is determined uniquely as a function of the cargo service j and the mixed quantities of the two services:*

$$p_i{}^* = \frac{\mu_i p_i{}^o}{\mu_i - \Theta(q_i)} + \frac{b[(c_i + h_i)\Lambda(q_i) - h_j(q_j - 1)\varpi(q_i) + (s_i - c_i)\Theta(q_i) - (p_j - s_j)(1 - q_j)\xi(q_i)]}{(b-1)(\mu_i - \Theta(q_i))}$$

where $p_i{}^o = \frac{b(c_i + p_j - c_j q_j)}{b-1}$

Proof For the multiplicative demand of extra-baggage, $p_i{}^o$ is the optimal riskless price, which maximizes the riskless profit $\psi(p_i, p_j) = (p_i - c_i - p_j + c_j q_j)y(p_i)\mu_i + (p_j - c_j q_j)\emptyset$, where $y(p_i) = a p_i{}^{-b}$, by definition. The maximum value of the riskless profit function can be obtained when equating the first derivative w.r.t p_i to zero, Thus, letting:

$$\frac{\partial\psi(p_i, p_j)}{\partial p_i} = (p_i - c_i - p_j + c_j q_j)y'(p_i)\mu_i + y(p_i)\mu_i;$$

$$a\mu_i p_i{}^{-b-1}[b(c_i + p_j - c_j q_j) - (b-1)p_i{}^o] = 0$$

Therefore, the maximum value of $\psi(p_i, p_j)$ is at $p_i{}^o = \frac{b(c_i + p_j - c_j q_j)}{b-1}$, Next, regarding the overall expected profit function in equation (4-6), determine the optimal price of extra-baggage as a function of the air cargo, and maximize the expected profit. It is needed to equate the first differentiation of the (4-6) w.r.t p_i to zero;

$$\frac{\partial E[(\Pi(q_i, p_i)]}{\partial p_i{}^*}$$

$$= \left(p_i - c_i - p_j + c_j q_j\right) y'(p_i)\mu_i + y(p_i)\mu_i - (c_i + h_i) y'(p_i)\Lambda(q_i)$$

$$+ h_j\left(q_j - 1\right) y'(p_i)\varpi(q_i) - (p_i + s_i - c_i) y'(p_i)\Theta(q_i) - y(p_i)\Theta(q_i)$$

$$+ \left(p_j + s_j\right)\left(1 - q_j\right) y'^{(p_i)}\xi(q_i)$$

hence;

$$-abp_i{}^{-b-1}\left(p_i{}^* - c_i - p_j + c_j q_j\right)\mu_i + ap_i{}^{-b}\mu_i + abp_i{}^{-b-1}(c_i + h_i)\Lambda(q_i)$$

$$- abp_i{}^{-b-1} h_j\left(q_j - 1\right)\varpi(q_i) + abp_i{}^{-b-1}(p_i{}^* + s_i - c_i)\Theta(q_i) - ap_i{}^{-b-1}\Theta(q_i)$$

$$- p_i{}^*\Theta(q_i) - ab\, p_i{}^{-b-1}\left(p_j + s_j\right)\left(1 - q_j\right)\xi(q_i) = 0$$

Thus,

$$p_i{}^*$$

$$= \frac{\mu_i p_i{}^o}{\mu_i - \Theta(q_i)}$$

$$+ \frac{b\left[(c_i + h_i)\Lambda(q_i) - h_j\left(q_j - 1\right)\varpi(q_i) + (s_i - c_i)\Theta(q_i) - \left(p_j - s_j\right)\left(1 - q_j\right)\xi(q_i)\right]}{(b - 1)(\mu_i - \Theta(q_i))}. \quad \blacksquare$$

The riskless price $p_i{}^o$ is concave in the cargo price, where the extra-baggage riskless price increases with the increase of cargo price until it reaches a turn down point then the extra-baggage riskless price decreases. The airline can forecast short-term market demand, and is most likely a combination of the Gamma and normal distributions as mentioned by Swan (2002). Thus, the random variable is normally distributed in the application of numerical analysis with $\mu_i = 0.6, and\ \ \sigma_i = 0.2$. See *Figure 4-3*.

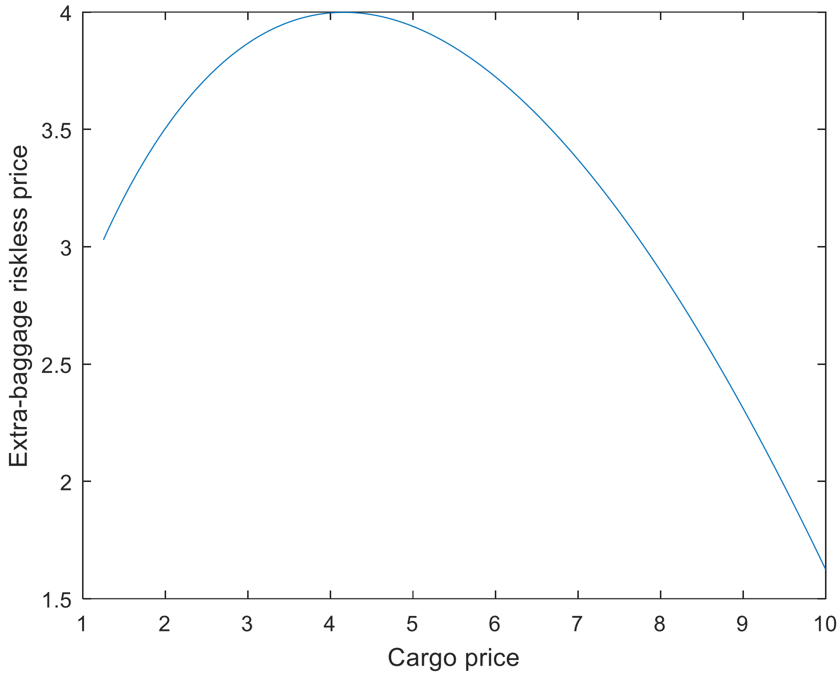


Figure 4-3 A plot of extra- baggage riskless price $p_i{}^0$ as a function of cargo price p_j ranging from 0.5 to 10 in increment 0.025, the cargo quantity is assumed as 16000, a_1=20000, b_1=1.5, and b_2=1.25

The extra-baggage price elasticity b sets the maxima of the extra-baggage riskless price, as shown in *Figure 4-4*, where the riskless price of the extra-baggage decreases exponentially with the increase of the extra-baggage price elasticity.

Lemma 4-2 captures the optimal price of the extra-baggage i as a function of the cargo price and mixed quatities of both services. The price equation containes three terms; each term expresses an important concern in order to set the price for extra-baggage with reference to the cargo price. The next theorem summarizes these three terms.

Theorem 4-1 *For given extra-baggage and cargo quantities, setting the optimal price for the extra-baggage with reference of cargo price j requires the airline to define three terms;*

i. *The safety factor* $\frac{\mu_i}{\mu_i - \Theta(q_i)}$

ii. *The riskless price* p_i^o

iii. *The premium value* $\frac{b[(c_i+h_i)\Lambda(q_i)-h_j(q_j-1)\varpi(q_i)+(s_i-c_i)\Theta(q_i)-(p_j-s_j)(1-q_j)\xi(q_i)]}{(b-1)(\mu_i-\Theta(q_i))}$

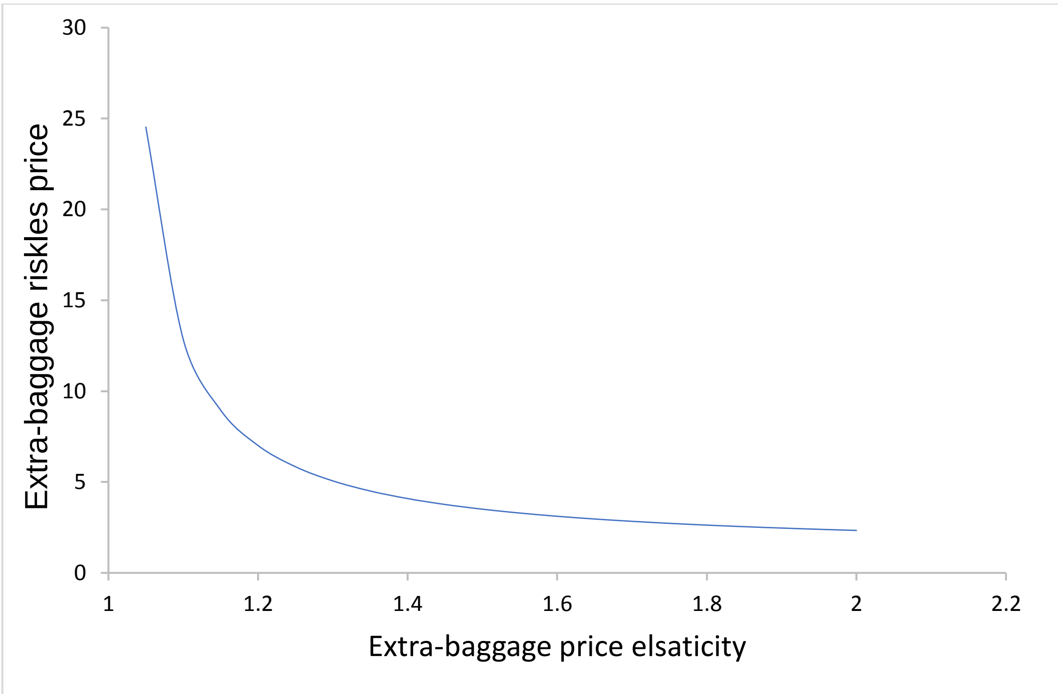


Figure 4-4 A plot of extra-baggage riskless price as a function of price elasticities, (a) Cargo price elasticity and, (b) Extra-baggage price elasticity.

The theorem explains the main theme of the pricing scheme which can be followed to set the price of the extra-baggage with the aid of the cargo price. This model is inspired from Petruzzi and Dada (1999), who's model considers the use of single period newsvendor model to set the price of a single product. The authors defined the optimal price of the product as the sum of the base price and the premium amount in the multiplicative demand function, whereas our model uses product price information to set a different product price. **Theorem 4-1** and **lemma 4-2** define the base as price equalling the riskless price of the extra-baggage multiplied by a safety factor and the premium value which is a function of the overall expected shortage and the overall expected leftover amount, and the expected sales of the extra-baggage. Hence, the extra-baggage optimal price can be expressed by equation (4-13),

$$p_i^* = p_{B_i} + \frac{b[(c_i+h_i)E[leftover\ (q_i,p_i)]+(s_i-c_i)E[shortage\ (q_i,p_i)]-[h_j[overage\ of\ q_j]+(p_j-s_j)E[shortage\ of\ q_j]]}{(b-1)E[sales(q_i,p_i)]} \quad (4\text{-}13)$$

Therefore, the interpretation of the base and premium prices may be described next; the base price is obtainable from estimating the total costs of the extra-baggage service multiplied by the safety factor "SF" which ensures that the riskless price is not underestimated by dividing the mean demand over the expected sales, where $SF \geq 1$, The base price is also concave in the cargo price, see *Figure 4-5*.

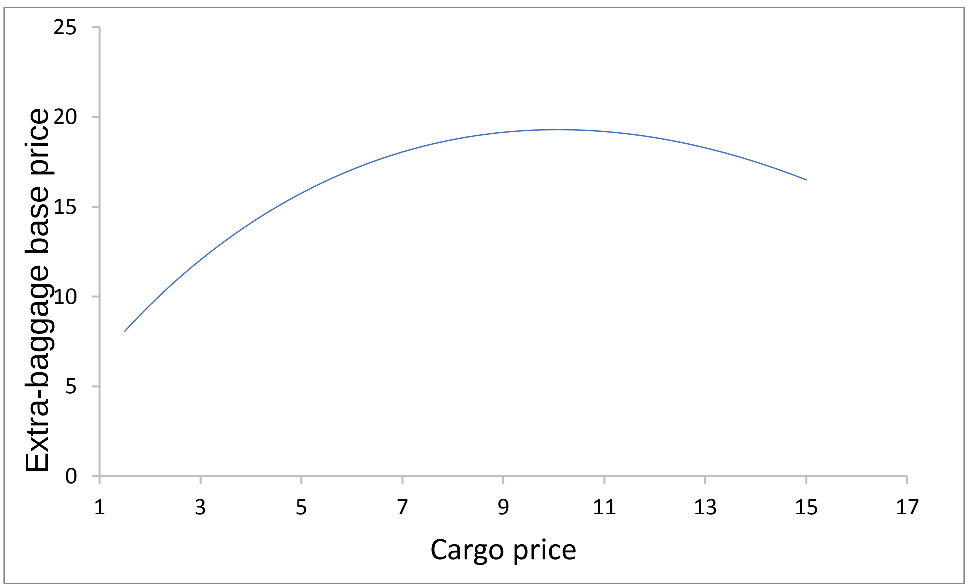


Figure 4-5 A plot of extra-baggage base price as a function of cargo prices.

The base price concavity is flatter in the actual range of cargo prices, so it is assumed that a larger range of extra-baggage at cargo prices to show the curve behaviour. The airline can manage the safety factor by studying the demand average and the expected shortage. Moreover, the premium value in selling price for the extra-baggage is based on the formula which considers the overall expected leftover of the extra-baggage, in addition to the overall expected shortage costs of the same service. The result agrees with Petruzzi's results, but this model holds a defined service, cargo service, which is the airline's main service, so the cargo service affects the price of the new extra-baggage service. This is because of the demand uncertainty in the extra-baggage, thus the sum of the expected penalties of the j cargo service is subtracted from the expected penalties of the i extra-baggage and divied on the overall expected extra-baggage sales. The cargo deterministic demand represents a big limitation in this model, where the premium value increases exponentially with respect to the increase of the cargo price, see *Figure 4-6*.

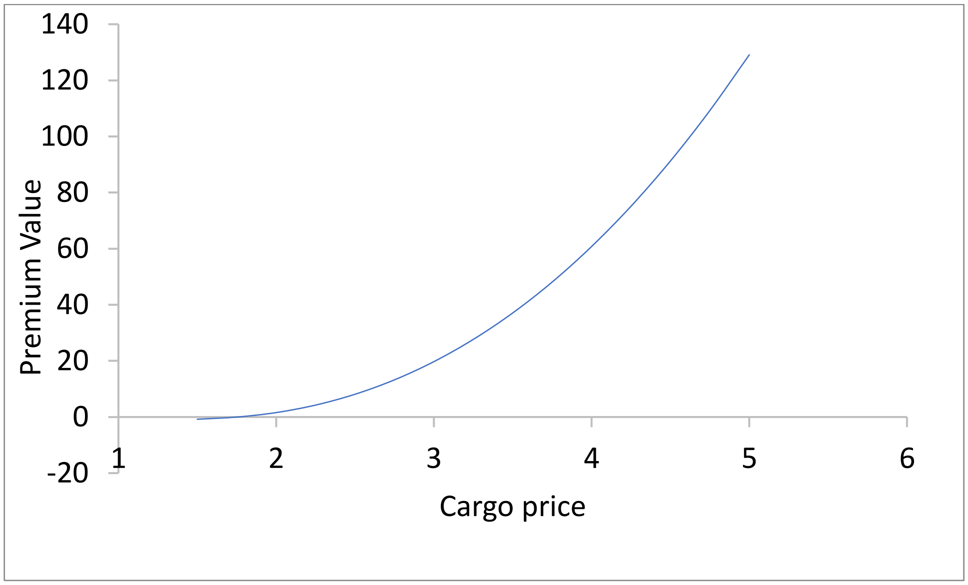


Figure 4-6 A plot of premium value as a function of cargo price in the stochastic-deterministic model where, x_1=16000, x_2=18000, b_1=1.25, $\mu = 0.6$, and $\sigma = 0.2$

This vast upsurge in premium value leads to an overestimated optimum price and converts the concave behaviour of the base price to a monotonic form at the optimum price, see *Figure 4-7*.

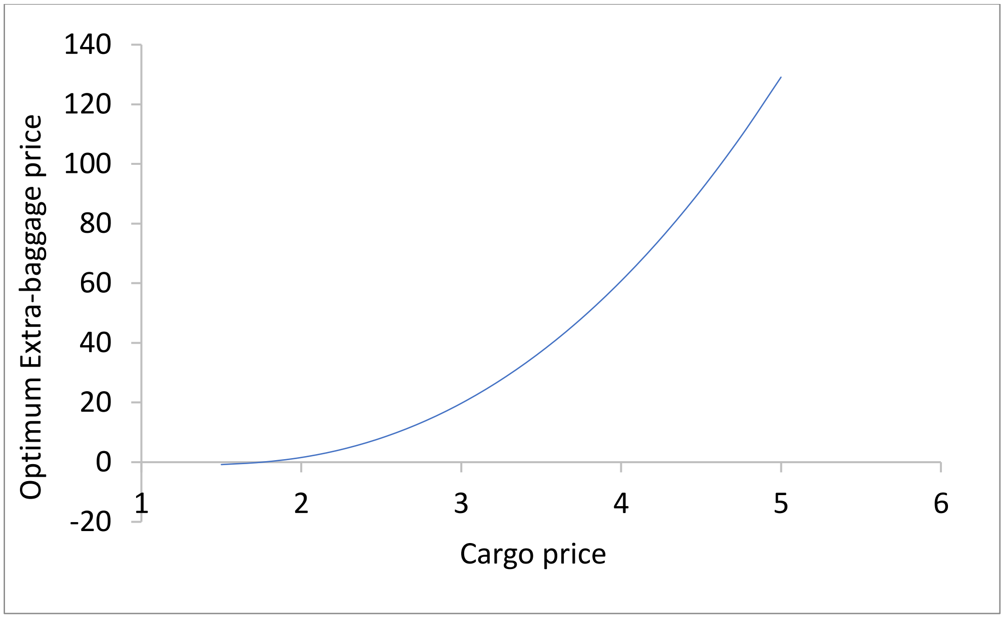


Figure 4-7 A plot of extra-baggage optimum price as a function of cargo price

4.4.2 Stochastic extra-baggage-stochastic cargo SESC model

In the previous section, an extra-baggage pricing newsvendor model was developed based on a stochastic extra-baggage demand and deterministic cargo demand. Because of the limitation of the stochastic-deterministic SEDC model, which appeared the exponential increase in the premium value, in this model, the cargo demand is also formulated in stochastic form, assuming the demand function of the cargo as,

$$D(p_j, \varepsilon_j) = y(p_j) + \varepsilon_j \tag{4-14}$$

and thus, the profit function in equation (4-4) can be changed to;

$$\Pi(q_i, q_j, p_i, p_j) = \begin{cases} p_i y(p_i)\varepsilon_i + p_j(\emptyset - y(p_i)\varepsilon_i) - c_i q_i y(p_i) - c_j \emptyset + c_j y(p_i)\varepsilon_i - c_j(q_j - \varepsilon_j) \\ -h_i y(p_i)(q_i - \varepsilon_i) - h_j(q_i - \varepsilon_j); \qquad \varepsilon_i \le q_i, \varepsilon_j \le q_j \\ p_i y(p_i) q_i + p_j \emptyset - p_j(\varepsilon_j - q_j) - p_j y(p_i)\varepsilon_i - c_i q_i y(p_i) - c_j(\varepsilon_j - q_j) - c_j \emptyset - \\ c_j y(p_i)\varepsilon_i - s_i y(p_i)(\varepsilon_i - q_i) - s_j(\varepsilon_j - q_j); \qquad \varepsilon_i > q_i, \varepsilon_j > q_j \end{cases} \tag{4-15}$$

The advantage of modelling the cargo in the formulation removes the effect of the extra-baggage noise on the cargo penalties, which also decreases the price of the extra-baggage. Thus, the corresponding optimal capacity offering and pricing policy changes, where ${x_i}^* = y({p_i}^*){q_i}^*$ but under the random cargo demand, also the optimal extra-baggage price ${p_i}^*$ is also a function of cargo price. These values ${q_i}^*, {p_i}^*$can be determined from the new expected profit;

$$
\begin{aligned}
E[(\Pi(q_i, p_i, q_j, p_j)] = {} & [p_i - c_i - p_j + c_j]y(p_i)\mu_i + (p_j - c_j)\emptyset \\
& - (c_i + h_i)y(p_i)\int_{A_1}^{q_i}[q_i - \varepsilon_i]\, f(\varepsilon_i)\varepsilon_i \\
& - (c_j + h_j)\int_{A_2}^{q_j}[q_j - \varepsilon_j]\, f(\varepsilon_j)d\varepsilon_j \\
& - [p_i + s_i - c_i]\, y(p_i)\int_{q_i}^{B_1}[\varepsilon_i - q_i]\, f(\varepsilon_i)d\varepsilon_i \\
& - [p_j + s_j - c_j]\int_{q_j}^{B_2}[\varepsilon_j - q_j]\, f(\varepsilon_j)d\varepsilon_j
\end{aligned}
\tag{4-16}
$$

Equation (4-16) can be written in terms of riskless profit and loss in a different form than equation (4-6) as;

$$E[(\Pi(q_i, p_i, q_j, p_j)] = \psi(p_i, p_j) + L(q_i, p_i) + L(q_j, p_j) \tag{4-17}$$

where the riskless profit is

$$\psi(p_i, p_j) = [p_i - c_i - p_j + c_j]y(p_i)\mu_i + (p_j - c_j)\emptyset \tag{4-18}$$

Lemma 4-3 *For two stochastic demand items, if the extra-baggage is the first item and its demand is formulated in multiplicative form, and the cargo is the second item which is modelled* *in additive demand form, then the riskless profit can be estimated by the sum of mean profit of the extra-baggage service and the mean profit of the cargo service,*

$$\psi(p_i, p_j) = [p_i - c_i]y(p_i)\mu_i + (p_j - c_j)[y(p_j) + \mu_j]$$

Proof The proof of this lemma can be derived as far as **lemma 4-1**.

