Three Essays on Non-Price Competition

by

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Preface

The basis of this dissertation originally stemmed from my interest in studying the role of non-price competition among firms. Nowadays, as more consumers are no longer restricted by their financial conditions, competition among firms is more diversified. Firms do not confine themselves to the traditional price competition to maximize their profits. My interest is to discover how non-price factors, especially service, would affect the market equilibrium.

This thesis is comprised of three chapters. Chapter two and chapter three are solely authored by me. The first chapter is co-authored with my supervisor Zhiqi Chen. I was fully involved in and mainly contributed to the entire research process, including setting up and conducting the derivation, as well as the writing of the chapter. I hereby acknowledge the contributions of Zhiqi Chen for the research related to chapter one.
Abstract

This thesis is comprised of three chapters that examine aspects of non-price competition among firms. The first chapter theoretically studies the effects of exclusive dealing in the presence of service competition. In our model, retailers compete not only in price but also in service. We find that the adoption of exclusive dealing by upstream manufacturers induces the retailers to offer higher service levels than under common agency. Depending on consumers’ marginal valuation of service, the manufacturers may indeed adopt exclusive contracts in equilibrium.

The second and third chapters consider a specific aspect of services in airline industry, namely flight delays. Specifically, the second chapter analyzes the flight delay impact on equilibrium airfare and passenger volume in metropolitan and secondary airport market in the United States. Using quarterly data from 2013 to 2019, we find that delay is more likely to increase the airfare of connecting flights in metropolitan markets and reduce the price of direct flights in less busy routes. Passenger volumes between metropolises may not be affected by delay, but secondary airport markets may lose passengers because of delay.

In the third chapter, we continue the study of the flight delay impact and explore the effect of flight delay on welfare. By using the three-stage least squares method to estimate a simultaneous equations system, we quantify the welfare change of both consumers and airlines in response to delay reduction. We find that existing passengers would substantially benefit from improvement of flights’ on-time performance, and airlines would mainly gain from increases in passenger volumes.
Acknowledgements

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Chapter 1: Exclusive Dealing and Non-price Competition

1.1 Introduction

A manufacturer engages in exclusive dealing when it restricts its retailer(s) from selling the products from his direct competitors. It is a common form of vertical restraints adopted in many markets. For example, when you order a meal in McDonald’s and decide cola as your drink, Coke becomes your only choice. Although there are many other kinds of beverages in McDonald’s, in the product line of fizzy cola, Coke is the only brand.\(^1\) Exclusive dealing is also widely applied in automobile industry, where most dealers sell vehicles of just one brand.

In early years, however, exclusive dealing was treated severely by the courts. One of the most well-known examples is the Standard Fashion (SF) Company case in 1922, where Standard, a dress pattern manufacturer, offered an exclusive contract to a retailer called Magrane-Houston and required the store not to sell patterns of other manufacturers. The contract was in the end struck down by the court based on the reason that it would foreclose the competitors in the resale market. Many economists complained that SF Company has been treated unfairly afterwards. Marvel (1982) argues that SF’s requirement of exclusion was a way to get compensation for its fashion investment. Moreover, after analyzing several historical cases, he concludes that exclusive contract is an efficient way for the manufacturers to protect their own rights, that is to recover their intangible capital investments. In fact, after the court’s decision, SF Company began to charge an up-front fee for the right to sell its patterns.

Consistent with Marvel’s opinion, Bork (1978) writes that exclusive dealing is appropriate to prevent cartels and horizontal mergers that create monopolies. He points out that any contract is agreed by both parties. A manufacturer never has the power to force a retailer’s response. A retailer, on the other hand, has its own right to either accept or reject the contract, and will only accept exclusivity when some extra benefits, such as

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\(^1\) This exclusive relationship between McDonald’s and Coca Cola dates back to 1955, when McDonald’s opened its first restaurant and the executives of both companies agreed to form an alliance (The Economist, 1998).
lower price or increased efficiencies, are offered by the upstream firm. After referring to historical cases, he concludes that exclusive contract intensifies competition and does not harm consumers thus should not be prohibited by the antitrust laws. The viewpoint that exclusive dealing is pro-competitive is supported by the Chicago School of antitrust analysis (Ponsner, 1979). It points out that while people, especially the courts, observe only potential monopolization in both upstream and downstream markets as a result of exclusive contract, they overlook the fact that in order to maintain such monopolization, the upstream firm has to face huge capital cost, which drives the decision away from the long run optimal point. A rational manufacturer will not behave in such way just for the purpose of erecting a “barrier to entry”: it costs more than the benefit it brings. Instead of a social evil, exclusive dealing is a social benefit because it saves consumer’s informational cost.