Regarding the loss function, and unlike equation (4-6), which describe the losses of both extra-baggage and cargo in a form depending on the extra-baggage status, the loss function in (4-17) is the sum of the expected losses of extra-baggage and cargo losses where the extra-baggage losses can be expressed as;

$$L(q_i, p_i) = [(c_i + h_i)\Lambda(q_i) + [p_i + s_i - c_i]\Theta(q_i)]y(p_i)$$

and the loss function with respect to the cargo is;

$$L(q_j, p_j) = (c_j + h_j)\Lambda(q_j) + [p_j + s_j - c_j]\,\Theta(q_j)$$

As shown in the loss functions of both the extra-baggage and cargo, the formulas are not interrelated with each other, which means that penalties have a different interpretation than in the old model. The shortage and the leftover of the extra-baggage does not change, but the cargo penalty cost is the shortage $[p_j + s_j - c_j]$ when too small a value of q_j is chosen over the $\Theta(q_j)$ range, and the penalty is the overbooking cost $(c_j + h_j)$ when the airline selects a too large q_j over the $\Lambda(q_j)$ range.

The objective also can be represented by equation (4-7), and the optimum quantity of extra-baggage can also be obtained through equation (4-10) by equating the equation to zero, and similarly for the optimal extra-baggage price in equation (4-12). Lemma 4-4 can be inferred from equation (4-12) and (4-16);

Lemma 4-4 *For a fixed extra-baggage quantity and cargo quantity, the optimal price of the extra-baggage is uniquely determined as a function of the cargo price and the mixed extra-baggage and cargo quantities:*

$$p_i^* = \frac{\mu_i p_i^o}{\mu_i - \Theta(q_i)} + \frac{b}{(b-1)} \frac{[(c_i + h_i)\Lambda(q_i) + (s_i - c_i)\Theta(q_i)]}{\mu_i - \Theta(q_i)}$$

Proof For the multiplicative demand of the extra-baggage, and additive demand of the cargo, p_i^o is the optimal riskless price, which maximizes the riskless profit $\psi(p_i, p_j) = (p_i - c_i - p_j + c_j)y(p_i)\mu_i + (p_j - c_j)\emptyset$, where $y(p_i) = ap_i^{-b}$, by definition, and the maximum value of the riskless profit function can be obtained when equating the first derivative w.r.t p_i to zero, Thus:

$\frac{\partial\psi(p_i,p_j)}{\partial p_i} = (p_i - c_i - p_j + c_j)y'(p_i)\mu_i + y(p_i)\mu_i;$

$$a\mu_i(b-1)p_i^{-b-1}\left[\frac{b}{(b-1)}(c_i + p_j - c_j) - p_i^o\right] = 0$$

Therefore, the maximum value of $\psi(p_i, p_j)$ is at $p_i^o = \frac{b}{b-1}(c_i + p_j - c_j)$,

Next, regarding the overall expected profit function in equation (4-6), determine the optimal price of extra-baggage as a function of the air cargo, and maximize the expected profit. By equating the first differentiate of the (4-6) w.r.t p_i to zero:

$$\frac{\partial E[(\Pi(q_i, p_i)]}{\partial p_i^*}$$

$$= (p_i - c_i - p_j + c_j q_j)y'(p_i)\mu_i + y(p_i)\mu_i - (c_i + h_i)y'(p_i)\Lambda(q_i)$$

$$+ h_j(q_j - 1)y'(p_i)\varpi(q_i) - (p_i + s_i - c_i)y'(p_i)\Theta(q_i) - y(p_i)\Theta(q_i)$$

$$+ (p_j + s_j)(1 - q_j)y'(p_i)\xi(q_i)$$

hence;

$$a(b-1){p_i}^{-b-1}[\mu_i - \Theta(q_i)]\left[\frac{\mu_i}{\mu_i - \Theta(q_i)}{p_i}^o + \frac{b}{(b-1)}\frac{[(c_i + h_i)\Lambda(q_i) + (s_i - c_i)\Theta(q_i)]}{\mu_i - \Theta(q_i)} - {p_i}^*\right]$$
$$= 0$$

Thus,

$${p_i}^* = \frac{\mu_i {p_i}^o}{\mu_i - \Theta(q_i)} + \frac{b}{(b-1)}\frac{[(c_i+h_i)\Lambda(q_i)+(s_i-c_i)\Theta(q_i)]}{(\mu_i - \Theta(q_i))} \quad \blacksquare$$

Lemma 4-4 depicts the optimal price of the extra-baggage as a function of the cargo price and mixed quantities of both services. The extra-baggage riskless price in this model is a linear function of cargo price. The riskless price equals the extra-baggage operational costs plus the cargo profit, and this price can set the demand elasticity factor $b/(b-1)$. *Figure 4-8*, and *Figure 4-9* show the effect of price elasticity on the riskless price, where the extra-baggage riskless price decreases exponentially with the increase in the demand elasticity. The price equation contains three terms; each term expresses an important concern in order to set the price for the extra-baggage with reference to the cargo price. The next theorem summarizes these three terms.

Theorem 4-2 *For given extra-baggage and cargo quantities q_i and q_j, respectively, setting the optimal price for the extra-baggage with reference of product j requires the airline to define three terms;*

i. *The safety factor SF* = $\frac{\mu_i}{\mu_i - \Theta(q_i)}$

ii. *The riskless price* ${p_i}^o$

iii. *The premium value* = $\frac{b}{(b-1)}\frac{[(c_i+h_i)\Lambda(q_i)+(s_i-c_i)\Theta(q_i)]}{(\mu_i-\Theta(q_i))}$

The theorem explains the main theme of the pricing scheme which can be followed to set the price of the extra-baggage with the aid of the cargo price. **Theorem 4-2** and **lemma 4-4** define the extra-baggage base price as equal to the riskless price multiplied by the safety factor, and the premium value is a function of the overall expected shortage and the overall expected leftover amount, and the expected sales of the extra-baggage. So, the extra-baggage optimal price can be expressed by equation (4-19),

$$p_i^* = p_{B_i} + \frac{b}{(b-1)} \frac{[(c_i+h_i)E[leftover\ (q_i,p_i)]+(s_i-c_i)E[shortage\ (q_i,p_i)]]}{E[sales(q_i,p_i)]} \quad (4\text{-}19)$$

Therefore, in this theorem, the base price is obtainable from the estimation of the total costs of the extra-baggage service multiplied by the safety factor "SF" which is related the expected sales of the extra-baggage, and the premium selling price for the extra-baggage based on the formula which takes the overall expected leftover of extra-baggage into account, in addition to the overall expected shortage costs of the same service. This is because the demand is uncertain between the two services, and thus the sum of the expected penalties of the cargo service is deducted from the expected penalties in theorem 4-2, and the results are divided into the overall expected sales of extra-baggage i .

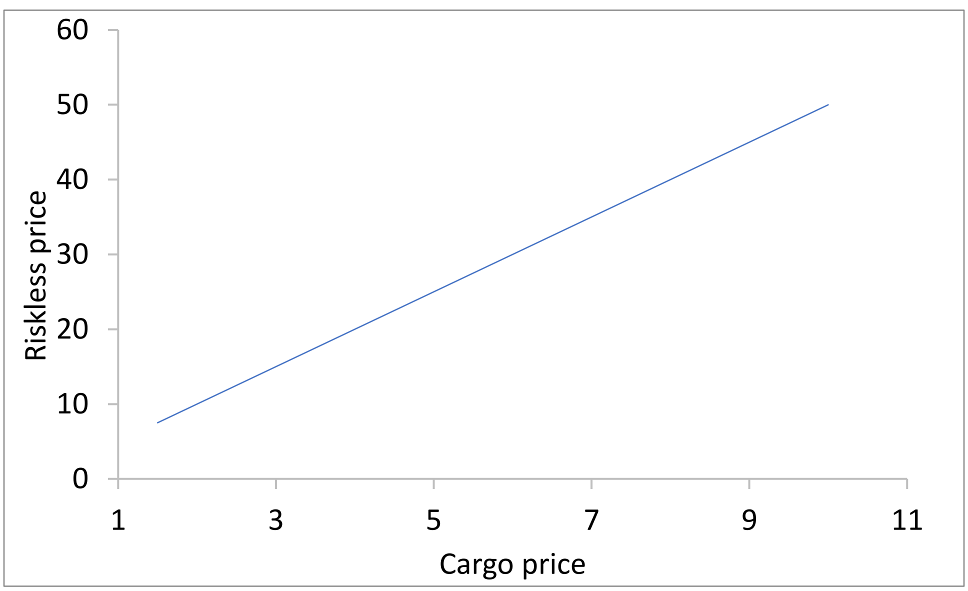


Figure 4-8 A plot of extra-baggage riskless price as a function of cargo price when the extra-baggage price elasticity b=1.25

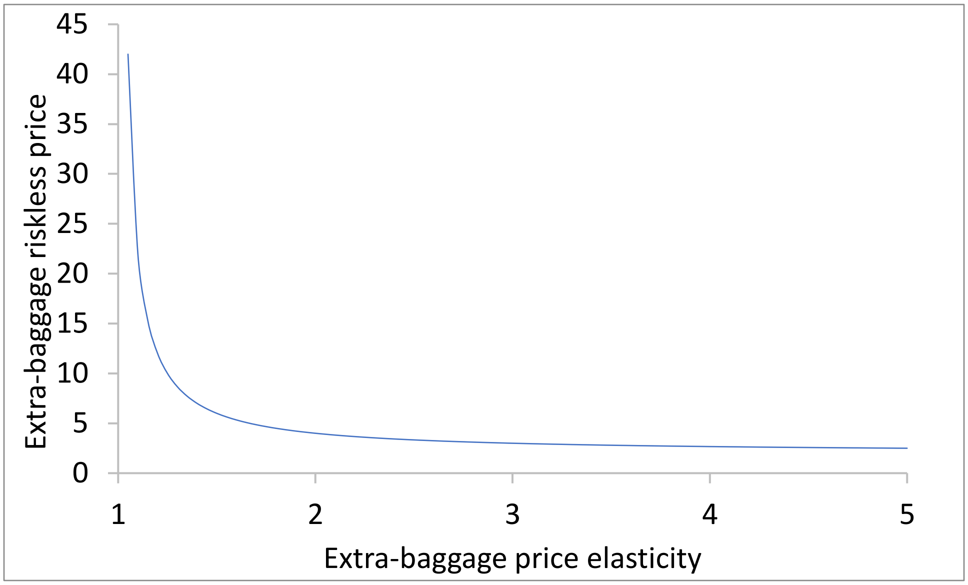


Figure 4-9 The effect of the extra-baggage price elasticity on the riskless price

Equation (4-19) shows the difference between formulating the cargo in deterministic or stochastic forms. It can be induced that the deterministic formulation of the cargo shows the way the extra-baggage uncertainty affects the cargo, see equation (4-5). However, when the cargo uncertainty is included in the model, it neutralizes the extra-baggage effect, and therefore cargo penalties cannot be involved in the extra-baggage price. Therefore, the limitation of the previous model is avoided, more over the penalty can be negative or positive, see *Figure 4-10*.

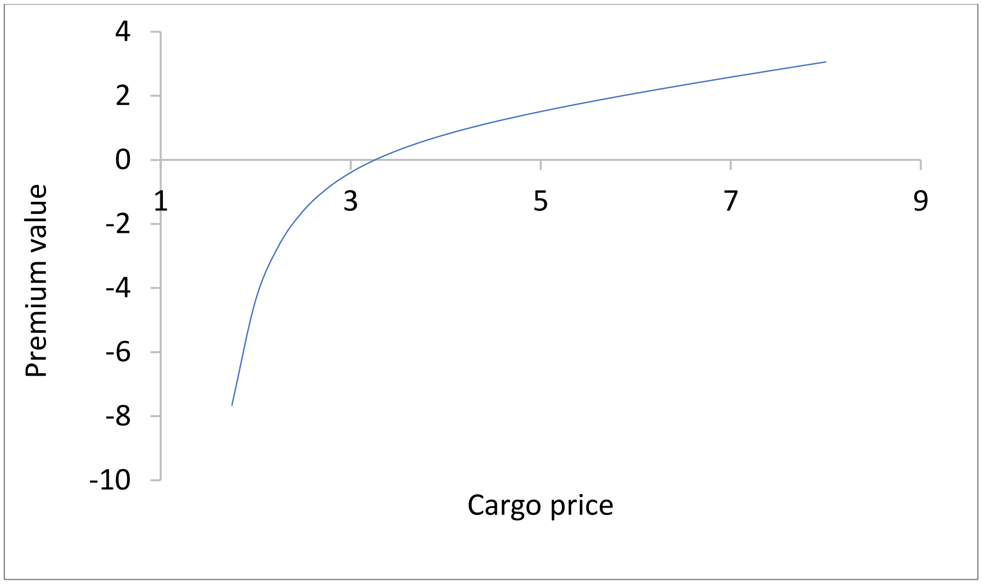


Figure 4-10 A plot of Premium value as a function of cargo price in the stochastic-stochastic model, x_1=16000, x_2=18000, b_1=1.25, μ=0.6, and σ=0.2

As shown in *Figure 4-10*, the premium value is not always positive, and this leads to the result that the optimum price of the extra-baggage is not always bigger than the base price. However, the premium value is negative when the cargo price is low, and hence the extra-baggage optimum price will be less than the base price and, in some cases, less than the cargo price. and vice versa for positive premium value. The logic contradicts this behaviour, because the smaller the cargo price means the larger the cargo demand and less space remains in the aircraft belly-hold. Thus, the airline must increase the extra-baggage price. Therefore, the optimum extra-baggage can be estimated by

$$p_i^* = p_{B_i} + [-premium\ value]$$

On the other hand, if the airline needs to penetrate the market, so they may offer less extra-baggage prices to accelerate the extra-baggage adoption they can then use the derived equation

$$p_i^* = p_{B_i} + [premium\ value]$$

4.5 Current Excess-baggage Practice

The current excess-baggage practice in the majority of airlines is to segment the flight routes into different zones. The airlines rate the excess-baggage between the different zones either by a piece of baggage and/or by unit weight of the excess-baggage. This pricing scheme can be formulated as below:

- Let Z is the set of routes in a geographical zone, indexed by i (Origin), and j (Destination) where $i \in \{1, 2, 3, \dots\}$,and $j \in \{1, 2, 3, \dots\}$, where $i \neq j$.
- P_{ij} is the price to carry a unit weight from Origin i to Destination j.
- P'_{ij} is the price to carry one piece of baggage from zone i to zone j.
- N is the number of bags (piece) for a single passenger.
- M is the number of excess-baggage weight units.
- k is the number of passengers who book excess-baggage in advance, where $k \in \{1,2,3, \dots, K\}$. where K is the total number of seats on the aircraft[4].
- l is the number of passengers who bring overweight baggage where $l \in \{1,2,3, \dots, K\}$.

The airline revenue from the excess-baggage (EBR) in flight leg (ij) can be calculated as in equation (4-20),

$$EBR = \sum_{k=1}^{K} (NP_{ij})_k + \sum_{l=1}^{K} (MP'_{ij})_l \qquad (4\text{-}20)$$

[4] Number of seats differs among the different aircraft models.

It is noted that some airlines have different pricing policies. For example, the price of the first bag is different than the next n bags. Therefore, the excess-baggage price in flight leg (ij) is; $NP_{ij} = p_1 + np$, for $n = (0,1, \dots, \varkappa)$, where $\varkappa$ is the maximum allowed number of excess bags.

Because the excess-baggage service is received with the regular checked-baggage and they need almost the same operations, the excess-baggage cost (EBC) can be calculated as a function of the cost per available seat (CAS),

$$EBC = \gamma k(CAS) \qquad (4\text{-}21)$$

where γ is the percentage of excess-baggage cost out of the (CAS). Hence, the total excess-baggage profit (EBP) is estimated by equation (4-22),

$$EBP = EBR - EBC \qquad (4\text{-}22)$$

Each airline puts its own excess-baggage constraint either in the number of pieces or in the number of weight units in each zone. Moreover, the major difference between the current excess-baggage and the extra-baggage scheme is that the profit of the current excess-baggage is added to the passenger profit, while the extra-baggage in the new scheme profit is loaded to the cargo compartment profit.

4.6 Numerical Analyses

A numerical analysis is conducted with two main objectives. First, to investigate the cargo /extra-baggage combinations on the expected profit of the proposed model. Second, to examine the profit improvement over the old excess-baggage scheme. To keep the model calculations simpler, firstly, it is assumed that the booking control is fixed, i.e. without allocation limits, for both extra-baggage and cargo. Secondly, the analysis is only concerned with a single fare class; for example, i.e.

economy class. Thirdly, the analysis also excludes the routing changes in extra-baggage and cargo densities, and weight /volume ratio.

4.6.1 Cargo and extra-baggage parameters

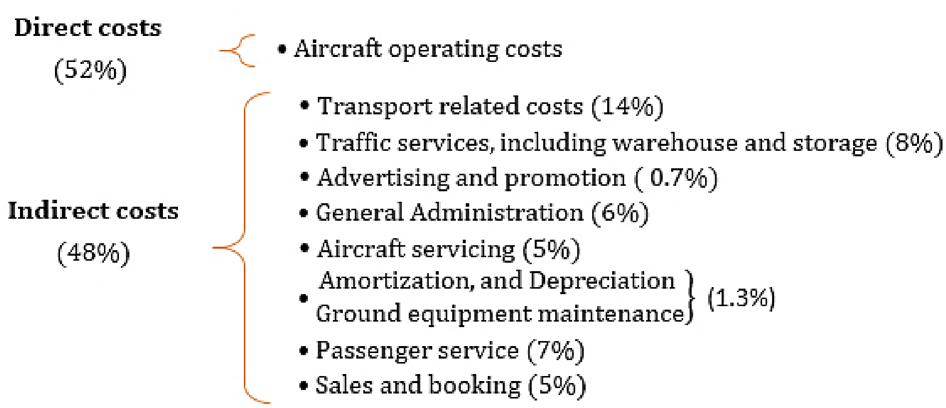
In order to make the analysis of our model non-trivial and manageable, the individual flight cost analysis of Tsai and Kuo (2004) was implemented with some tolerance to fit the proposed model. In this regard, data was collected from a northern American combination airline A. This airline uses wide-body aircraft (B787-9). Based on the specifications of this aircraft in *Table 4-1*, the extra-baggage unit costs and cargo unit costs were estimated for a selected route (X-Y).

Table 4-1 Aircraft B787-9 specifications

Characteristics	**MTOW(kg)**	**Maximum fuel capacity (US gallon)**	**Range (nm)**	**Freight Capacity(kg)**
Value	254000	33379.72	7800	17,942

From this standpoint, the travelled distance between the origin X and destination Y is approximately 6000 nm. The airline annual reports in 2014 reveal that the average direct operating cost per ATM was 0.390 USD, and the indirect unit cost was 0.388 USD per ATM. On the extra-baggage service, because it is planned to replace the current excess-baggage scheme, the extra-baggage costs can be added to the passenger costs. The extra-baggage costs are almost the same as the regular checked baggage, which costs (8 -14)% of the unit passenger cost (ICAO, 2017). The Boeing 787-9 aircraft unit cost is 7.33 US cents per ASM.

For penalty costs, Chao and Hsu (2014) and Reis and Silva (2016) divided the flight operations costs into direct and indirect costs, as shown in *Figure 4-11*. The direct costs can be variable; based on the travelled distance and fixed costs which are incurred regardless of the traveled distance. As formulated in the model, the airlines incur two contradicting penalty costs; first the shortage, which occurs when the sum of offered quantity from the extra-baggage and the cargo is less than the real market demand of these two services. The shortage costs equal to the fixed costs per unit cargo and extra-baggage, because the flight fixed cost is incurred regardless of the amount of cargo and/or extra-baggage in the cargo compartment. The flight fixed costs are approximated to 57% of the overall flight operating cost. On the other hand, the airline offloads the excess cargo and/or extra-baggage costs. The offloading cost is the sum of warehousing cost (50 US cents/kg), and delay cost penalty (92 US cents/kg).



**Source*: Based on Federal Aviation Administration (FAA) benefit-cost analysis (2016).

*Figure 4-11 Direct and indirect flight costs**

Next, collected three months cargo demand has been collected from the same airline A on route (X-Y). The freight maximum demand is 470-tonne, and the minimum demand is 28-tonne. Because it is a combination airline, it plans the demand for the freighters, such as Boeing 747-400, and Boeing 767-800. The rest of this cargo is allocated in the belly-hold space of the passenger aircraft, Boeing 787-9. In order to estimate the demand function that represents the real demand, a linear regression analysis is conducted. *Table 4-2* shows the regression results summary, which reveals that more than 85% of the data fits the developed regression model. Furthermore, the P-value is less than the significance level[5] of our experiment, which means that price as an independent variable is statistically significant. The linear regression model describes the empirical cargo demand with coefficients $a_2 = 42940$,$b_2 = 4078$.

Table 4-2 Regression analysis results summary

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1775.42	85.86%	85.79%	85.59%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	42940	945	45.43	0.000	
Prices	-4078	114	-35.79	0.000	1.00

Moreover, the demand functions normality test in the form of the normal probability plot shows that the demand-based price is homoscedastic, see *Figure 4-12*.

On the other hand, the proposed scheme is not yet implemented, and it does not make sense if the current pricing scheme for the excess-baggage is used to estimate the demand function of the extra-baggage service. In this connection, the main factors that affect the extra-baggage demand-based price function were studied.

[5] The significance level in this model is 0.01

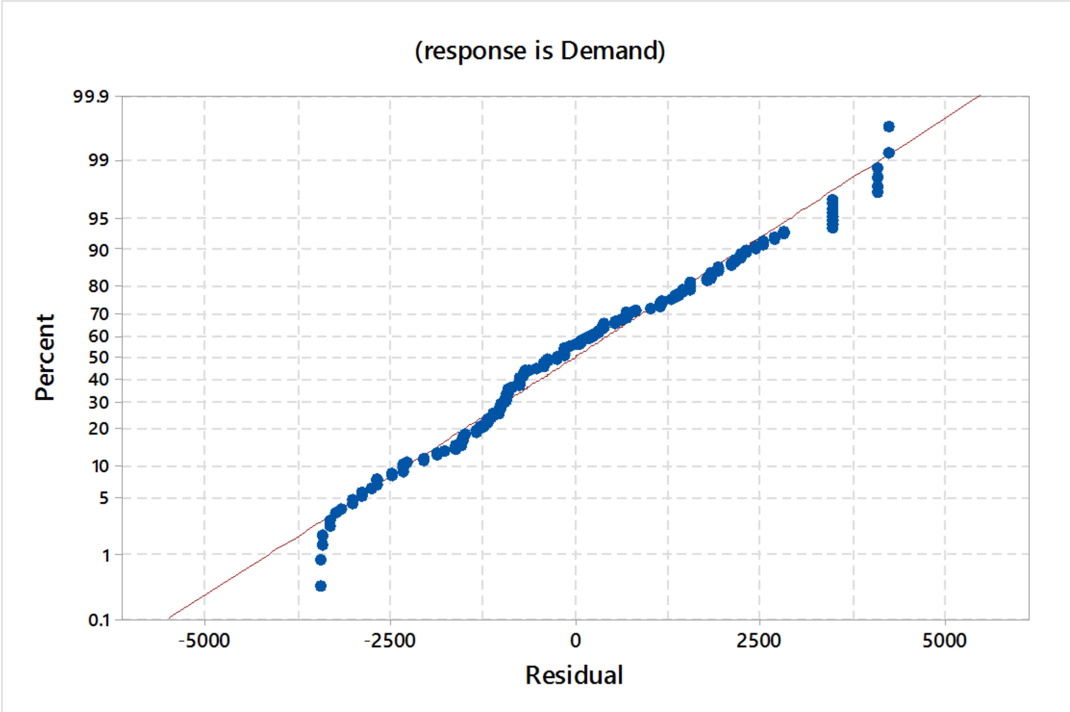


Figure 4-12 Normal probability plot of the cargo demand

As aforementioned, the extra-baggage scheme is treated as special cargo, but its customers are the same passenger.

Therefore, the extra-baggage demand is different from the cargo demand, but metaphorically the cargo demand function is used as a reference to the extra-baggage demand. This is because the cargo and extra-baggage services share the same compartment, so they complement each other. Thus, the effect of demand function coefficients on the cargo compartment profit are studied. The results are shown in *Figure 4-13*.

The cargo compartment profit decreases exponentially with increasing price coefficient b_1. On the other hand, the extra-baggage price increases dramatically when b_1 decreases. In this regard, the mid-range values were selected for b_1, and a_1 to be 2000 and 50000, respectively.

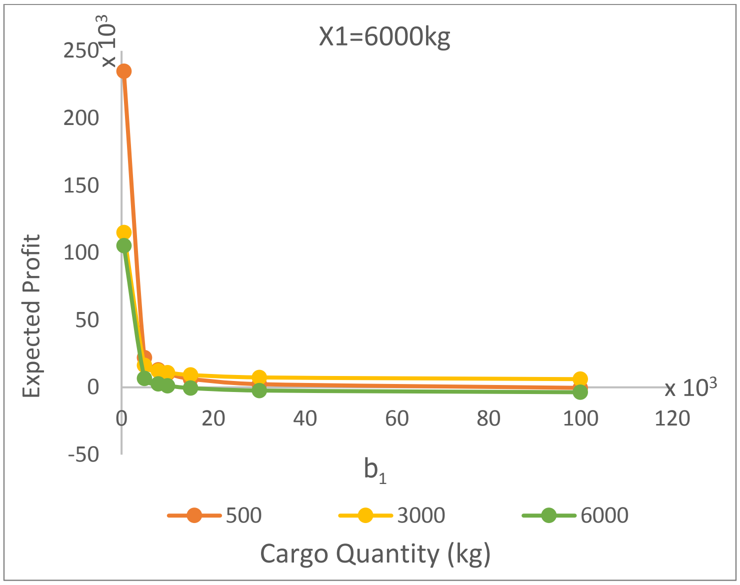


Figure 4-13 Effect of b_1 on the profit

The air cargo price (p_c) is determined with reference to the International Air Transport Association (IATA) Tact rules (IATA, 2009). The Tact rates of the (X-Y) route have a decreasing price for each weight level, thus, the more the booked cargo, the lower the unit price. Moreover, a Tact rules use chargeable weight analysis. Chargeable weight is the maximum value between the gross and the volumetric weight, and the cargo price is estimated from equation (4-23)

$$w_c = \max(w_{gc}, v_c u) \tag{4-23}$$

where w_c is the unit cargo chargeable weight, w_{gc} is the unit cargo gross weight, v_c is the unit cargo volume, and u is the volumetric weight convertor, based on IATA conversion values.

4.6.2 Analyses results

In this section, the difference between the new extra-baggage scheme and the existing excess-baggage scheme in airline A is discussed. The excess-baggage scheme in airline A follows the piece-based option. At most, ten excess bags are permitted, with a maximum of 23 kg per bag.

Even though the airline theoretically allows the passenger to book a maximum ten of excess bags, it may reduce the number of these bags, if the compartment is only sufficient to transport regular checked-baggage. They offer an option to accept the excess-baggage, but it will be scheduled to the next flight.

To keep the analysis consistent with the same Boeing 787-9 aircraft, the excess-baggage profit (EBP) in route (X-Y) is calculated by equations (4-20), (4-21), and (4-22). The input parameters for the model includes the cost per available seat mile, the traveled distance, seating plan in the airline, (total number of seats) which are designated in the aircraft, and the maximum acceptable weight of excess-baggage (23kg).

The extra-baggage model has been adapted to compare with the excess-baggage model. The extra-baggage prices are estimated with reference to the cargo Tact rates (IATA, 2009). The extra-baggage analysis ignores the cargo combination and the profit are obtained from the extra-baggage only. It is worth mentioning that the description of the extra-baggage service as a special cargo service solves the cost per piece and/or weight dilemma. In this regard, the passenger will be charged for the extra-baggage using the IATA chargeable weight rule, similar to equation (4-23). *Table 4-3* represents the comparison between the excess-baggage profits with a fixed price for each piece on route (X-Y) and the extra-baggage scheme profits.

The first and third columns give the core difference between the excess and the extra-baggage schemes. The excess-baggage amounts are counted by the number of pieces. For example, a 220-piece combination is obtained from 40 passengers. On the other hand, the extra-baggage scheme is offered based on unit weight, for instance, 5060 kg, equivalent to 220-piece in the excess-baggage scheme and can be booked from any number of passengers on the flight. The extra-baggage prices are obtained from the cargo Tact rates, and the extra-baggage price varies when the demand changes. The results show that the airline profit increases if the flexible extra-baggage pricing scheme is implemented. Moreover, the cargo compartment profit resulting from increasing the extra-baggage quantity is greater than the resulting profit from increasing the excess-baggage quantity. In more detail, for cargo price of 9.89 USD, the profit from 5060 kg of extra-baggage is less than its equivalent excess-baggage by almost 9.6%, while the profit improves gradually when the extra-baggage amount increases. The extra-baggage profit surpasses the excess-baggage profit by 25.3%. However, this increase in the profit depends on our model assumptions, i.e. extra-baggage model is performed on a particular aircraft, a certain route, and IATA cargo prices in this route. The change of these parameters may either increase or decrease extra-baggage profits. For example, the aircraft type affects the cost function which lead to an indirect change in the flight profit (FAA, 2016).

Also, the different cargo price range in the selected route affects the airline profit as it is revealed in the four columns (7.16- 8.02- 8.88- 9.89) in *Table 4-3*. It means that the change in cargo price implies that the cargo demand changes, and in turn the extra-baggage price is sensitive to the change of cargo demand, i.e. when the cargo demand increases, the extra-baggage price is raised to decrease the demand, and of low cargo price is imposed. This reflected in the high super high profit in the cargo price 7.16. As an example of the high cargo demand routes, the growth of e-commerce between Europe and the Asia Pacific region leads to increase the cargo demand in these routes. So, the extra-baggage price in those routes will be very high in order to reduce its demand (IATA, 2018b).

Table 4-3 Profits from extra- baggage compared with current excess-baggage scheme

Excess-baggage		**Extra-baggage**					
		equivalent	Cargo price[6] (USD)				
No. of pieces	**Profit (USD)**	**weight** (kg)	7.16	8.02	8.88	**9.89**	**(9.89) Profit difference %**
			Profit (USD)				
220	**34969**	**5060**	78334	63615	48896	**31610**	**- 9.6**
275	43712	**6325**	98835	81506	64177	43826	0.3
550	93782	**13570**	201340	170960	140580	104900	11.9
590	87424	**12650**	216250	183970	151690	113790	30.2
675	107293	**15525**	247930	211620	175310	132670	23.7
700	111266	**16100**	257250	219750	182260	138220	24.2
750	**119214**	**17250**	275890	236020	196150	**149320**	**25.3**

4.7 Managerial Implications

Combination airlines work in two business formats: First, Business to Customer format, B2C; the airline sells the extra-baggage service to each individual passenger. Second, Business to Business format, B2B, the airline sells the aircraft capacity to freight forwarder companies. Regarding B2B, it requires complicated operations between the airline and the freight forwarders, including

[6] The cargo prices have been nominated from IATA Tact rates for the same flight in route (X-Y). and the extra-baggage is estimated by equation (4), the extra-baggage price in inversely proportional to the cargo price, and hence, the highest cargo price, gives the lowest extra-baggage price.

negotiations, bidding, tenders, and contracting. B2C, on the other hand, bypassing all the previous complicated operations, as it imposes different pricing strategies on individual customers.

Because the airline uses the B2C format to sell the extra-baggage, it can flexibly move between different pricing strategies, as follows:

- The airline may use the cost-based pricing strategy since it is one of the most common strategies. However, this strategy is difficult to be implemented because airline cost analysis is still not well studied, and it may cause inaccurate calculations. So, if the airline has a strong cost analysis system, the selling price of extra-baggage unit may equal the sum of cost and profit of each unit.
- The airline may conduct price differentiation for different passenger classes. In this case, the price and the booking amount will be assigned differently for each class.
- The airline may also implement pricing based on operations. Therefore, the extra-baggage pricing will be strongly correlated to the cargo service. This may affect the pricing strategies by changing the prices in different seasons. However, the cargo business is a complex one, but it still provides a higher transaction as a B2B format. Thus, the price of extra-baggage may rely on the cargo demand. For instance, in some seasons, the cargo demand is high and the price drops, and thus, the airline is recommended to impose high extra-baggage prices to minimize its demand.

As the extra-baggage is designed to be allocated in the cargo compartment, the planning process of the cargo should be affected by the extra-baggage, because of the random weight and volume of extra-baggage and cargo, which cannot be controlled. Thus, the airline will need to adjust the cargo plans with respect to the extra-baggage. During the cargo seasons, some routes will suffer an over demand. Therefore, the airline should find flexible scheduling and planning approaches to take advantage of the high cargo demand with low price and the consequent high price of extra-baggage which lead to higher profits. Furthermore, the extra-baggage may take advantage of the Baggage Improvement Programme (BIP) to follow the passenger regular baggage processes (IATA, 2010). Thus, it will not affect the cargo processing which is separately performed.

The extra-baggage scheme may provide a good reason for a passenger to choose the airline because of his/her need for this service. Consequently, the airlines which provide the new extra-baggage scheme will attract new passengers. Those passengers can be added to their passenger demand. Therefore, the passenger load factor will be increased. Furthermore, the passenger demand growth will lead to price decrease.

In this chapter, the underutilization problem is tackled by the proposing and formulating the extra-baggage service. Other solutions may be proposed, such as lowering the cargo rates to attract more demand. This hypothesis is not reasonable because of the nature of the cargo business which needs much negotiation and gaming with the freight forwarders. Moreover, air transportation has many other rivals such as shipping and ground transportation, so even if the air freight rates are lowered, the increase in demand will not cover the capacity (Freightos, 2018).

4.8 Summary

In this chapter, a new excess-baggage and the overweight scheme are identified and discussed as an extra-baggage scheme in a combination airline. The service is described and compared with both the current excess-baggage schemes in the different airlines, and with the cargo scheme side. The extra-baggage scheme is proposed as a solution for overcapacity resulting from the extensive use of wide-bodied aircraft and the reduction in the sea shipping rates. The extra-baggage is treated as a special cargo service, and it was shown that the extra-baggage can be considered as a cargo if the passenger acts as a shipper and sends luggage to a freight forwarder. The frieght forwader inturn forwards them to the airline which assign these luggage to the aircraft belly-hold, in addition to permitted baggage.

In this aspect, the multi-item newsvendor model is adopted to set the extra-baggage price with reference to the cargo price. The model is formulated in a stochastic-deterministic environment, and because of the model limitation, it is then formulated in stochastic-stochastic form, where the premium value in the second model shows better results over the first one. The extra-baggage price can be set with reference to the cargo prices, in terms of base price, and premium value. The extra-baggage price is the sum of the base price and the estimated premium value. The premium value is the expected penalties over the expected sold capacity and can be either positive or negative. This means that the optimum price may be larger than the base price, or may be less than the base price,but it cannot be less than the riskless price.

Chapter 5 Air Cargo Pre-allocation Puppet-Cournot-Quantity Discount Model

5.1 Introduction

In the prior chapter, the demand imbalance problem has been initially dealt with by filling up the unused space in the underutilized routes. The demand growth in passengers' market has been exploited by proposing the extra-baggage scheme to be allocated beside the cargo in the belly-hold of the aircraft. However, the problem has not been fully solved, since the interrelationship between the hot-selling and the underutilized routes was not considered. The underutilized routes were only considered. The continuous increase of the cargo capacity and the unexpected decline in the cargo demand were the basic motivations.

To deal with the demand imbalance problem, it is necessary to consider the interdependence between the hot-selling and the underutilized routes. In this vein, airlines need to plan for suitable freight quantities which give better utilization between the hot-selling and the underutilized routes. Then, they need to find incentives to motivate the freight forwarders to follow these pre-planned quantities.

In this chapter, the Puppet-Cournot duopoly game model is developed to make a proactive plan which maintains a balance between the hot-selling and the underutilized routes. In this game, the carrier is the only player who runs this game through the traditional Cournot model. It is supposed that the carrier treats two types of routes; hot-selling route and underutilized route. It should be noted here that these two routes are treated in a competitive way, and hence, the profit of each route is dependent on the sold quantity of freight space in each route individually – i.e. the hot-selling profit and the underutilized route profit are estimated via two different profit functions. The sum of profits of these two routes stands for the overall profit of the carrier. The Puppet-Cournot game captures the different quantity scenarios in the form of the best response for each route with respect to the other. These scenarios are most likely dependent on the market demand of the two routes.

However, the traditional Puppet-Cournot game does not consider the thirst of freight forwarders in buying from the hot-selling routes. To cope with this issue, a quantity discount policy provides the incentive to freight forwarders to follow the quantity plan of the carriers. Quantity discount is mainly used to change the buyers ordering quantities and maximize the profit of both seller and buyers. The quantity discount is integrated into the Puppet-Cournot model to develop the Puppet-Cournot-Quantity Discount (PCQD) model. The resulting model follows these assumptions: (i) Each freight forwarder orders a fixed amount from the hot-selling and the underutilized routes; (ii) in the imbalance condition, the order of the freight forwarders from the hot-selling route is greater than the underutilized route; and (iii) a quantity discount is offered to the freight forwarder who orders more in the underutilized route and reduces the same amount in the hot-selling route.

5.2 The Puppet-Cournot Model

Suppose that an airline sells cargo capacity in two routes, Route 1 and Route 2. The total market demand of the cargo step-up the airline capacity in Route 1 is called the hot-selling route, while the market demand is drastically insufficient to fill up Route 2's capacity which makes it underutilized. It is assumed that the airline sells the unit cargo at price P_1 and P_2 in the hot selling route and the underutilized route, respectively. The price of each route is sensitive to the ordered cargo quantities, such that $P_1(Q_1) = \alpha_1 - \beta_1 Q_1$, and $P_2(Q_2) = \alpha_2 - \beta_2 Q_2$, where Q_1 is the ordered cargo quantity of the hot-selling route, Q_2 is the ordered cargo quantity of the underutilized route, and $\alpha_1, \beta_1, \alpha_2$ and β_2 are the equations coefficients[7]. Also, the demand in the hot-selling route is D_1 and the demand in the underutilized route is D_2. Furthermore, the sum of the ordered cargo quantities equals the overall demand. This means that $Q_1 + Q_2 = D_1 + D_2$.