One assumption in the Chicago School analysis is that even if the upstream firm manages to control all the downstream retail channels, it cannot prohibit the entrant from opening its own channel at the cost no higher than the incumbent’s capital cost. Comanor and Frech (1985) challenge this assumption and considers an alternative situation where the cost of setting up a distribution channel is higher for an entrant. With such model construction, they overturn Bork’s conclusion and find that exclusive contract can be applied for anticompetitive purposes. The anticompetitive effects may arise despite the efficiency rationale for exclusive dealing stated by Marvel (1982). Depending on the gap between distribution costs, the loss in consumer’s surplus may exceed the increase in producer’s profits, which eventually makes exclusive dealing socially harmful.

A key assumption in Comanor and Frech (1985) is that exclusive dealing raises the cost of entry. Later work by Segal and Whinston (2000) shows that even when the entry cost remains the same, exclusive contract can still have the effect of entry deterrence. When there exists a fixed entry cost, the upstream incumbent can sign exclusive contracts with just a portion of the downstream retailers, leaving the rest of downstream market not large enough for the entrant to recover the fixed cost of entry. Moreover, Bernheim and Whinston (1998) demonstrate that Bork’s conclusion holds only when they keep the
model in the simplest form. That is, when two manufacturers are competing perfectly for the only retailer in the downstream market, regardless of the size of consumers, the equilibrium shows that a higher joint profit cannot be achieved by exclusion. However, when they proceed to the case where two retail markets develop sequentially, they prove that exclusion of competitors from one market enhances an upstream firm’s market power in the other market. Thus, exclusive dealing might be applied for anti-competitive reasons.

Mathewson and Winter (1987) state that by providing exclusive contract to retailers and using lower wholesale price to induce them to sign it, manufacturers compete for the right to be selected by retailers. Being different from actual competition, which represents the traditional retail price competition, they call it “potential competition”. They find that exclusive dealing enhances potential competition in the upstream market, while it reduces actual competition in downstream market. In general, however, it is not clear which of the two effects dominates. They find that while lower wholesale prices resulted from exclusive dealing lower the retail price level, less competition in downstream market tends to raise retail price. The net effect on retail price is, in general, ambiguous. Therefore, their analysis is inconclusive on the impact of exclusive contract on consumer’s surplus and social welfare.

In a more recent study, Calzolari and Denicolo (2013) extend Mathewson and Winter’s work by incorporating non-linear pricing and asymmetric information into their model. They find that exclusive contract does show pro-competitive effects in their model: it lowers price level and benefits consumers. They also take product differentiation into account and find that independent of whether the products are substitutes or complements, upstream firms always have incentive to require exclusion, consequently exclusive contracts are indeed offered at one of the many equilibria.

Instead of focusing on its exclusionary effect (or the lack of), another strand of literature studies the costs and benefits of exclusive dealing as an organizational form. In particular, Martimort (1996) analyzes manufacturers’ choice between exclusive dealing
and common agency in a retail market with asymmetric information between manufacturers and retailers. He finds that exclusive dealing results in a lack of downstream coordination, but it brings additional informational benefit if goods are substitutes. Only when the informational benefit exceeds the cost of less coordination will exclusive dealing be a more profitable choice than common agency. Thus, in perfect information competition, common agency is a dominant strategy for all players, while exclusive dealing becomes manufacturers’ dominant strategy when goods are substitutes and there exists enough private information in the downstream market. In terms of market efficiency, Martimort (1996) finds that when products are substitutes, the more private information there is in the market, the more efficient exclusive dealing is. When the spread of private information’s distribution is sufficiently small, exclusive dealing is proved to be a manufacturer’s optimal strategy and, meanwhile, is socially efficient. Beyond that range, however, either manufacturers choose common agency while exclusive dealing is still socially efficient, or common agency is indeed socially efficient.