In connection with the demand imbalance between the hot-selling and the underutilized routes, it is supposed that the airline considers them as two profit resources. The profit of the two routes are gained individually. In this regard, the overall profit of the airline equals the profit from the hot-selling route plus the profit from the underutilized route. Since the objective of the airline is to solve the imbalance between these two routes, the two routes act as two competing routes. This description means that the problem can be represented by the Cournot duopoly game. However, the airline is the only player who controls the two competing routes. The airline plays the game for the two routes as the puppeteer, so this game can be called the “Puppet-Cournot game”. The advantage of using the Puppet-Cournot game in the demand imbalance problem is that the airline is able to determine the best quantity allocation scenarios between both the hot-selling and underutilized routes. This can be achieved by estimating the best response of each route to the other. In addition, the model uses the price as a function of the quantity, which is also reversely used to set the prices in both routes. The airline’s profit from Route 1 is,

$$APR1 = P_1(Q_1) \times D_1 - C_1 Q_1 \tag{5-1}$$

where C_1 is the unit cargo operational costs, and the airline’s profit from Route 2 is,

$$APR2 = P_2(Q_2) \times D_2 - C_2 Q_2 \tag{5-2}$$

The application of our model “Puppet-Cournot” introduces the following proposition,

---

[7] These coefficients can be estimated based on the International Air Transport Association (IATA) Tact rules (IATA, 2009)

Proposition 5-1 *Given the profit of airline in Route 1 from equation (5-1) and the profit in Route 2 from equation (5-2), the quantity best response of each route to the other is,*

i. $Q_1{}^* = PR_1(Q_2) = \frac{\alpha_1+\beta_1 D_2 - C_1}{2\beta_1} - 0.5Q_2$ *; and*

ii. $Q_2{}^* = PR_2(Q_1) = \frac{\alpha_2+\beta_2 D_1 - C_2}{2\beta_2} - 0.5Q_1$

The unique Nash equilibrium is the point in which the airline receives quantities

$$(\hat{Q}_1, \hat{Q}_2) = \left(\frac{2\beta_2(\alpha_1+\beta_1 D_2-C_1)-\beta_1(\alpha_2+\beta_2 D_1-C_2)}{3\beta_1\beta_2}, \frac{2\beta_1(\alpha_2+\beta_2 D_1-C_2)-(\alpha_1+\beta_1 D_2-C_1)}{3\beta_1\beta_2}\right),$$

Proof In this problem, the best response is the quantity which achieves the balance between Route 1 and Route 2, i.e. the best responses are the optimum scenarios the of cargo quantities which should be sold in each route to maximize the profit of airline. The partial differentiation of profit in Route 1 with respect to the Route 1 cargo quantity Q_1 is $\frac{\partial(APR1)}{\partial\, Q_1} = \alpha_2 - 2\beta_2 Q_1 - \beta_1 Q_2 + \beta_1 D_2 - C_1$. From the problem description, $Q_1 \gg Q_2$, and the airline is expected to sell quantities in Route 1 more than the market demand in Route 2, i.e. $Q_1 \gg D_2$. Therefore, $2\beta_2 Q_1 + \beta_1 Q_2 + C_1 > \alpha_2 + \beta_1 D_2$, and $\frac{\partial(APR1)}{\partial\, Q_1} < 0$. In addition, $\frac{\partial^2(APR1)}{\partial\, Q_1{}^2} = -2\beta_2 < 0$. Hence, the airline's profit in Route 1 is concave in Q_1, and $\frac{\partial(APR1)}{\partial\, Q_1} = 0$ gives the best response of Route 1 to the quantity Q_2 in Route 2.

Similarly, the first derivative of the airline's profit in Route 2 with respect to the cargo quantity Q_2 is $\frac{\partial(APR2)}{\partial\, Q_2} = \alpha_1 - 2\beta_1 Q_2 - \beta_2 Q_1 + \beta_2 D_1 - C_1$, and the best response of Route 2 to the quantity Q_1 in Route 1 is estimated by $\frac{\partial(APR2)}{\partial\, Q_2} = 0$.

The best response of Route 1, $PR_1(Q_2)$, and the best response of Route 2, $PR_2(Q_1)$, are two linear equations. The intersection of these two equations stands for the unique Nash equilibrium of this game. ■

The unique Nash equilibrium represents the point at which the imbalance between Route 1 and Route 2 is exchanged in which the Route 1 demand is drastically less than its capacity, and the demand in Route 2 exceeds its capacity. This means that Route 1 becomes underutilized, and Route 2 becomes hot-selling. *Figure 5-1* shows that the Route 1 and Route 2 are substitutable routes, and this leads to a role exchange between the two routes in different seasons. In other words, the route may be hot-selling route in a particular season, while it changes to underutilized in another season. Moreover, two more reasons can change the route from hot-selling to underutilized and vice versa; first the cargo dimensions (volume and weight), and the second is the change in route capacity which depends on the aircraft assignment. Therefore, the Nash equilibrium in this model represents the reverse point ($R.P$). The $R.P$ point divides the graph into two areas, the $R.P$ left side provides the best response when Route 1 is the hot-selling and Route 2 is underutilized. On the right side, the best response of each route to the other is obtainable when Route 1 is underutilized, and Route 2 is hot-selling.

The values of $\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}$ and $\boldsymbol{D}$ points in *Figure 5-1* reveal that the reverse process is not symmetric, i.e., unlike the traditional Cournot duopoly model, the reverse calculation in the Puppet-Cournot model does not depend only on the quantity, but it also depends on the route capacity and the gap between the demand and the capacity. The reverse point can be symmetric, if and only if the capacity and demand of the route are identical, and thus the points $\boldsymbol{A} = \boldsymbol{D}$, and $\boldsymbol{B} = \boldsymbol{C}$. Consequently, the Nash equilibrium represents the condition that the airline sells equal quantities in both routes, and in this case, the problem is changed from the imbalance problem to either shortage, if the overall demand is not sufficient to fulfil the two routes capacities and thus Chapter 1 deals with it, or an overbooking problem, when the cargo demand is excessively booming, and the sum routes capacities cannot cover that demand.

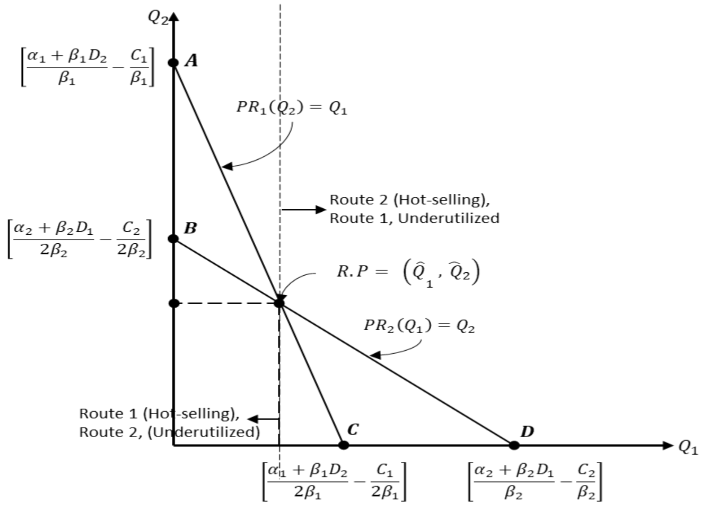


Figure 5-1 Schematic diagram of the exchange between the hot-selling and the underutilized routes.

Although the Puppet-Cournot game provides calculations of the quantities which keep the balance between the hot-selling and the underutilized routes, the implementation of this method is very difficult, because it is not applicable to enforce the freight forwarders to follow the airline's quantity allocation plan. Consequently, it is necessary to find an incentive policy to encourage the freight forwarders to change the ordering policy and fit the airline's optimum quantity allocation in both the hot-selling and underutilized routes. In the next section, a quantity discount strategy is proposed to motivate freight forwarders to buy the cargo quantities from the two competing routes, according to the Puppet-Cournot results.

5.3 The Puppet-Cournot-Quantity Discount PCQD Model

In this section, a quantity discount policy is adopted to encourage the freight forwarders to change their ordering between the hot-selling route and the underutilized route. The difference between the Puppet-Cournot-Quantity Discount model (PCQD) and the traditional quantity discount model is that the airline aims to balance the hot-selling route and the underutilized route, while the traditional quantity discount is used to reduce the number of orders by increasing the quantity in each order, when the overall demand is fixed along the booking horizon. Moreover, the PCQD model has some features and some assumptions. They can be summarized as follows:

- The sum of the hot-selling and the underutilized routes demand is fixed,
- Since the cargo service is perishable, it is not available in the hot-selling and the underutilized routes after the flight departure.
- Even though the quantity discount is only offered for Route 2 or the underutilized route, the hot-selling route or Route 1 is also affected and the airline's overall capacity allocation as well.
- As commonly used in the literature, the quantity discount has no effect on the market demand, but it changes the freight forwarders purchases between the hot-selling routes and the underutilized routes.
- The demands of the hot-selling route and the underutilized route are deterministic.

Referring to the first assumption, the sum of Route 1 and Route 2 demands equals the sum of the order quantities in these routes, which is also used in the above model. Based on the other assumptions, the model uses a quantity discount as an incentive to freight forwarders in the underutilized routes to solve the imbalance problem between the hot-selling and underutilized routes. In this manner, the cargo unit price in the underutilized route decreases by increasing the ordered quantity. Also, it is supposed that the increase in cargo quantity in the underutilized route decreases the cargo quantity in the hot-selling route. The new quantities when applying the quantity discount policy can be described by the following equation,

$$Q_i = \begin{cases} Q_1{}^o = kQ_1, & Q_1{}^o < Q_1 \\ Q_2{}^o = Q_2 + (1-k)Q_1, & Q_2{}^o > Q_2 \end{cases} \; for\ 0 < k < 1, \tag{5-3}$$

where $i = \{1,2\}$, k is the discount factor, and $Q_1{}^o + Q_2{}^o = Q_2 + Q_1$.

As a consequence of the quantity change, the price in Route 2 (underutilized route) also changes. This change yields the discount factor k. The Route 2 price decreasing ratio is a function of the decrease in the quantity in the Route 1 (hot-selling route).

$$P_2(Q_1{}^o, Q_2{}^o, k)$$
$$= \begin{cases} kP_2, & 0 < k < 1, \quad Q_1{}^o = kQ_1, \&\ Q_2{}^o = Q_2 + (1-k)Q_1, \\ P_2, & k = 1, \quad Q_1{}^o = Q_1,\ \&\ Q_2{}^o = Q_2 \end{cases} \tag{5-4}$$

The advantage of setting the quantity discount in this form is that the extra-quantity in the hot-selling routes is passed to the underutilized routes. From equation (5-3), the quantity in the hot-selling route is decreased by ratio $(1-k)$. This is reflected on the price decrease in the underutilized route. In addition, the airline is supposed to tie the quantity discount in the underutilized route with the reduced quantity in the hot-selling route $(1-k)Q_1$. Consequently, the quantity of freight forwarder decreases in the hot-selling is reflected in a price discount in the underutilized route. The resultant of the quantity discount model should also be able to maximize the profit of airline. The profit from Route 1 with the quantity discount is

$$APRD1 = APR1 = P_1(Q_1{}^o) \times D_1 - C_1 Q_1{}^o \tag{5-5}$$

, and the profit from the discounted quantity in Route 2 is

$$APRD2 = P_2{}^o\left(Q_1{}^0\right) \times D_2 - C_2 Q_2{}^o \tag{5-6}$$

The combination of the properties of equations (5-3), (5-4), (5-5), and (5-6) leads to the following fundamental proposition,

Proposition 5-2 *For the integrated Puppet-Cournot-Quantity Discount PCQD model, the optimum quantity combinations in Route 1 and Route 2, which solves the imbalance problem, is obtainable from the best response of Route 1 to the quantity in Route 2;*

i. $Q_1{}^{o*} = PR_1(Q_2{}^o) = \frac{\alpha_1 + k\beta_1 D_2 - kC_1}{2k\beta_1} - 0.5Q_2{}^o,$

, the best response of Route 2 to each ordered quantity in Route 1

ii. $Q_2{}^{o*} = PR_2(Q_1{}^o) = \frac{k(\alpha_2 + \beta_2 D_1) - C_2}{2k\beta_2} - 0.5(2-k)Q_1{}^o,$

, and the Discount Reverse Point RPD is

iii. $\left(\hat{Q}_1{}^o, \hat{Q}_2{}^o\right) = \left(\frac{2\beta_2(\alpha_1 + k\beta_1 D_2 - kC_1) - \beta_1(k\alpha_2 + k\beta_2 D_1 - C_2)}{k(2+k)\beta_1\beta_2}, \frac{2\beta_1(k\alpha_2 + k\beta_2 D_1 - C_2) - \beta_2(2-k)(\alpha_1 + k\beta_1 D_2 - kC_1)}{k(2+k)\beta_1\beta_2}\right),$

Proof When applying the quantity discount to sell the cargo quantity in the underutilized route (Route 2), the airline profit in Route 1 is influenced by the price discount factor k, i.e. the airline offers a price discount in Route 2 by the discount factor k, when the freight forwarder reduces the quantity ordered in Route 1 by the $(1-k)$ ratio. Similar to **Proposition 5-1**, the airline profit in Route 1 can be represented by a quadratic function of the sold cargo quantity in Route 1. The partial derivative of this profit under quantity discount with respect to the quantity ordered from Route 1 is $\frac{\partial(APRD1)}{\partial Q_1{}^o} = \alpha_1 - 2\beta_1 Q_1{}^o - \beta_1 Q_2{}^o + \beta_1 k D_1 - kC_1$, and $2\beta_1 Q_1{}^o + \beta_1 Q_2{}^o + kC_1 \geq \alpha_1 + \beta_1 k D_1$. Consequently $\frac{\partial(APRD1)}{\partial Q_1{}^o} \leq 0$, and the second derivative is $-2\beta_1, i.e. \frac{\partial^2(APRD1)}{\partial Q_1{}^{o^2}} < 0$. Therefore, the airline profit is concave in the sold quantity from Route 1. The airline's best response of Route 1 to the ordered quantity in Route 2 can be estimated when $\frac{\partial(APRD1)}{\partial Q_1{}^o} = 0$. Likely, under quantity discount policy, the airline profit from Route 2 with respect to the ordered quantity is $\frac{\partial(APRD2)}{\partial Q_2{}^o} = k[-\beta_2(Q_1{}^o + Q_2{}^o - D_1) + (\alpha_2 - \beta_2)Q_2{}^o) - C_2$, and the best response of the quantities in Route 2 to the ordered quantities in Route 1 can be achieved when $\frac{\partial(APRD2)}{\partial Q_2{}^o} = 0$. Moreover, the partial derivatives of the airline profit in both the underutilized route and hot-selling route with respect to the new quantities $Q_1{}^o$and $Q_2{}^o$, respectively, gives two linear equations. The intersection of these two lines is the Nash equilibrium of the Puppet-Cournot-Quantity Discount game $\left(\hat{Q}_1{}^o, \hat{Q}_2{}^o\right)$. ■

Figure 5-2 shows the major changes in the Puppet-Cournot game when it is combined with the quantity discount policy than that is obtained from the original Puppet-Cournot. The points $\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C},$ and $\boldsymbol{D}$ change to $\boldsymbol{A}', \boldsymbol{B}', \boldsymbol{C}',$ and $\boldsymbol{D}'$. The change is a consequence of using the discount factor k. Also, in *Figure 5-2*, the values of $\boldsymbol{A}$ and $\boldsymbol{C}$ are changed to $\boldsymbol{A}'$ and $\boldsymbol{C}'$. The coefficient β_1 is decreased to $k\beta_1$. The value of $\boldsymbol{A}'$ increases by the decrease of the discount ratio k. Furthermore, the discount factor k changes the value of $\boldsymbol{B}$ to $\boldsymbol{B}'$ by increasing the cost value, which makes the value $\boldsymbol{B} \geq \boldsymbol{B}'$. The discount factor affects the point $\boldsymbol{D}$ and changes it to $\boldsymbol{D}'$ where the value of $\boldsymbol{D}'$ is reduced because of two factors; first, it decreased upon the increase of the cost factor $\frac{C_1}{2\beta_1}$ by $\frac{1}{k}$, where $\frac{1}{k} > 1$. Second, the overall value of $\left(\frac{(\alpha_2+\beta_2 D_1)}{\beta_2} - \frac{C_2}{k\beta_2}\right)$ is decrease by the value $\frac{1}{(2-k)}$.

For the same parameters, the change in the best responses in Route 1 and Route 2 should also affect the sum of the Route 1 and Route 2 profits. In this regard, a numerical analysis is inevitably needed.

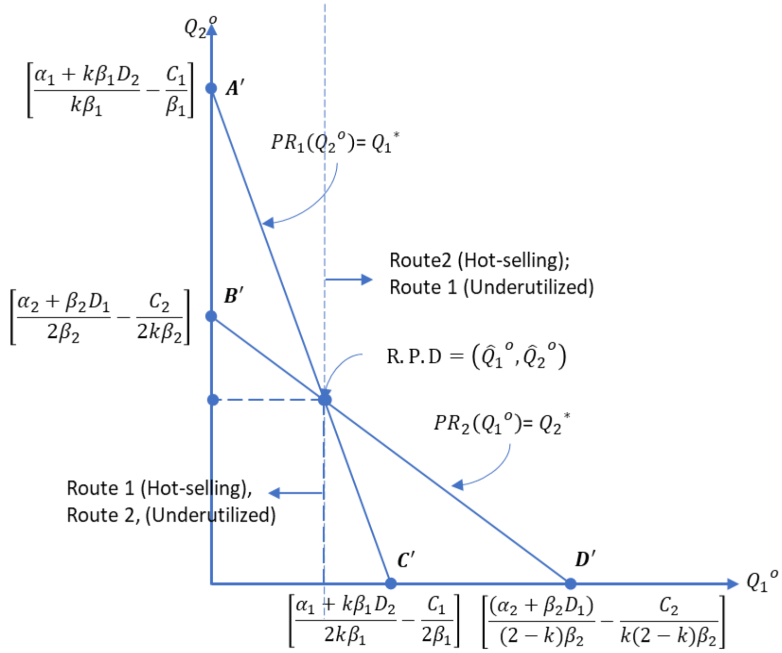


Figure 5-2 A schematic diagram of the quantity discount under Cournot setup

5.4 Numerical Analyses

It is worth to note that the PCQD model takes advantage of the Cournot model to estimate the optimum quantity reactions for Route 2 when the freight forwarder orders a certain quantity in Route 1 and vice versa. Also, it revokes the operation cost reduction from the quantity discount policy. In this section, the effect of the PCQD model is investigated in solving the demand imbalance problem.

In the beginning, numerical analyses examine the quantity allocation scenarios between the hot-selling and the underutilized routes, when the Puppet-Cournot game is adopted. The allocated quantities are achieved by using the best response of each route to the other. In this manner, the extracted data from (Feng et al., 2015a) are used. The price-based quantity equation has been determined by using the International Air Transport Association (IATA) Tact rates (IATA, 2009). Two linear regression models were used to estimate the coefficients of the price equations in the hot-selling route and the underutilized route, and the inverse demand function coefficients in Route1 are $\alpha_1 = 4624$, $\beta_1 = 5.503$, and in Route 2 $\alpha_2 = 2015.54$, $\beta_2 = 2.220$. The operating costs in Route 1 and Route 2 are $\$430/\text{tonne}$, and $\$480/\text{tonne}$ respectively. Moreover, the deterministic demand has been extracted from (Feng et al., 2015a). The average demand from these data are used, where the demand in Route 1 is $D_2 = 221.08$ tonne, and the demand in Route 2 is $D_1 = 86.20$ tonne.

Figure 5-3 proves the concavity of the profit from Route 1 with respect to the sold quantity Q_1. In addition, because Route 2 competes with Route 1, the sold quantities in Route 2 affect the airline profit in Route 1. The profit in Route 1 increases with the increase of the sold quantity in Route 2. Also, the figure shows the loss in profits in Route 2 due to the imbalance problem.

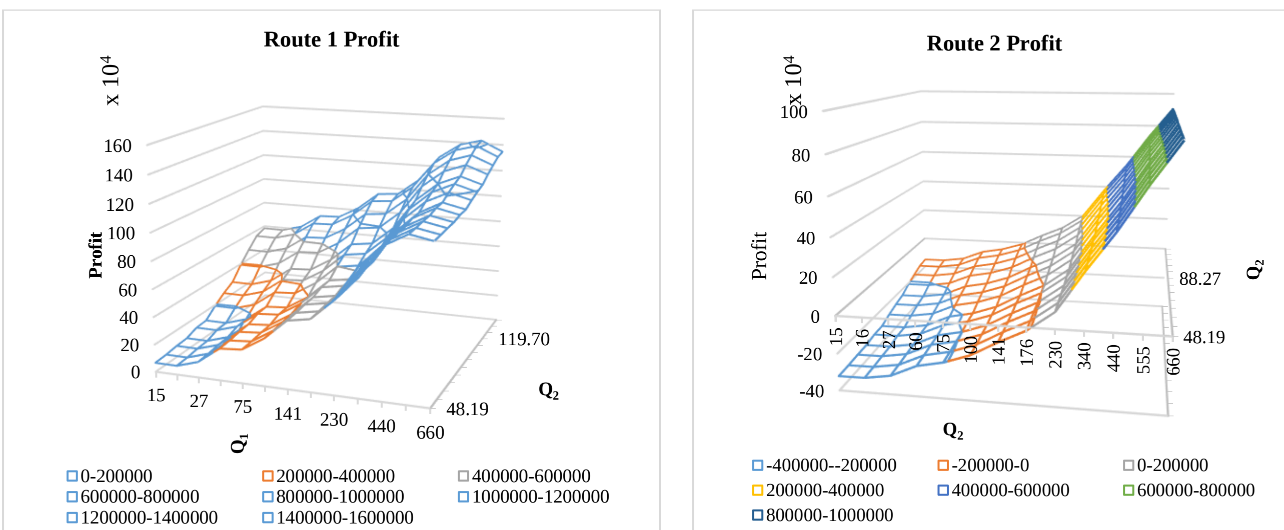


Figure 5-3 Airline profit from Route 1 with respect to Q1 and Q2

By applying the Cournot model, the results in **Proposition 5-1** are shown in *Figure 5-4*. Also, the actual response lines are represented. From the actual best responses, the points $\boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}$, and $\boldsymbol{D}$ values are $849, 452.88, 424.165$, and 905.76 tonnes. The change in these four points affect the best response which is practical proof to the applicability of our model, because the change in these points depends directly on the route price and cost.

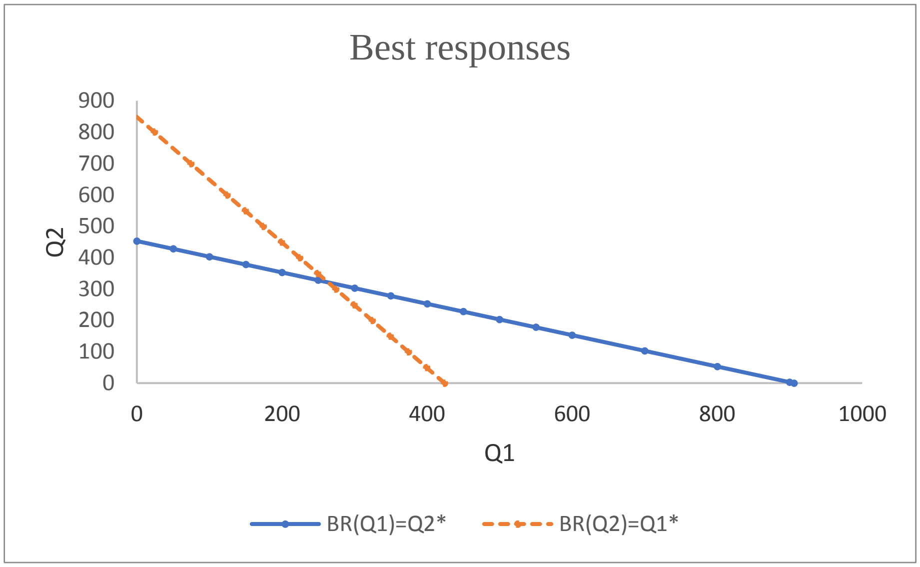


Figure 5-4 The best responses of the Puppet-Cournot model

Also, the cost differs in the distinct routes, and so our model gives suitable quantity balancing between any two competing routes, as long as the airline has the price-quantity equations and the flight cost functions.

As discussed, the quantity discount advantage is taken to attract the freight forwarders to purchase in the underutilized routes. The subsequent proposition describes the effect of integrating quantity discount with Cournot setup.

Proposition 5-3 *The quantity balance between the hot-selling and the underutilized routes with the PCQD model leads to an increase in the total airline profit if and only if,* $(\beta_1 D_1 + C_1)Q_1 + [\beta_2(Q_2 - kQ_1) - \alpha_2]D_2 + C_2 Q_1 > 0$,

Proof This proposition states the impacts of using the quantity discount factor k on the airline profit. The total airline profit from the Puppet-Cournot game is $TAP = APR1 + APR2$, and the total airline profit from the PCQD model is $TAPD = APRD1 + APRD2$. Intuitively, the airline profit will be increased if $TAPD - TAP > 0$. Under the Puppet-Cournot model, this condition can be achieved when $(APRD1 - APR1) + (APRD2 - APR2) > 0$, because it considers the two routes compete on the quantities. From this standpoint, the profit difference from upgrading the Puppet-Cournot game to the Puppet-Cournot-Quantity Discount PCQD model in Route 1 can be determined by

$$APRD1 - APR1 = (\alpha_1 - k\beta_1 Q_1)D_1 - C_1 kQ_1 - [(\alpha_1 - \beta_1 Q_1)D_1 - C_1 Q_1)]$$

$$= (1-k)Q_1(\beta_1 D_1 + C_1)$$

, and $APRD2 - APR2 = k\big(\alpha_2 - \beta_2(Q_2 + (1-k)Q_1)\big)D_2 - C_2(Q_2 + (1-k)Q_1) -$

$$[(\alpha_2 - \beta_2 Q_2)D_2 - C_2 Q_2]$$

$$= (1-k)[(\beta_2(Q_2 - kQ_1) - \alpha_2)D_2 - C_2 Q_1],$$

Therefore, $APRD1 - APR1 + APRD2 - APR2 = (1-k)Q_1(\beta_1 D_1 + C_1) + (1 - k)[(\beta_2(Q_2 - kQ_1) - \alpha_2)D_2 - C_2 Q_1]$, and the profit increases when $(\beta_1 D_1 + C_1)Q_1 + [\beta_2(Q_2 - kQ_1) - \alpha_2]D_2 + C_2 Q_1 > 0$. ■

This proposition states that the quantity discount is not always applicable to be used with the Puppet-Cournot game, and it is only applicable in the condition $(\beta_1 D_1 + C_1)Q_1 + [\beta_2(Q_2 - kQ_1) - \alpha_2]D_2 - C_2 Q_1 > 0$. For further details, the situations in Route 1 and Route 2 are different because of the Cournot duopoly property, i.e. the fixed cost and the unit cargo price are affected by the quantity change. In the PCQD model, the quantities in Route 1 and Route 2 change inevitably because the discount is proposed when the quantity is reduced in Route 1 by the discount factor k, and the discounted quantity from Route 1 is added to the quantity in Route 2. **Proposition 5-3** shows that the profit in Route 1 is always increasing when applying the quantity discount, because the quantity decrease reduces the total operation cost by $(1-k)Q_1$. Also, in the Puppet-Cournot model, the cargo price is a negative function of quantity, which means that the price increases when the quantity decreases. On the other hand, the quantity increases because the quantity discount leads to profit decrease in Route 2. The profit decrease in Route 2 can be reduced if $\beta_2(Q_2 - kQ_1)D_2 - \alpha_2 D_2 - C_2 Q_1 > 0$. This most likely happens when the quantity in Route 1, after applying the discount factor k, becomes less than the ordered quantity Q_2.This explains the reasons for the profit upsurge. Table 5-1 reveals that the application of quantity discount factor can improve the airline profits.

To summarize, **Proposition 5-3** provides the constraint that limits the application of PCQD model, i.e. the quantity discount is only applicable if the airline profit increases. Also, the quantity discount value affects the best response of Route 1 to Route 2 and vice versa. *Figure 5-5* reveals that the Quantity best response in Route 2 is when the discount factor increases, while it decreases with the increase of the cargo quantity in Route 1. In addition, after a certain quantity discount level, the best response becomes almost fixed, which as represented by the yellow colour in *Figure 5-5.*

Table 5-1 The sum of airline profits when no quantity discount ($k = 1$), and with quantity factor ($k = 0.85$)

Q_1(tonne)	Q_2(tonne) (k = 1)												
	48	49	52	53	60	61	76	88	98	120	138	155	161
15	-261907	-254351	-238207	-229791	-188299	-179992	-88573	-12738	47422	177623	286415	386291	421938
27	-197852	-190407	-174501	-166209	-125330	-117147	-27091	47602	106848	235050	342147	440445	475525
60	-35269	-28129	-12876	-4926	34266	42110	128417	199969	256705	379409	481843	575804	609321
75	-2003	4998	19953	27749	66173	73864	158467	228591	284185	404390	504705	596694	629502
100	128148	134916	149371	156906	194039	201471	283206	350929	404602	520602	617351	706022	737635
141	318193	324587	338245	345364	380439	387457	464619	528510	579119	688411	779472	862852	892560
176	390105	396167	409115	415862	449105	455755	528844	589323	637204	740523	826519	905187	933198
230	587774	593337	605215	611405	641887	647984	714939	770282	814055	908380	986750	1058323	1083779
340	908321	912872	922588	927649	952550	957526	1012078	1057032	1092497	1168634	1231579	1288803	1309093
440	1101419	1105040	1112765	1116786	1136549	1140494	1183628	1219018	1246835	1306227	1354973	1398988	**1414521**
555	1200268	1202824	1208271	1211103	1224987	1227750	1257819	1282266	1301330	1341563	1374062	1402961	1413052
660	1160300	1161884	1165251	1166997	1175512	1177198	1195338	1209792	1220866	1243605	1261269	1276367	1281489

Q_1 (tonne)	Q_2(tonne) ($k = 0.85$)												
	48	49	52	53	60	61	76	88	98	120	138	155	161
15	-765286	-757575	-741097	-732504	-690124	-681636	-588125	-510428	-448706	-155173	-46797	52892	88520
27	-693905	-686280	-669987	-661492	-619590	-611198	-518750	-441944	-380933	-89329	17726	116185	151369
60	-503747	-496360	-480577	-472348	-431762	-423634	-334110	-259752	-200700	85603	189022	284099	318065
75	-420288	-413011	-397459	-389351	-349363	-341355	-253159	-179915	-121753	162140	263906	357446	390859
100	-284056	-276961	-261799	-253894	-214913	-207107	-121147	-49775	6889	286726	385712	476665	509146
141	-77658	-70853	-56314	-48734	-11357	-3873	78520	146904	201179	474548	569098	655925	686920
176	94848	101394	115380	122671	158619	165815	245032	310756	362904	630513	721114	804266	833939
230	334543	340699	353851	360707	394502	401267	475702	537420	586364	845301	929955	1007574	1035255
340	745654	751022	762487	768463	797906	803797	868560	922178	964644	1206040	1278667	1345098	1368750
440	1036980	1041623	1051536	1056701	1082138	1087224	1143084	1189244	1225746	**1450995**	**1512550**	**1568680**	**1588623**
555	1267859	1271671	1279808	1284046	1304898	1309064	1354736	1392362	**1422040**	**1628813**	**1677698**	**1722042**	**1737741**
660	1383140	1386194	1392709	1396100	1412766	**1416092**	**1452461**	**1482296**	**1505743**	**1695646**	**1732963**	**1766546**	**1778370**

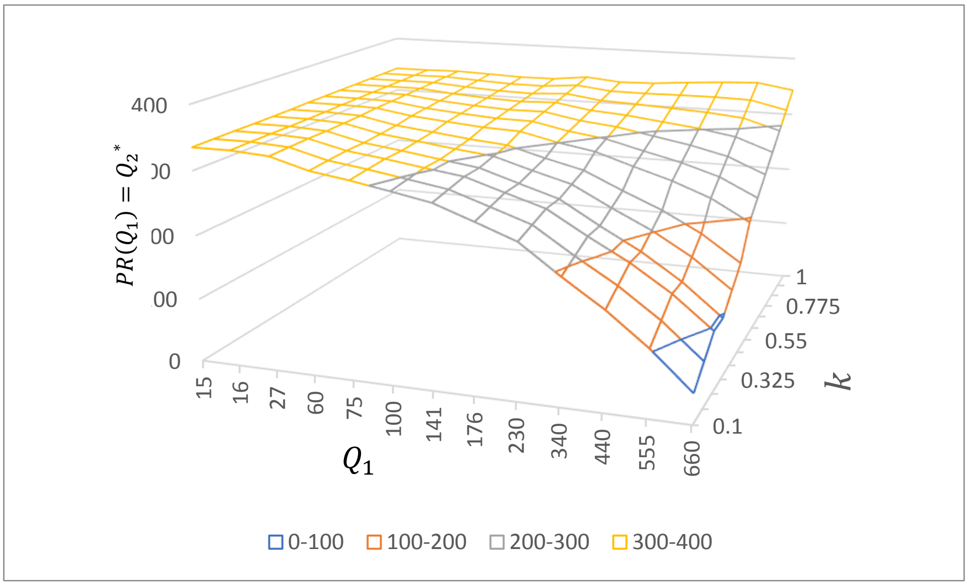


Figure 5-5 The effect of discount factor k and cargo quantity in Route 1 on the best response of Route 2.

5.5 Managerial Implications

With complete information, the top management of combination airlines can perform the Puppet-Cournot duopoly game. The application of this game necessitates airline to collect the historical records of the demand in the hot-selling and the underutilized routes. Also, the cost function of each route is necessary to estimate the best quantity responses. The game results imply that the market is split between the two competing routes. In other words, the Puppet-Cournot game model divides the overall demand of airline between the hot-selling route and the underutilized route. The results give the optimum quantity in each route, and hence solve the imbalance problem. The game in this form is applicable if the airline is monopolistic. This means that the airline can use the power of the monopoly to control the market by applying the Puppet-Cournot model.

When the airline has rivals, it is recommended to use the quantity discount as a marketing strategy. The aim of using the quantity discount is to attract freight forwarders to change their demand between the hot-selling and the underutilized routes. Since the overall demand is fixed, the airline uses the quantity discount to pump an amount of cargo from the hot-selling route to the underutilized route. Furthermore, **Proposition 5-3** implies that the unit cargo price in a hot-selling route increases when adopting the quantity discount policy. Consequently, airline is recommended to control the discount factor to avoid the exaggerated increase in the price of hot-selling route. Similarly, the quantity increase in underutilized route is reflected on its unit cargo price and this also should be considered.

Controlling the value of the discount factor is one of the main difficulties which face the top management of airline. In more detail, the demand gap between the hot-selling and the underutilized routes may affect the determination of the discount factor. This gap brings a trade-off between the airline's profit and the discount factor. The trade-off is revealed in *Figure 5-5*. When the demand gap is large, the airline increases the discount factor and the best response of the quantity in the underutilized route increases. The increase in the underutilized route leads to a decrease in its unit cargo price which may decrease the airline's profit.

5.6 Summary

This chapter helps the airline to set the best quantity combination between a hot-selling and an underutilized route, solving the demand imbalance problem. It is assumed that (i) the two routes, hot-selling and underutilized routes, compete for the quantities, (ii) the airline operation costs are fixed on both routes, and (iii) the price of cargo units is dependent on the sold quantity. The Puppet-Cournot model is proposed to cope with this problem. The Puppet-Cournot model is a duopoly game between a hot-selling and underutilized route but the whole game is controlled by the airline. The model gives the best responses for each route so that the airline negotiation with the freight forwarder can be based on these quantity limits.

Although the Puppet-Cournot model gives the optimum quantities which balance between hot-selling and the underutilized routes, the airline needs an incentive to persuade the freight forwarders to follow the proposed allocation quantities from Puppet-Cournot setup. In this regard, a quantity discount strategy is integrated with Cournot model. The integration of the Cournot setup and quantity discount policy leads to an increase in the profit in a certain route and profit decrease in the other route. This brings the conclusion: the quantity discount cannot always be used to attract the freight forwarders. It can only be used when the increase in a route profit surpasses the profit drop in the other route.

Chapter 6 Air Cargo Capacity Allocation with a Mixed Wholesale-option Contract Model

6.1 Introduction

Focusing on the global objective of this research, which is developing strong capacity allocation model to cope with the demand imbalance between the cargo routes, the two previous chapters covered both passengers and cargo from the perspective of the airline. In Chapter 4, the interdependence between passengers and cargo is covered by taking advantage of excess-baggage of passenger to utilize the underutilized routes. In Chapter 5, the hot-selling route is combined with the underutilized route to set a quantity plan which avoids the demand imbalance. This plan provides reference quantities for airline when it negotiates with the freight forwarders. The drawback of these two models are: (i) the first model considers the underutilized routes which is not sufficient to solve the imbalance problem, (ii) although the second model includes the hot-selling and the underutilized routes, it is formulated to solve the problem between two single routes. Moreover, the model does not consider the relationship between airline and freight forwarders. Also, as it is shown in the second model results, quantity discount policy cannot always be used.

In this chapter, the drawbacks of the first two models are considered through undertaking the negotiation process between the airline and the freight forwarders. A sequential cooperative game between a single airline and multiple freight forwarders is performed in the form of a flexible contracting model. This flexible model takes advantage of the wholesale and the option-contracts for the airline and freight forwarders together (Zhao et al., 2010). It is used to sell the capacities on the 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 airline's power to sell the capacity of the hot-selling route in a wholesale contract. With this in mind, the airline suffers from low demand in the underutilized routes. Consequently, the airline needs to motivate the freight forwarder to buy more quantities of freight space from the underutilized routes, so the option-contract is a perfect incentive to the freight forwarder. Therefore, it is suggested that airlines 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 which can then be added to the underutilized routes. The cooperative game is played on two phases. In the first phase, it is assumed that the freight forwarders are risk neutral, while in the second phase, the airline offers buy-back incentives under the assumption that some freight forwarders are risk-averse (Nagarajan & Sosic, 2008).

Although the mixed wholesale-option-contracting model uses a suitable contracting method on the proper routes, the airline and freight forwarders may have different opinions. The airline may prefer to use its full power to impose the wholesale contract to sell the cargo space in the two routes, while, the freight forwarders may only negotiate to decide the option of the two substitutable routes. Therefore, the game is modelled in both pure wholesale and pure option contracting forms to show their effect on the capacity allocation process. Then, the mixed wholesale-option-contract model is compared with the pure wholesale and pure option-contract models. The results reveal that the mixed wholesale-option-contract model provides the best quantity allocation in the two-phase game. The pure option models give the smallest allocation to the airline.

6.2 The Model Description

This model tackles the ordering process between an airline and multiple freight forwarders which has not been included in the first two models. In addition, it improves the previous model by tackling the imbalance problem in multiple routes rather than a single hot-selling and a single underutilized route. In this manner, a negotiation process between an airline and *n*-freight forwarders is proposed. The negotiation process is suggested to be performed through a bargaining game. The bargaining process is subsequently explained.