In addition to Martimort (1996), Dobson and Waterson (1996) study the incentives for firms to enter into exclusive trading relationships from the perspective of inter-brand competition and intra-brand competition.

A notable feature of the existing literature on exclusive dealing is the absence of retail services in the analysis. Most of the studies cited above have focused on price competition and rarely examined service competition among retailers. While Dobson and Waterson (1996) view the intra-brand rivalry as a representation of service differentiation among retailers, they treat the degree of service differentiation as exogenously fixed. As a result, there is no meaningful service competition in their model because the retailers do not choose service levels.

Since service provided by retailers can improve consumer’s utility from purchasing and consuming a good, price is not the only factor that affects consumer’s purchase decision.² For example, a survey of US grocery consumers by Carpenter and Moore

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² In a study of retail price maintenance, Winter (1993) points out that retail services can reduce consumer’s opportunity cost and thus improve consumer’s utility.
(2006) finds that price competitiveness is never the consumer’s most concerned factor. The influence of price is even more insignificant among infrequent shoppers. However, cleanliness ranks top among all store attributes in both frequent and occasional shoppers. In addition, Bodkin and Sewell (2012) provide another empirical evidence that infrequent shoppers prefer stores which provide greater service. Therefore, it seems reasonable to ask whether non-price competition, such as service competition, at the retail level might play a role in a manufacturer’s decision to adopt exclusive dealing.

The objective of this paper is to study the effects of exclusive dealing in the presence of non-price competition. We construct a model where services provided by a retailer increases consumers’ utility from consuming a good and the contractual relationship between manufacturers and retailers can take the form of exclusive dealing or common agency. Using this model, we analyze the market conditions under which exclusive contract is adopted in equilibrium as well as its effects on prices, service levels, and consumer’s welfare. Our main finding is that the use of exclusive contract motivates retailers to provide a higher level of services, but its profitability for a manufacturer depends on consumers’ marginal valuation of services. If consumers have relatively low valuation of services, exclusive dealing benefits the manufacturers but harms consumers. If consumer’s valuation of services is high, on the other hand, a number of scenarios are possible. We show that the effects of exclusive contract may be qualitatively the same as in the low-valuation case, or the manufacturers may not even require exclusivity because common agency is more profitable. There also exists a scenario where both manufacturers and consumers are better off under exclusive dealing.

This paper is organized as follows. In section 1.2, we present a model in which two manufacturers sell their products through two retailers. We then solve for the equilibria under exclusive dealing and common agency in sections 1.3 and 1.4, respectively. In section 1.5 we examine a benchmark case of joint profit maximization. In section 1.6, we compare the equilibria in previous sections and analyze the effects of exclusive dealing. Finally, we present concluding remarks in section 1.7.
1.2 Description of the model

We consider two levels of markets: one upstream market and one downstream market. In the upstream market there are two manufacturers who produce and wholesale two differentiated goods A and B respectively. Their per unit production costs are the same and assumed to be equal to $c$. At the same location, there are two retailers, named 1 and 2, stocking goods from the manufacturers and competing with each other in terms of retail price and service level in the downstream market. Besides the cost of purchasing products from the manufacturers, a retailer $j$ faces an additional cost of $\frac{1}{2} s_{ij}^2$ on the service it provides for brand $i$.

Each manufacturer offers wholesale contracts to the retailers. The basic contract is in a form of two-part tariff: manufacturer $i$ sells its product to the retailer at a per unit wholesale price $w_i$ and charges a lump-sum fee $F_{ij}$ from retailer $j$ who sells its brand. Additionally the manufacturer may also require exclusivity, in which case it will prohibit the retailer who accepts this contract from selling the rival’s product. The retailers firstly decide whether or not to accept the wholesale contracts. Then they determine the retail price and service level for each brand they carry.

There is a continuum of consumers and each consumer purchases at most one unit of either brand. Consumer preferences over the two goods are heterogeneous. Suppose that there are two types of consumers, the “switchers” and the “loyals”.\(^3\) Depending on the prices and service levels, switchers would consider purchase either of the two brands. The loyals, on the other hand, would consider buying one particular brand only.