Consider an (*n*+1)-player bargaining game, single airline $\mathfrak{A}$ and *n*-freight forwarder $\mathfrak{F}$, for a set of freight forwarders $\mathfrak{F} = \{\mathfrak{f} : \mathfrak{f} \in \mathbb{N}\}$. Also, let the airline has two sets of routes: first, the routes with hot-selling demand $\mathcal{I}$, where $\mathcal{I} = \{\imath : \imath \in \mathbb{N}\}$. Second, the routes with underutilized demand $\mathcal{J} = \{\jmath : \jmath \in \mathbb{N}\}$. The airline $\mathfrak{A}$ and each freight forwarder $\mathfrak{f}$ negotiate the capacity allocation in the routes $\mathcal{I}$ 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 $\imath$ be $\mathcal{K}_\imath$, and the capacity of an underutilized route $\jmath$ be $\mathcal{K}_\jmath$. The sum of capacities in the hot-selling and the underutilized routes are $\sum_\imath^{\mathcal{I}} \mathcal{K}_\imath$, and $\sum_\jmath^{\mathcal{J}} \mathcal{K}_\jmath$, respectively. The market demand for the hot-selling route is represented by a random variable $X_\imath$. The demand cumulative distribution function of each route is $F(X_\imath)$ with $x_\imath \geq zero$, and the random variable of market demand for the underutilized routes is $X_\jmath$. The demand cumulative distribution function of each underutilized route is $F(X_\jmath)$ with $x_\jmath \geq zero$. The airline and *n*-freight forwarders negotiate set of quantities $\boldsymbol{q}$, i.e. the game is a function of this variable, where the current quantity set is $\boldsymbol{q} = \{\boldsymbol{Q_\imath}, \boldsymbol{Q_\jmath} \in \mathbb{R}^+ : \sum_{\imath=1}^{\mathcal{I}} \boldsymbol{Q_\imath} \geq \sum_\imath^{\mathcal{I}} \mathcal{K}_\imath, \sum_{\jmath=1}^{\mathcal{J}} \boldsymbol{Q_\jmath} < \sum_\jmath^{\mathcal{J}} \mathcal{K}_\jmath\}$.

This research gives advantage of the wholesale price contract to the airline and the option-contract to the freight forwarder. Accordingly, the wholesale pricing contract $\mathfrak{w}$ is used to sell the hot-selling routes because the demand of these routes is almost guaranteed. In this vein, the airline needs to induce the freight forwarders to specify the accurate demand instead of inflating their request to guarantee their allocation in the hot-selling routes. The option-contract $\boldsymbol{\mathcal{O}}$ is used to sell the underutilized routes because demand is very low on these routes. So, the airline encourages the forwarders to get more space on these routes by exercising higher demand.

The game between the airline and freight forwarders is run in consecutive steps. In each step, the airline plays with only one freight forwarder, i.e. the forwarder $\boldsymbol{f}_{\mathbf{1}}$ negotiates the quantity of the freight space $\boldsymbol{Q}_{\boldsymbol{i}}$ in a hot-selling route i at a wholesale unit price w_i, and quantity of the freight space $\boldsymbol{Q}_{\boldsymbol{j}}$ 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**.** Suppose 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 C_i, C_j for each unit in the hot-selling and the underutilized routes respectively.

6.3 Two-phase Mixed Wholesale-option Contract Model

Since the airlines control aircraft and airport slots, and they own the full freight capacity, it is supposed that the airline starts the negotiation from the lower incentive levels to the higher incentive levels. Moreover, because the game is performed sequentially, the airline repeats the same approach with each new freight forwarder**,** bringing to the fore the first lemma,

Lemma 6-1 *For identical freight forwarders in a sequential game, the possible capacity allocation for the forwarder $\boldsymbol{f}_{\boldsymbol{r}}$ from the underutilized routes $\mathcal{J}$, is higher than what is allocated to the forwarder $\boldsymbol{f}_{\boldsymbol{r-1}}$, i.e.,* $\left(\sum_j^{\mathcal{J}} \boldsymbol{Q}_{\boldsymbol{j}}\right)_{\boldsymbol{r}} > \left(\sum_j^{\mathcal{J}} \boldsymbol{Q}_{\boldsymbol{j}}\right)_{\boldsymbol{r-1}}$.

Proof Following 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 $\boldsymbol{f}_{\mathbf{1}}$**.**

This agreement encompasses the sum of quantities $\left(\sum_{i}^{\mathcal{I}} \boldsymbol{Q_i}\right)$, 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 $\sum_{i}^{\mathcal{I}} \mathcal{K}_i - \left(\sum_{i}^{\mathcal{I}} \boldsymbol{Q_i}\right)_{\mathbf{1}}$ and $\sum_{j}^{\mathcal{J}} \mathcal{K}_j - \left(\sum_{j}^{\mathcal{J}} \boldsymbol{Q_j}\right)_{\mathbf{1}}$. Similarly, the remaining capacity after the $\boldsymbol{r^{th}}$ freight forwarder is $\sum_{i}^{\mathcal{I}} \mathcal{K}_i - \sum_{f=1}^{r}\left(\sum_{i}^{\mathcal{I}} \boldsymbol{Q_i}\right)_{f}$ 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**.** ■

In the negotiation process, the freight forwarder starts with incomplete information because the airline does not show the complete offer at the beginning of the game. Moreover, the freight forwarder $\boldsymbol{f_r}$ has no idea about the current capacity situation after the preceding forwarders' allocations. In this regard, the airline and the freight forwarders negotiate the reservation quantities in the hot-selling and underutilized routes. Both players want to gain maximum profits from getting the best capacity allocation in the unbalanced routes. The airline starts the game with no incentives to the freight forwarder, hoping that they will get the maximum payoffs from the negotiation in the first phase. Therefore, the game in **phase I** is basic in the hot-selling and the underutilized routes.

6.3.1 Phase I - No incentives

Suppose 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

$$\left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q_{fi}})\right]\right)_{\boldsymbol{w}} = (p_i - w_i)\boldsymbol{Q_{fi}} - (p_i + v_i)\int_0^{\boldsymbol{Q_{fi}}} F(x_i)dx_i \tag{6-1}$$

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-contract method is used, See equation (6-2):

$$\left(E\left[\Pi_{\mathfrak{F}}\left(\boldsymbol{Q}_{\mathfrak{f}\jmath}\right)\right]\right)_{\mathcal{O}} = \left(p_{\jmath} - \Omega_{\jmath} - e_{\jmath}\right)\boldsymbol{Q}_{\mathfrak{f}\jmath} - \left(p_{\jmath} - e_{\jmath}\right)\int_{0}^{\boldsymbol{Q}_{\mathfrak{f}\jmath}} F(x_{\jmath})dx_{\jmath} \tag{6-2}$$

Equations (6-1), (6-2) lead to the following corollary:

Corollary 6-1 *The expected profit of the freight forwarder in* $\mathfrak{F}$ *is estimated by equation* (6-3)

$$E\left[\Pi_{\mathfrak{F}}\left(\boldsymbol{Q}_{\mathfrak{f}\imath}, \boldsymbol{Q}_{\mathfrak{f}\jmath}\right)\right] = \left(E\left[\Pi_{\mathfrak{F}}\left(\boldsymbol{Q}_{\mathfrak{f}\imath}\right)\right]\right)_{\mathfrak{w}} + \left(E\left[\Pi_{\mathfrak{F}}\left(\boldsymbol{Q}_{\mathfrak{f}\jmath}\right)\right]\right)_{\mathcal{O}} \tag{6-3}$$

Corollary 6-1 states that the freight forwarder's overall expected profit is the total of two sums; first, the sum of profits from selling quantities $\sum_{\imath}^{\mathcal{I}} \boldsymbol{Q}_{\imath}$ in the hot-selling routes by wholesale contract. Second, the sum of profits from selling quantities $\sum_{\jmath}^{\mathcal{J}} \boldsymbol{Q}_{\jmath}$ from the underutilized routes by option-contract.

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 cargo space from the underutilized routes and the hot-selling routes. Therefore, the following proposition describes this condition.

Proposition 6-1 *The optimum quantity for freight forwarder* $\mathfrak{f}$ *from the hot-selling can be obtained from the following the* ***balance ratio***

$$\boldsymbol{\alpha}_{\mathfrak{f}}^{*} = \frac{\boldsymbol{F}\left(\overline{\boldsymbol{Q}}_{\mathfrak{f}\imath}\right)(p_{\imath} + v_{\imath}) + \boldsymbol{F}\left(\overline{\boldsymbol{Q}}_{\mathfrak{f}\jmath}\right)\left(p_{\jmath} - e_{\jmath}\right) - (p_{\imath} - w_{\imath})}{\left(p_{\jmath} - \Omega_{\jmath} - e_{\jmath}\right)} \tag{6-4}$$

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

Proof Equations (6-1) and (6-2) are derived from the following two equations which are used to solve the wholesale and the option-contracts for the freight forwarder side respectively:

$$\max_{Q_{fi} \geq 0} \left(E\left[\Pi_{\mathfrak{F}}(Q_{fi})\right]\right)_{\mathfrak{w}} = E\left[p_i \min\{Q_{fi}, x_i\} - w_i Q_{fi} - v_i\{Q_{fi} - x_i\}^{+}\right] \quad (6\text{-}5)$$

, and

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

Further, from **Corollary 6-1**, the overall expected profit can be obtained in Equation (6-7)

$$\begin{aligned} &E\left[\Pi_{\mathfrak{F}}(Q_{fi}, Q_{fj})\right] \\ &= (p_i - w_i)Q_i - (p_i + v_i)\int_0^{Q_i} F(x_i)dx_i \\ &+ (p_j - \Omega_j - e_j)Q_j - (p_j - e_j)\int_0^{Q_j} F(x_j)dx_j \end{aligned} \quad (6\text{-}7)$$

It is assumed that the airline and each freight forwarder are able to reach an agreement on condition that the airline gives the freight forwarder an amount in the underutilized routes proportional to the quantity of the hot-selling routes. Equation (6-8) defines the relation

$$\therefore Q_j \propto Q_i \qquad \therefore Q_j = \alpha_i Q_i \text{ such that } 0 \leq \alpha_i \leq 1 \quad (6\text{-}8)$$

By substituting (6-8) in (6-7), the overall expected profit becomes a function of hot-selling quantity Q_i. Additionally, it is easy to prove that equation (6-7) is concave (Zhao et al., 2010). Consequently, the maximum expected profit of the freight forwarder is obtainable when the partial derivative of equation (6-7) w.r.t the hot-selling quantity equals zero, and so, the value α_f^* is obtained and the forwarder will be satisfied. ■

Indeed, it can be said that the solution in **Proposition 5-1** is realistic. In real life, individual customers send their parcels, packages and cargo 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 cargo 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 assigning routes is achievable by negotiation between the freight forwarders and the airline.

The airline 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;

$$\left(E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}j}\right)\right]\right)_{\boldsymbol{O}} = \left(\Omega_j + e_j - C_j\right)\boldsymbol{Q}_{\mathfrak{A}j} - \left(e_j + s_j\right)\int_0^{\boldsymbol{Q}_{\mathfrak{A}j}} F(x_j)dx_j \tag{6-9}$$

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

$$(E[\Pi_{\mathfrak{A}}(\boldsymbol{Q}_{\mathfrak{A}i})])_{\mathfrak{w}} = (w_i - C_i)\boldsymbol{Q}_{\mathfrak{A}i} - w_i\int_0^{\boldsymbol{Q}_{\mathfrak{A}i}} F(x_i)dx_i \tag{6-10}$$

Equations (6-9) and (6-10) bring to the fore **corollary 6-2**, which gives the airline possible profit from the hot-selling and the underutilized routes.

Corollary 6-2 *The overall expected profit of the airline is the total of two sums; first, the sold quantities of the cargo 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.*

$$E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}i}, \boldsymbol{Q}_{\mathfrak{A}j}\right)\right] = (E[\Pi_{\mathfrak{A}}(\boldsymbol{Q}_{\mathfrak{A}i})])_{\mathfrak{w}} + \left(E\left[\Pi_{\mathfrak{A}}\left(\boldsymbol{Q}_{\mathfrak{A}j}\right)\right]\right)_{\boldsymbol{O}} \tag{6-11}$$

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

Proposition 6-2 *The optimum quantity of the airline from the hot-selling can be obtained from the following formula:*

$$\alpha_{\mathfrak{A}}{}^{*} = \frac{w_i F(\bar{Q}_{\mathfrak{A}i}) + F(\bar{Q}_{\mathfrak{A}j})(e_j + s_j) - (w_i - C_i)}{(\Omega_j + e_j - C_j)} \quad (6\text{-}12)$$

, 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 cargo space quantities in the hot-selling routes; 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 6-1*, and it is compatible with the model of Feng et al. (2015a).

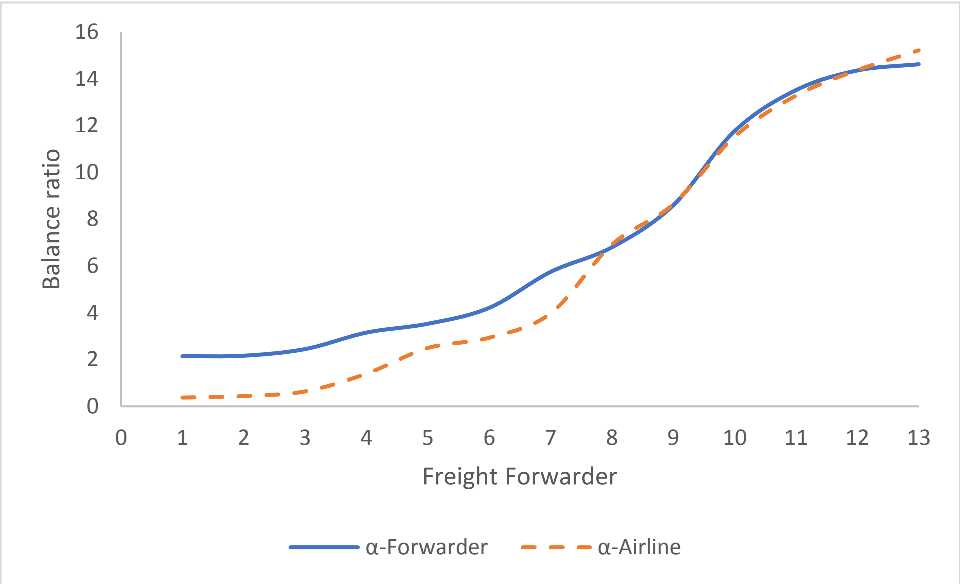


Figure 6-1 The airline and freight forwarders[8] balance ratios

The proof of **Proposition 6-2** is similar to **Proposition 6-1.** Moreover, **Proposition 6-1** and **Proposition 6-2** result in a new proposition which describes the relationship between the two types of routes.

[8] The freight forwarders are arranged ascendingly according to the orders from the hot-selling routes.

Proposition 6-3 *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. Thus, the cargo quantities allocated to the underutilized routes follow the self-replicating distributions such as normal, gamma and exponential distribution.*

$$F\left(\boldsymbol{Q}_j{}^*\right) = \{A\, F(\boldsymbol{Q}_i{}^*) + B\}^+ \tag{6-13}$$

, where

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

, and

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

Proof In real practice, the freight forwarders go to the airline individually to reserve the quantity of cargo space in the different routes through negotiation. Usually, the forwarder requests higher quantities of cargo 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 6-1** for the freight forwarder, and in **Proposition 6-2** for the airline. Therefore, the baragining equilibrium can be achieved when $\boldsymbol{\alpha}_{\mathfrak{A}i}{}^* = \boldsymbol{\alpha}_{\mathfrak{f}i}{}^*$**.** Therefore, the freight forwarder and the airline agree on the quantites allocated to underuilized routes, following from equation (6-13). Furthermore, 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 holds only when the demand follows self-replicated probabilty distribtutions. ■

The statement in **Proposition 6-3** proves the flexibility and validity of the model to the real market, where it is flexible enough to the freight forwarder to get an allocation in the hot-selling , if and only if, the freight forwarder orders a quantity of,

$$\boldsymbol{Q}_i{}^{**} = F^{-1}\left\{\frac{(w_i - C_i)(p_j - \Omega_j - e_j) - (p_i - w_i)(\Omega_j + e_j - C_j)}{(p_i + v_i)(\Omega_j + e_j - C_j) - w_i(p_j - \Omega_j - e_j)}\right\}^+ \quad (6\text{-}14)$$

, and the capacity is large enough, and in this case, the freight forwarder is considered as the airline's strategic partner. Moreover, **Proposition 6-3** and **Lemma 6-1** affirm that the allocated cargo in the underutilized routes increases with the increase in the freight forwarder's order in the hot-selling routes as shown in *Figure 6-2*. However, the increase is not strictly dominating because the model also considers the high demand to the forwarder and considers the negotiation power. Thus, adding to **Lemma 6-1**, the airline should give-up the negotiation power from the decreased capacity to the potential freight forwarders.

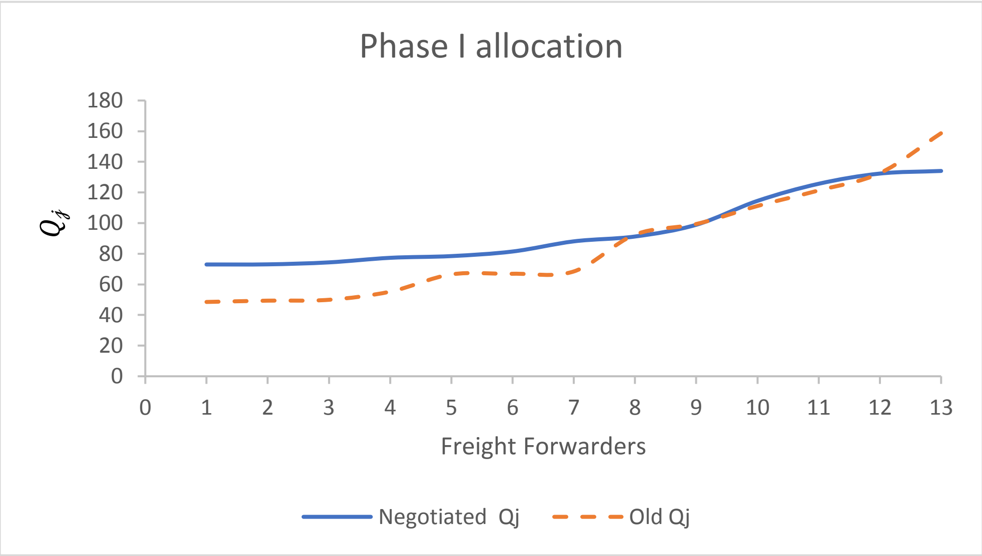


Figure 6-2 Allocation from negotiated allocation vs. the old allocation[9]

[9] This data is extracted from Feng et al. (2015a).

On the other hand, the airline is concerned that the freight forwarders have no penalties upon canceling the booking in the underutilized routes. This means that the airline may experience the underutilization problem because of the cancellations and the no shows. Consequently, our model tackles this issue, i.e. the airline is the only party who knows the routes capacity condition, and it can allocate an amount $F^{-1}(B)$ to the late-freight forwarder in the underutilized routes. At the same time, the allocation of late-freight forwarder in the hot-selling routes is zero. Therefore, the airline's overall allocation of the underutilized routes is $\sum_{j}^{J} \mathcal{K}_j + [F^{-1}(B)\ ]_{F(\boldsymbol{Q}_i)=0}$. See *Figure 6-3*.

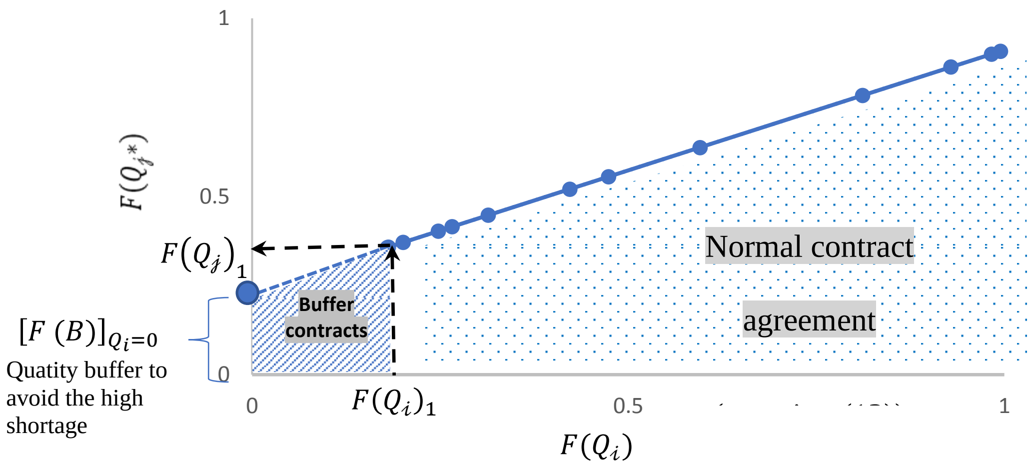


Figure 6-3 The new allocation of the underutilized routes w.r.t the hot-selling route.

Regarding the cooperation between the airline and the freight forwarder, fixing the imbalance among the underutilized and hot-selling routes can be achieved according to the following theorem:

Theorem 6-1 *In the cooperative game formed between the airline and the freight forwarder, the two parties need to give up some of their profit in the two types of route, i.e. the freight forwarder needs to commit to giving up a small share of the profit in some routes to obtain a better allocation on this route while the airline commits to giving up a small share of profit on the substituting route to make a better mixed allocation in the underutilized and hot-selling* *routes. This leads to a **Profit balance** between the airline and the freight forwarder, leading to reach an agreement.*

Proof The optimum allocation quantity of the underutilized routes is the inverse of the cumulative function scaled by A and relocated to position B. To maintain the property that

$1 \geq F(Q) \geq 0$; A and B values may have two different combinations:

- $A = \{a: a < 0\}$, and $B = \{b: b > 0\}$.
- $A \geq 0$, and $0 \leq B \leq 1$.

In the first combination, either the numerator or the denominator in A must be negative, but not both. However, the negative value of the denominator does not make sense because it is completley composed of the underutilized routes variables and it should be positive to avoid the losses in the undeutilized routes. Consequently, to obtain a negative value of A, the condition $\frac{(p_i+v_i)}{w_i} < \frac{(p_j-\Omega_j-e_j)}{(\Omega_j+e_j-C_j)}$ must be achieved. Moreover, since $p_i > w_i$, then $\frac{(p_i+v_i)}{w_i} > 1$**,** and hence the condition is achieved by $\frac{(p_j-\Omega_j-e_j)}{(\Omega_j+e_j-C_j)} < 1$, and thus, the first part in the theory holds. On the other hand, B is positive when $\frac{(w_i-C_i)}{(p_i-w_i)} > \frac{(\Omega_j+e_j-C_j)}{(p_j-\Omega_j-e_j)}$. This condition is achieved when $\frac{(w_i-C_i)}{(p_i-w_i)} > 1$, and thus, the second part of the theorem holds for this combination.

In the second condition, A is positive when $\frac{(p_j-\Omega_j-e_j)}{(\Omega_j+e_j-C_j)} > \frac{(p_i+v_i)}{w_i}$**,** and this only occurs when $\frac{(p_j-\Omega_j-e_j)}{(\Omega_j+e_j-C_j)} > 1$, which means that the airline unit profit is less than the freight forwarder's unit profit on the underutilized route. While, by holding that $\frac{(p_j-\Omega_j-e_j)}{(\Omega_j+e_j-C_j)} > 1$,the inequality $0 \leq B \leq 1$ is obtainable when $0 < \frac{(w_i-C_i)}{(p_i-w_i)} < 1$, which means that the airline unit profit is higher than the unit profit of the freight forwarder on the hot-selling routes. ■

Stopping the game in **phase I** involves two cases; first, the airline and the freight forwarder agree to the game results or the profit balance amounts. Second, they do not reach an agreement. As soon as the game in **phase I** stops between the airline and the freight forwarder $\mathscr{f}$, etiher by agreement or disagreement, the airline plays the game with a new freight fowarder in a new capacity and a higher negotaiton power. The game is repetitive along *n*-freight forwarders until the airline sells the full capacity on both the hot-selling and underutilized routes, or at least reaches an optimum balance for these routes. This gives the following lemma;

Lemma 6-2 *The game may stop in* **phase I***, if and only if*

i) *The n-freight forwarders are risk neutral;*

ii) *The first* $\mathscr{r}$*-freight forwarder agree to buy the quantities of*

$$\sum_{\mathscr{f}=1}^{\mathscr{r}}\left(\sum_{\mathscr{i}=1}^{\mathscr{I}}(\boldsymbol{Q}_{\mathscr{i}})\right) = \sum_{\mathscr{i}}^{\mathscr{I}}\mathcal{K}_{\mathscr{i}}, \textit{ and}$$
$$\sum_{\mathscr{f}=1}^{\mathscr{r}}\left(\sum_{\mathscr{j}=1}^{\mathscr{J}}(\boldsymbol{Q}_{\mathscr{j}})\right) = \sum_{\mathscr{j}}^{\mathscr{J}}\mathcal{K}_{\mathscr{j}} + [F^{-1}\{B\}^{+}]_{F(\boldsymbol{Q}_{\mathscr{i}})=0} \quad (6\text{-}15)$$

for hot-selling and underutilized routes respectively.

Proof This lemma holds if one of the two items in (i) and (ii) is achieved. If (i) and (ii) are violated, then the airline and the freight forwarder cannot reach an agreement in **phase I**, so the airline moves to **phase II** with the same freight forwarder. The game starts with a risk-neutral airline and freight forwarders are expected to be a blend of risk neutral and risk-averse players. Since the game is sequential, it may happen that the first $\mathscr{r}$-freight forwarders are risk neutral. Consequently, each freight forwarder $\mathscr{f}$ purchases a quantity of $\sum_{\mathscr{i}=1}^{\mathscr{I}}(\boldsymbol{Q}_{\mathscr{i}})$, and $\sum_{\mathscr{j}=1}^{\mathscr{J}}(\boldsymbol{Q}_{\mathscr{j}})$ from the hot-selling and underutilized routes respectively. The airline continues to receive the booking requests of freight forwarders until they sell the full capacity $\sum_{\mathscr{i}}^{\mathscr{I}}\mathcal{K}_{\mathscr{i}}$ on hot-selling routes and the full capacity $\sum_{j}^{J} \mathcal{K}_{j}$ plus buffer $[F^{-1}(B)\ ]_{F(\boldsymbol{Q}_{i})=0}$ on the underutilized routes, as discussed in **proposition 6-3**, this may only occur in **phase I**. ■

Although the game needs a profit balance between the airline and the freight forwarders, the airline always has the higher negotiation power, and thus, has the ultimate choice to move from **phase I** to **phase II** or stop the game after **phase I**, either by an agreement or disagreement. However, this gives full power to the airline, and the freight forwarder may quit the game in **phase I**. There is a possibility that some freight forwarders are risk averse, i.e. they may not be willing to get the estimated cargo quantities for the underutilized routes. Consequently, they may leave the game and move to the airline's rival. In this regard, it is suggested that the airline should offer an incentive on the underutilized routes to overcome the risk aversion behaviour. In this situation, the airline moves from **phase I** to **phase II**.

6.3.2 Phase II – Buy-back incentives

In this phase, the airline proceeds to the next negotiation level in a cooperative game when the airline and a freight forwarder f cannot reach an agreement in **phase I**. The game rules in **phase I** continue to **phase II**, i.e., each freight forwarder plays the two-phase game only once, but they cannot renegotiate their quantities after **phase II**. The movement from **phase I** to **phase II** relies on the efficiency of the freight forwarder f in negotiation. If it is an inevitable consequence to move to **phase II**, the airline should try to cope with the risk-averse forwarders. Buy-back policy is one of the tools used in the literature to cope with the risk aversion behaviour (Nagarajan & Sosic, 2008). This policy has been adopted in **phase II** to deal with the risk-averse freight forwarders.

The buy-back policy in **phase II** is involved in the positive and negative demand-capacity gaps or hot-selling and underutilized routes. In the hot-selling routes, the airline offers a buy-back for each freight forwarder at a value b_i for each unit of the unsold cargo quantity such that

$b_i < w_i < p_i$,moreover, b_j is the buy-back value for each unsold cargo unit in the underutilized routes such that $b_j < \Omega_j < e_j < w_i$. In this regard, the freight forwarder's expected profit in **phase II** from the wholesale contract $\bar{\mathfrak{w}}$ is,

$$\left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q}_{\mathfrak{f}j})\right]\right)_{\bar{\mathfrak{w}}} = (p_i - w_i)\boldsymbol{Q}_{\mathfrak{f}j} - (p_i - b_i + v_i)\int_{\mathbf{0}}^{\boldsymbol{Q}_{\mathfrak{f}j}} \boldsymbol{F}(x_i)dx_i \quad (6\text{-}16)$$

on the hot-selling routes under wholesale price w_i, and the expected forwarders profit on the underutilized routes under the option-contract $\bar{\mathcal{O}}$ is,

$$\left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q}_{\mathfrak{f}j})\right]\right)_{\bar{\mathcal{O}}} = \left(p_j - \Omega_j - e_j\right)\boldsymbol{Q}_{\boldsymbol{i}} - \left(p_j - e_j - b_j\right)\int_{0}^{\boldsymbol{Q}_j} \boldsymbol{F}(x_j)dx_j \quad (6\text{-}17)$$

Similar to **Corollary 6-2**, **Corollary 6-3** can be expressed as follows:

Corollary 6-3 *The expected profit of the freight forwarder $\mathfrak{F}$ is estimated by equation (6-18),*

$$E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q}_{\mathfrak{f}i}, \boldsymbol{Q}_{\mathfrak{f}j})\right] = \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q}_{\mathfrak{f}i})\right]\right)_{\bar{\mathfrak{w}}} + \left(E\left[\Pi_{\mathfrak{F}}(\boldsymbol{Q}_{\mathfrak{f}j})\right]\right)_{\bar{\mathcal{O}}} \quad (6\text{-}18)$$

In this corollary, the overall expected profit of a freight forwarder is the sum of the expected profit based-buy-back from the hot-selling routes which is obtained from the wholesale contract and the expected profit-based-buy-back from the underutilized routes which is estimated from the option-contract. It is worth noting that the expected profit of the freight forwarder changes from **phase I** and it cancels out the **phase I** results. Thus, the expected profit in **phase II** differs from the expected profit from **phase I**; consequently, the optimal allocation for the two parties' changes. This change is described in **Proposition 6-4** which defines the new allocation ratio based on the use of the buy-back policy in **phase II**.

Proposition 6-4 *The freight forwarder balance ratio from the underutilized routes with respect to the priority of the optimal allocation of the hot-selling routes is obtained through,*

$$\boldsymbol{\alpha}_{\boldsymbol{\mathfrak{f}}}{}^{**} = \frac{(p_i - b_i + v_i)\boldsymbol{F}\left(\overline{\overline{\boldsymbol{Q}}}_{\boldsymbol{\mathfrak{f}i}}\right) + \boldsymbol{F}\left(\overline{\overline{\boldsymbol{Q}}}_{\boldsymbol{\mathfrak{f}j}}\right)\left(p_j - e_j - b_j\right) - (p_i - w_i)}{\left(p_j - \Omega_j - e_j\right)}$$

Proof This is similar to **Proposition 6-1**.

Since the airline plays the same game in **phase II**, the game has a similar objective, but with different game inputs and rationalities. Consequently, the output of the game also changes for the airline. Again, the airline sets its own optimal quantities. Therefore, the airline's optimal balance ratio, which is used to estimate the underutilized route from the optimum hot-selling routes allocation, is:

$$\boldsymbol{\alpha}_{\boldsymbol{\mathfrak{U}}}{}^{**} = \frac{(w_i + b_i + s_i)\boldsymbol{F}\left(\overline{\overline{\boldsymbol{Q}}}_{\boldsymbol{\mathfrak{U}i}}\right) + \left(e_j + b_j\right)\boldsymbol{F}\left(\overline{\overline{\boldsymbol{Q}}}_{\boldsymbol{\mathfrak{U}j}}\right) - (w_i - C_i)}{\left(\Omega_j + e_j - C_j\right)} \qquad (6\text{-}19)$$

The buy-back value motivates the small forwarders to reset their own allocation balance ratio to be closer to the airlines' ratio. Moreover, if the airline keeps offering buy-back to the large sized freight forwarders, the forwarders may bet more quantity of cargo space on the underutilized routes so as to guarantee larger space on the hot-selling routes. Therefore, the larger forwarder's balance ratio exceeds the airline's value as shown in *Figure 6-4*.

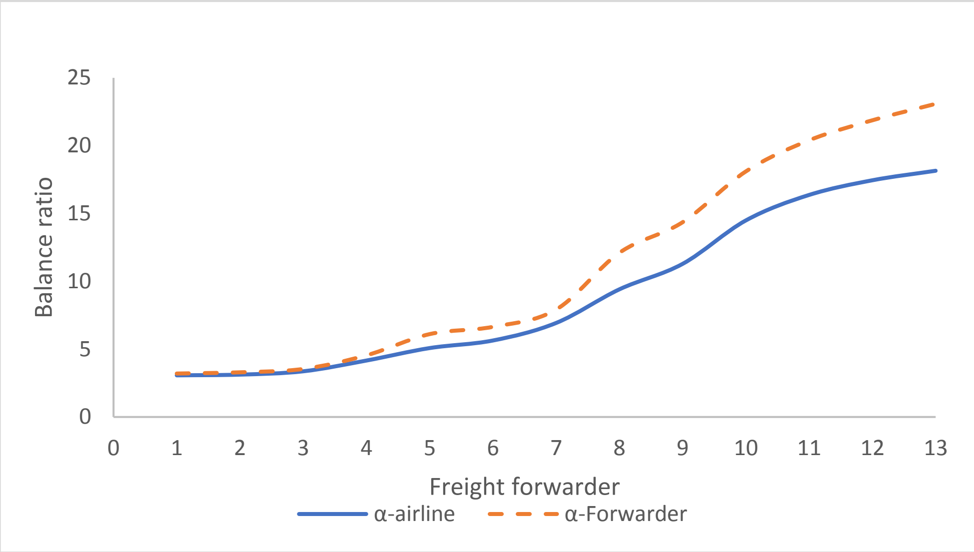


Figure 6-4 The allocation ratio behavior under buy-back policy in phase II

Similar to the **Proposition 6-3**, the quantity in the underutilized routes when applying incentives to the wholesale-option-contract is the inverse of the relocation of the scaled cumulative distribution of the allocated quantities to the hot-selling routes,

$$\widehat{\boldsymbol{Q}_j} = F^{-1}\{\hat{A}\, F(\boldsymbol{Q}_i{}^{*}) + \hat{B}\}^{+} \tag{6-20}$$

where,

$$\hat{A} = \frac{(p_i - b_i + v_i)(\Omega_j + e_j - C_j) - (w_i + b_i + s_i)(p_j - \Omega_j - e_j)}{(e_j + b_j)(p_j - \Omega_j - e_j) - (p_j - e_j - b_j)(\Omega_j + e_j - C_j)}$$

, and

$$\hat{B} = \frac{(w_i - C_i)(p_j - \Omega_j - e_j) - (p_i - w_i)(\Omega_j + e_j - C_j)}{(e_j + b_j)(p_j - \Omega_j - e_j) - (p_j - e_j - b_j)((\Omega_j + e_j - C_j)}$$

Furthermore, the strategic partner can get an allocation of,

$$\widehat{\boldsymbol{Q}_i}^{*} = F^{-1}\left\{\frac{(w_i - C_i)(p_j - \Omega_j - e_j) - (p_i - w_i)(\Omega_j + e_j - C_j)}{(p_i - b_i + v_i)(\Omega_j + e_j - C_j) - (w_i + b_i + s_i)(p_j - \Omega_j - e_j)}\right\}^{+}$$

When **phase I** and **phase II** allocation ratios are compared, it can be observed that the airline achieves better allocation balance between the underutilized routes and the hot-selling routes in **phase II** than in **phase I**. A numerical experiment based on **phase I** data was used to compare the results between the two phases. To avoid unreasonable results, b_i is selected less than the v_i, and more than s_i. Moreover, to avoid the high drop in the profit of the airline, it is assumed that $b_j < \Omega_j$. *Figure 6-5* shows that the allocated quantities on the underutilized routes from **phase II** is higher than the allocated quantities from **phase I**. Furthermore, the freight forwarder allocation increases with the increase in its ordered quantity of the freight space from the hot-selling routes. The interesting part in *Figure 6-5* is that the allocation of the smallest freight forwarder in **phase II** is less than its allocation in **phase I**. This may be attributed to the view that the small freight forwarder has very low negotiation power. Consequently, when this forwarder insists on taking the incentives (buy-back), the airline reduces its quantity in the underutilized routes because the profit that this freight forwarder gives up in the hot-selling routes may be less than the buy-back amount from the underutilized routes.

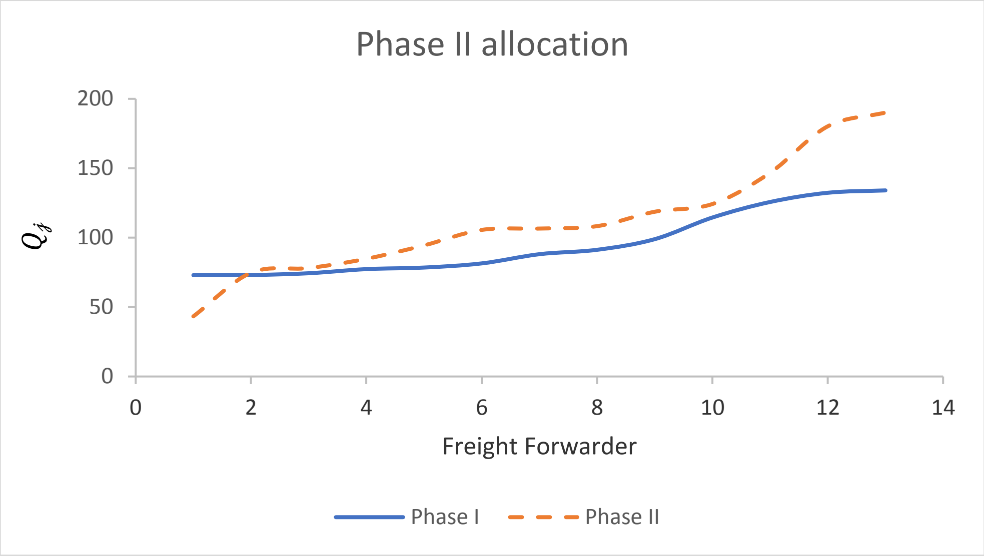


Figure 6-5 The difference between the phase I and phase II allocation in the underutilized allocation

6.4 Pure Wholesale Balancing Model

Because the airline has the full power to decide the contracting method to sell the cargo capacity, it may sell this capacity in wholesale price or in any other method. In this section, the airline adopts the wholesale price to sell the capacity on underutilized and hot-selling routes; hence, the freight forwarder's allocation ratio in wholesale price is,

$$\boldsymbol{\beta}_{\mathfrak{f}} = \frac{(p_i + v_i)\boldsymbol{F}(\boldsymbol{Q}_{\mathfrak{f}i}) + (p_j + v_j)\boldsymbol{F}(\boldsymbol{Q}_{\mathfrak{f}j}) - (p_i - w_i)}{(p_j - w_j)} \tag{6-21}$$

, and the airline allocation ratio is

$$\boldsymbol{\beta}_{\mathfrak{A}} = \frac{w_i\boldsymbol{F}(\boldsymbol{Q}_{\mathfrak{A}i}) + (w_j + s_j)\boldsymbol{F}(\boldsymbol{Q}_{\mathfrak{A}j}) - (w_i - C_i)}{(w_j - C_j)} \tag{6-22}$$

Hence, the optimal allocation for the underutilized routes when applying the wholesale contract to the underutilized and the hot-selling routes is described as follows:

$$(\boldsymbol{Q}_j{}^*)_{\hat{\mathfrak{w}}} == \boldsymbol{F}^{-1}\{A_{\mathfrak{w}}\boldsymbol{F}(\boldsymbol{Q}_i) + \boldsymbol{B}_{\mathfrak{w}}\}^+ \tag{6-23}$$

Where

$$A_{\hat{w}} = \frac{(p_i + v_i)(w_j - C_j) - w_i(p_j - w_j)}{(w_j + s_j)(p_j - w_j) - (p_j + v_j)(w_j - C_j)}$$

, and

$$B_{\hat{w}} = \frac{(w_i - C_i)(p_j - w_j) - (p_i - w_i)(w_j - C_j)}{(w_j + s_j)(p_j - w_j) - (p_j + v_j)(w_j - C_j)}$$

From the wholesale pricing contract properties, it is expected that the model will be advantageous to the airline rather than the freight forwarder, at least in the expected profit, regardless of the allocation balance. Conversely, the option-contract properties make the freight forwarder better-off, making it needful to study the pure option-contract model in order to ensure a fair comparison.