We use $M$ to denote the mass of switchers. The switchers’ preferences are represented by points on a Hotelling line. To be more specific, suppose that the switchers are uniformly distributed on $[0,1]$ interval, and goods A and B are located at point 0 and

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\(^3\) We have borrowed these terms from a study of private label products by Gabrielsen and Sorgard (2007). In their model, a switcher is a consumer who chooses between a private label product and a national brand product, while a loyal is a consumer who never considers buying anything else than the national brand.
point 1, respectively. A switcher’s utility from consuming a unit of good $i$ purchased from retailer $j$ is represented by

$$U^S = v + \theta \cdot s_{ij} - p_{ij} - t \cdot d,$$

(1.1)

where $d$ denotes the distance between good $i$ and his most-preferred good, $p_{ij}$ the price of good $i$ offered by retailer $j$, $s_{ij}$ the level of services offered on good $i$ by retailer $j$. Parameter $v (> 0)$ represents a switcher’s reservation price for his most-preferred good in the absence of any retail services. We assume $v$ is sufficiently large that $U^S$ is always non-negative. Since retail price cannot fall below the unit cost of production in equilibrium, this assumption entails that $v > c$. Parameters $\theta (> 0)$ and $t (> 0)$ represent the marginal utility of retail services and marginal mismatch cost, respectively.

Unlike the switchers, a loyal will consider purchasing one brand only. Suppose that each brand has an equal mass of loyal consumers, denoted by $N$. The utility that a consumer loyal to brand $i$ derives from consuming a unit of the good purchased from retailer $j$ is

$$U^{Li} = VR + \theta \cdot s_{ij} - p_{ij},$$

(1.2)

where $V(> 0)$ is a parameter and $R$ is a random variable uniformly distributed over the interval $[0, 1]$. The term $VR$ reflects the idea that loyals have heterogeneous valuations over their preferred good. To ensure that some loyals receive a positive utility from consuming a unit of his favourite good at any service level, it is necessary to assume that $V > c$.

Moreover, we need to impose the following restriction on the parameter values in order to ensure that the second-order conditions of the firms’ profit-maximization problems are satisfied:

$$\theta^2 < \frac{4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2}{2 \left( \frac{M}{2t} + \frac{N}{V} \right) \left[ \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 \right]}.$$

(1.3)

In (1.1), a switcher’s utility is linear in the distance ($d$). An alternative specification is to assume that utility is a quadratic function of $d$. This alternative specification, however, will not fundamentally change the demand function of a switcher, and thus will not have a qualitative impact on our results.
Condition (1.3) imposes an upper bound on consumers’ marginal valuation of service. It prevents the influence of services from overwhelming that of prices in consumers’ decision. As shown in the appendix, this condition is needed to satisfy the second-order conditions of a manufacturer’s profit maximization problem. For ease of reference, we will use $\theta_a^2$ to denote the right-hand side of (1.3).

The firms and consumers play the following game:
Stage 0: Manufacturers choose whether to require exclusivity;
Stage 1: Manufacturers simultaneously determine the terms of their wholesale contracts and offer them to retailers;
Stage 2: Retailers decide at the same time whether to accept the wholesale contracts offered by one or both manufacturers;
Stage 3: Retailers determine the retail prices and service levels simultaneously for each brand they carry. Consumers make their purchases.

We adopt the solution concept of subgame perfect Nash equilibrium (SPNE) and solve the model by backward induction. We start from considering consumer’s behavior at last stage, and derive market demands according to the utility functions. Next, we move on to solve retailer’s profit maximizing problem and represent optimal retail price and service level in terms of wholesale prices. Finally, we determine the manufacturer’s profit maximizing decision in the first stage.

1.3 Exclusive Contract

We firstly consider the case where exclusive dealing is active and we use superscript “EC” to label variables in this particular case. There are two possible situations at stage 0 but both lead to the same outcome. As the first possibility, both manufacturers may choose to require exclusivity, then in equilibrium, each retailer will carry only one brand. It is also probable that only one manufacturer decides to offer an exclusive contract while the other allows its product to be sold by both retailers. In equilibrium, the manufacturer who provides exclusive contract sells its product to the only one of the two retailers who accepts the exclusive contract. This precludes a second retailer from carrying this
product, even if the other manufacturer does not require exclusivity. Actively or passively, the contract between the pair of unrestricted manufacturer and retailer takes the form of exclusivity.