6.5 Pure Option Balancing Model

As mentioned in the literature review, several scholars adopted the option-contract to sell the cargo capacity to freight forwarders, but they used it only to sell the capacity, regardless of the route type. In this section, the option-contract is used to balance the demand-capacity gap between the substitutable routes. Hence, if the airline decided to adopt the option-contract to sell the capacity to freight forwarders on underutilized and hot-selling routes, the allocation ratio for the freight forwarder side would be:

$$(\boldsymbol{\gamma}_{f})_{\hat{o}} = \frac{(p_i - e_i)\boldsymbol{F}(\boldsymbol{Q}_{fi}) + \boldsymbol{F}(\boldsymbol{Q}_{fj})(p_j - e_j) - (p_i - \Omega_i - e_i)}{(p_j - \Omega_j - e_j)} \tag{6-24}$$

It is reasonable that the option-contract favours the freight forwarders because they do not incur any penalties in this contractual agreement. The option-contract is not very attractive to the airline because the solution of the imbalance problem is more challenging under this type of contract. The airline is exposed to shortage in the underutilized routes again. With shortage cost s_j on the underutilized routes, the airline allocation ratio is:

$$(\boldsymbol{\gamma}_{\mathfrak{U}})_{\hat{O}} = \frac{e_i \boldsymbol{F}(\bar{\bar{\boldsymbol{Q}}}_{\mathfrak{U}i}) + (e_j + s_j)\boldsymbol{F}(\bar{\bar{\boldsymbol{Q}}}_{\mathfrak{U}j}) - (\Omega_i + e_i - C_i)}{(\Omega_j + e_j - C_j)} \tag{6-25}$$

Thus, the optimal allocation of underutilized routes in the pure option-contract is a linear function of the positive route allocation and the equation coefficients are a function of the option and exercise prices as well as the shortage cost on the hot-selling and underutilized routes.

$$(\boldsymbol{Q}_j^{\;**})_{\hat{O}} = \boldsymbol{F}^{-1}\{A_O \boldsymbol{F}(\boldsymbol{Q}_i) + \boldsymbol{B}_O\}^{+} \tag{6-26}$$

Where,

$$\boldsymbol{A}_{\hat{O}} = \frac{(p_i - e_i)(\Omega_j + e_j - C_j) - e_j(p_j - \Omega_j - e_j)}{(e_j + s_j)(p_j - \Omega_j - e_j) - (p_j - e_j)(\Omega_j + e_j - C_j)}$$

, and

$$\boldsymbol{B}_{\hat{O}} = \frac{(p_i - \Omega_i - e_i)(\Omega_j + e_j - C_j) - (\Omega_i + e_i - C_i)(p_j - \Omega_j - e_j)}{(e_j + s_j)(p_j - \Omega_j - e_j) - (p_j - e_j)(\Omega_j + e_j - C_j)}$$

6.6 Numerical Analyses

The three models above are demonstrated in a numerical example and the implementation is performed on one airline and 13 freight forwarders using the data extracted from (Feng et al., 2015a). In this example, the fixed capacities of the hot-selling and underutilized routes are 2878 tonnes and 2789 tonnes respectively. Moreover, it is considered that the cargo prices on the underutilized and hot-selling routes are fixed and the quantities on the underutilized routes vis-à-vis the hot-selling cargo routes are varied. First, the two-phase mixed wholesale-option-contract game is examined. In **phase I**, the airline sells the capacity for the hot-selling route at a uniform wholesale price US$ 621.9/tonne. Based on the model of Tao et al. (2017) who used optioning in the cargo reservation prices, it is found that the airline can offer the capacity for the underutilized route for reservation at an option price of US$ 25/tonne. Moreover, the freight forwarders execute the actual demand at maximum exercise price US$530 per tonne of the actual demand. The freight forwarders selling prices are US$ 672, US$ 643 for each tonne of the hot-selling and underutilized routes respectively.

Regarding the costs of each player, the airline incurs fixed marginal operating costs of US$ 430 per tonne, and US$ 480 per tonne on the hot-selling and underutilized routes respectively. Furthermore, the airline's shortage cost on the underutilized route is US$200/tonne while the freight forwarders incur a leftover cost US$ 560/tonne. On the other hand, in **phase II**, the buy-back values for both route types are added to the costs of airline, where the unit buy-back values are US$ 510 and US$ 24.5/tonne on the hot-selling and underutilized routes respectively. Second, the data in the pure wholesale balancing and pure option balancing contracts are shown in *Table 6-1*.

Table 6-1 The input parameters of the wholesale and the option models

Variables	Wholesale model (US$/tonne)	Option model (US$/tonne)
p_i	672	672
p_j	643	643
w_i	621.9	-
w_j	612.6	-
C_i	430	430
C_j	480	480
Ω_i	-	40
Ω_j	-	25
e_i	-	560
e_j	-	530
s_j	200	200
v_j	560	-

The common parameters between the pure wholesale and the pure option model are the freight forwarder's selling price and the airline's costs for the underutilized and hot-selling routes. Additionally, there is a possibility that the airline incurs shortage cost s_j on the underutilized routes in both models. The difference in the wholesale and the option models can be seen in the freight forwarders' leftover cost v_j on the underutilized routes.

The allocation process was performed on the three models – the mixed wholesale option-model, the pure wholesale model, and the pure option-contract model. *Table 6-2* summarizes the allocation results from the three models for the underutilized and the hot-selling routes. The allocation results reveal that the mixed model of wholesale-option-contract model gives the highest possible allocations in the underutilized quantities. This shows the advantage of using flexible contracts to sell the different routes to the same destination. Also, taking advantage of the wholesale contract encourages freight forwarders to use the actual demand in order to avoid high leftover costs. Further, the adoption of the option-contract motivates the freight forwarders to bet on low option prices so as to get more space subsequent to which they execute the quantity according to their actual demand, thereby reducing their losses. The freight forwarders' incentives increase when the airline uses the buy-back in **phase II**; therefore, the allocation balancing in **Phase II** improves.

The pure wholesale and the pure option models give almost similar allocation results. The freight forwarder is indifferent to the hot-selling and the underutilized routes, and will, thus, prefer to put most of their demand on the hot-selling routes so as to compete for space.

Table 6-2 Capacity allocation results (in tonne) from the three models

No.	***Forwarder request***		***Mixed wholesale-option model***				***Wholesale model***		***Option model***	
			phase I		phase II					
	Underutilized route	**Hot-selling route**	**Underutilized route**	**Hot-selling route**	**Underutilized route**	**Hot-selling route**	**Underutilized route**	**Hot-selling route**	**Underutilized route**	**Hot-selling route**
1	48.529	14.657	72.986	0	43.3319	19.8541	56.73912	6.44688	60.84504	2.340961
2	49.365	15.52	73.066	0	74.70423	0	56.87818	8.006818	60.96463	3.920375
3	49.923	29.027	74.352	4.597617	78.10303	0.846965	59.07389	19.87611	62.86535	16.08465
4	55.234	58.055	77.332	35.95708	84.76306	28.52594	63.8989	49.3901	67.11642	46.17258
5	66.508	68.401	78.46003	56.44897	94.43128	40.47772	65.64766	69.26134	68.67914	66.22986
6	66.923	94.555	81.451	80.02681	105.5738	55.90421	70.12117	91.35683	72.72125	88.75675
7	68.438	148.011	88.078	128.3714	106.5428	109.9062	79.42017	137.0288	81.28186	135.1671
8	92.468	172.153	91.237	173.3836	108.2912	156.3298	83.65296	180.968	85.22911	179.3919
9	99.397	229.058	98.901	229.5536	118.6558	209.7992	93.60999	234.845	94.58642	233.8686
10	111.157	348.041	114.494	344.704	124.2134	334.9846	113.5846	345.6134	113.384	345.814
11	121.313	456.679	125.671	452.3206	146.7178	431.2742	128.979	449.013	127.496	450.496
12	132.624	577.387	132.319	577.6925	180.1751	529.8359	139.633	570.378	136.7315	573.2795
13	158.682	662.457	134.033	687.106	190.0861	631.0529	142.7653	678.3737	139.3084	681.8306
Total	1120.561	2874.001	1242.381	2770.162	1455.589*	2548.792*	1159.105	2830.058	1171.209	2823.353

Regarding the profits, it is not surprising that the airline's profits differ among the three models. Furthermore, the results show that the maximum benefit of the airline is achievable from the wholesale model. This result is compatible with Zhao et al. (2010) and supports our claim that the wholesale contract is the best for the airline. However, this may affect the freight forwarder's willingness to buy capacity from the airline. On the contrary, the option-contract model provides the minimum expected profit among the three models. This is because the option-contract is more advantageous to the freight forwarder than the airline (Zhao et al., 2010). See *Table 6-3.*

Table 6-3 Airline profit in (US$) from the three models

	Mixed model	*Wholesale model*	*Option model*
Hot-selling route	516653	523914	466018
Underutilized route	107319	138771	87841
Total	**623972 ***	**662685****	553858

Finally, the mixed wholesale-option model strikes a balance between the profits and the allocation, i.e. the model gives the highest allocation on the underutilized routes, but with 5% less profit than the profit of the wholesale model.

6.7 Managerial Implications

Although the airline in this game is considered as risk-neutral, applying buy-back prices for underutilized routes has a trade-off. This trade-off appears clearly when the freight forwarders collude to enforce the airline to move to **phase II**. Consequently, the airline may experience large amount of buy-back. Moreover, this solution may result in an inaccurate capacity allocation on the underutilized routes. On the other hand, if the airline stops the game in **phase I**, regardless of the forwarder risk behaviour, the company will incur shortage costs due to the unused spaces on the underutilized routes. Further, the airline may lose the opportunity to increase the profits from the possible capacity sales when implementing the buy-back policy.

Based on Xue et al. (2018) study, the buy-back policy will upsurge the competition among the freight forwarders. This may lead them to cheat in order to obtain more space on the hot-selling routes and guarantee them a buy-back on the underutilized routes. Therefore, the airline should think of imposing a penalty on the hot-selling routes if the forwarder is not able to fill the reserved capacity in the contract before flight departure.

As shown in the pure wholesale model, the use of wholesale price to sell the capacity to the freight forwarder is valuable to the airline. Nevertheless, this is not the best solution for the airline and the freight forwarders. It gives the maximum profit to the airline but contradicts the game rules. From **Theorem 6-1** , it has been established that the game uses the profit balance between the airline and the freight forwarder to solve the imbalance among the substitutable routes. This requires one party to give up some profits on a certain route and another to give up some profits on the substituting route. Although the airline does not commit to this rule in the pure wholesale model, the airline tries to maximize its profits regardless of the freight forwarders' profit margin, and thus, the freight forwarders' easiest solution is to go to the airline's rivals. On the contrary, the pure option-contract model offers the lowest allocation and profits to the airline which means that airline power is not used effectively. Finally, the mixed wholesale-option contract model is the most effective of the three models. It optimizes profit sharing and, thus, reduces the double marginalization effect which takes place when the hot-selling routes and the underutilized routes are combined (Vafa Arani et al., 2016).

6.8 Summary

In this chapter, the demand-capacity gaps between the hot-selling and the underutilized cargo routes were discussed. The existence of these two situations in the substitutable routes caused an imbalance problem to an airline. Consequently, a mixed whole-sale-option-contracting model is developed in a theoretic game form between a single airline and multiple freight forwarders to solve this problem. The model takes advantage of the airline power to adopt a wholesale contract for selling the hot-selling routes, while the option-contract is used to sell the underutilized routes to motivate freight forwarders to buy larger quantities.

The proposed model assumes that the airline and the freight forwarders can agree to allocate an amount on the underutilized routes proportional to their ordered cargo space on the hot-selling routes. The game in the mixed wholesale-option-contract model is played in two phases. In **phase I**, the airline tries to reach an agreement with the freight forwarder without incurring any buy-back values to the freight forwarders. In **phase II**, the airline considers the risk-aversion of freight forwarders by offering a buy-back policy. It was shown that it is important for the airline and the freight forwarders to give up some of their profits on the different routes in order to reach an acceptable agreement.

The model was also compared with pure wholesale and pure option-contract models. Further, the numerical example revealed that the mixed wholesale-option-contract model gives the highest allocation on the underutilized routes among the pure wholesale and the option-contract models. Moreover, the airline's profits from the mixed model were higher than the profits made using the pure option model. The wholesale model gave the greatest profit to the airline; however, the adoption of this model may negatively affect the freight forwarders who may stop the game in disagreement.

Chapter 7 Conclusions and Future Directions

This chapter briefly summarizes the research background, objectives and the work done in all of the previous chapters. Also, the research findings and contributions are outlined. Then, the limitations and the drawbacks of this study are highlighted. Finally, the possible future works to overcome these limitations and improve this study are presented.

7.1 Conclusions

Cargo capacity allocation in combination airlines has taken a complicated direction because of the lack of balance in cargo demand between different routes. These routes are classified into two categories; hot-selling-routes and underutilized routes. On this, airlines need to involve these two categories in one model when they sell capacities for both routes. In this research, three sequential models have been developed to cope with this problem. As it is found that most of the previous research focus on the hot-selling routes, the underutilized routes are considered in the first model. The second model includes the hot-selling and the underutilized routes in one model to make a proactive quantity plan for the airline. And lastly, the model has been upgraded to include the negotiation of freight forwarders with the airline in the contracting stage.

For underutilized routes, an extra-baggage scheme is proposed. The advantage of the proposed new service lies in the smoothness and ease of processing the extra-baggage. That is, the passenger gets to make his/her order himself/herself and bring his/her items directly to the flight. Consequently, complicated procedures are avoided as frequently happens in cargo services. Also, it is our position that there is a high likelihood that an airline that applies this new scheme will attract more passengers. The new scheme is likely to attract new customers, who need more space, while at the same time supporting its loyal customers. Eventually, The extra-baggage service is easy to be implemented because it does not need complex procedures compared to regular cargo services. Moreover, it is a profitable tool, so airlines should offer the proposed scheme to help in maximizing their profits.

Moreover, the price of the extra-baggage scheme is set with reference to cargo prices. The model is formulated by using the multi-item newsvendor model. It is concluded that the two-item newsvendor model can be used to set a new product and/or service price with reference to another product and/or service, provided that the two services and/or products share some common features and serve in the same market.

For the combined hot-selling and underutilized routes in the cargo capacity allocation, the Puppet-Cournot model is a proactive step which can be used by the airline as a preliminary stage to setting strategies for selling capacity. For example, there are different strategies to sell capacities on the hot-selling and underutilized routes, such as the pricing mechanism. This approach is expected to contribute to solving the price-demand change by the pre-estimation of the optimum freight quantities. This is because the Cournot model uses the price-based quantity, hence, price-demand sensitivity is already considered. Furthermore, a combinatorial auction is another option to solve the imbalance problem, and the model can help the carrier to set quantities on the hot-selling and the underutilized routes. These can be used as a reference for the accepted auctions. In addition, the combination of the hot-selling and the underutilized quantities from this model can be used as a reference for the carrier when they negotiate quantity booking on the two routes.

Eventually, the negotiation between an airline and multiple freight forwarders is studied by a sequential cooperative game. The game payoffs are to maximize the profits. The profits are determined from a mixed wholesale-option contracting model. Then, the capacity allocation and the profits are compared with the pure wholesale and pure hot-selling models. The results show that the mixed wholesale-option-contract model gives the highest allocation on the underutilized routes among the pure wholesale and the option-contract models. Moreover, the airline's profits from the mixed model are higher than the profits made using the pure option model. The wholesale model gives the greatest profit to the airline; however, the adoption of this model may negatively affect the freight forwarders who may stop the game due to disagreement.

7.2 Limitations of the Research

The limitations of this research can be outlined as follows:

- Although the extra-baggage scheme is considered as a special cargo service, a market study may give a better outlook in proving the readiness of customers to accept the new scheme. As the new scheme would need more evidence to show its capability to give better belly-hold utilization. Moreover, once the data from the market study is collected, it is expected that the demand of the passengers would be a major factor in the extra-baggage pricing model, and it would give real and applicable results.
- The parameters used, according to extra-baggage model assumption, have a direct effect on the profit of the airline, if they are changed. For example, the assignment of a different type of aircraft affects the cost function, which leads to an indirect change in the profit of the flight. This profit change may be either increasing or decreasing.
- The Puppet-Cournot-Quantity Discount model is formulated in the deterministic routes' demand, although the demand of the air cargo is very random, and it changes rapidly. Formulating the demand in stochastic environment would give more realistic results. Moreover, although the quantity discount policy is very popular incentive, it is not always applicable when solving the demand imbalance problem. Therefore, it would be better to find another incentive to overcome the quantity discount limitations.

- The models in Chapters 4 and 5 are built with fixed prices to set the allocation balance quantities between the hot-selling routes and the underutilized routes. It is suggested that joint prices and quantities are also modelled.
- All of the models in this research project have been formulated in a single period domain. As it is mentioned above, airlines offer the capacity for selling twelve months before the departure of the flight. Researchers divided booking horizon into guaranteed or long-term contracts, medium-term contracts and dynamic prices, and spot market with free sales. In this regard, the first model tackled the spot market to sell the extra-baggage for passengers, however, it would better to use the dynamic domain to avoid overlap between the hot-selling and the underutilized routes when passengers order extra-baggage in the hot-selling routes. On the other hand, the next two models deal with the guaranteed contracts, but because freight forwarders arrive sequentially, airlines could increase their profit by implementing dynamic domain during the negotiation process.
- Although the models give solutions for the demand imbalance between the hot-selling and the underutilized routes, they have different challenges when they are implemented. The implementation challenges include the vast uncertainty of the cargo demand and the uncertainty factors which affect the decision of the carriers. For example, the fuel price is one of the main uncertainty factors which dominate the decision of the airline.
- This study investigates the demand imbalance between the different hot-selling and underutilized routes for a single origin-destination (O-D), whereas the problem can be between multiple O-D in the network. Therefore, the models in this research are not applicable to solve the demand imbalance between the hot-selling and underutilized routes which serve in different origin-destination (O-D).

7.3 Future Directions

- Further investigation in the future will involve conducting a market survey for the proposed extra-baggage scheme. The forecasting models by Li and Trani (2014); (Nieto & Carmona-Benítez, 2018) may be used as guidance studies for checking the validity of using the PAX numbers and the PAX demand as determinants of the extra-baggage demand. The next step will be conducting a market study for this extra-baggage scheme to investigate suitable price policies for the extra-baggage scheme and examine the effect of seasonality on the offered prices. Because the extra-baggage scheme has not yet adopted in the industry, thus its demand cannot be forecasted. Hence, it is necessary to deploy advanced statistical approaches and optimization techniques to tackle the problem of demand forecasting.
- Future studies can extend the insights discussed in this study by considering the joint determination of optimum prices and quantities. Moreover, the model was formulated in a single period; hence, future studies can make improvements to it by including dynamic pricing. Additionally, with more investigation, the game can be performed simultaneously if the airline collects the freight forwarders' orders and uses lexicographic, uniform, linear or proportional allocation.
- Regarding the discount factor, its values have a direct effect on changing the quantity combination between the two routes. Because the profit function is neither convex not concave in the discount factor, the optimum values of the quantity discount need further investigation in the future by using advanced optimization methods.

- The models were performed with fixed prices to set the allocation balance between the routes. Future studies can extend the insights discussed in this study by considering the joint determination of optimum prices and quantities. Moreover, the model was formulated in a single period; hence, future studies can make improvements to it by including dynamic pricing. Additionally, with more investigation, the game can be performed simultaneously if the airline collects the freight forwarders' orders and uses lexicographic, uniform, linear or proportional allocation.

- To solve the demand imbalance between the underutilized and the hot-selling routes which serve in different origins-destinations flights, it is suggested to study the possibility of making connection flights between the destinations.

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