Without loss of generality, we assume that Retailer 1 accepts the exclusive contract offered by Manufacturer A, so Manufacturer B is paired with Retailer 2. By backward induction, we start from considering consumer’s behavior. In this case, the switchers face only two choices: either purchasing good A from Retailer 1 or buying good B from Retailer 2. A switcher $k$, whose preference is located at $z^k$ between 0 and 1, will choose good A if it generates more utility than good B:

\[ v + \theta s_{A1} - p_{A1} - tz^k \geq v + \theta s_{B2} - p_{B2} - t(1 - z^k). \]  \hfill (1.4)

Solving for $z^k$ in (1.4) gives us the critical level of preference at which a switcher is indifferent between the two behaviors:

\[ z^k \leq \frac{\theta(s_{A1} - s_{B2}) - p_{A1} + p_{B2} + t}{2t} = z^*_{EC}. \]  \hfill (1.5)

Switchers with preference $z^k \in [0, z^*_{EC}]$ will go to retailer 1 and purchase good A, while the rest will consume good B from Retailer 2. Thus, switcher’s demand function for good A is:

\[ Q_{A1}^{S \cdot EC} = \frac{\theta(s_{A1}^{EC} - s_{B2}^{EC}) - p_{A1}^{EC} + p_{B2}^{EC} + t}{2t} \cdot M. \]  \hfill (1.6)

A loyal’s behavior is straightforward since now a good A lover can only find his preferred good at Retailer 1. A loyal individual $h$ will make the purchase if it leads to non-negative utility:

\[ VR^h + \theta s_{A1} - p_{A1} \geq 0; \]  \hfill (1.7)

\[ R^h \geq \frac{p_{A1} - \theta s_{A1}}{V}. \]  \hfill (1.8)

Loyals with $R^h \in \left[\frac{p_{A1} - \theta s_{A1}}{V}, 1\right]$ will make the purchase but the rest will give up. So loyals’ demand function for good A is:

\[ Q_{A1}^{L \cdot EC} = \left(1 - \frac{p_{A1}^{EC} - \theta s_{A1}^{EC}}{V}\right) \cdot N. \]  \hfill (1.9)
Let $Q_A^{EC}$ to be the total demand of good A: $Q_A^{EC} = Q_A^{S_{A1}} + Q_A^{L_{A1}}$. Then Retailer 1’s profit equals to

$$
\pi_1^{EC}(p_{A1}^{EC}, s_{A1}^{EC}) = (p_{A1}^{EC} - w_{A1}^{EC})Q_A^{EC} - \frac{1}{2}s_{A1}^{EC2}.
$$

Retailer 1’s equilibrium retail price and service are characterized by the first order conditions with respect to service and retail price respectively:

$$
\begin{align*}
\left\{ \left( \frac{\theta M}{2t} + \frac{\theta N}{V} \right) (p_{A1}^{EC} - w_{A1}^{EC}) - s_{A1}^{EC} = 0; \\
Q_A^{EC} - \left( \frac{M}{2t} + \frac{N}{V} \right) (p_{A1}^{EC} - w_{A1}^{EC}) = 0. 
\right. 
\end{align*}
$$

To understand the intuition behind (1.11), note that $(\theta M/2t + \theta N/V)$ represents the increased demand brought by an additional unit of service and $(p_{A1}^{EC} - w_{A1}^{EC})$ is the retailer’s profit margin on each unit. Therefore, the first equation in (1.11) shows that at optimum, the marginal income from an additional unit of service should equal to the marginal cost of service, which is equal to the service level because of our quadratic service cost construction. The second equation means that at optimum the additional profit from increasing retail price by one unit, which equals to $Q_A^{EC}$, should be offset by reduction in profit caused by the loss in demand. Combining the two equations together, we observe that the optimal product demand is only related to the associated service level: $Q_A^{EC} = \frac{1}{\theta} s_{A1}^{EC}$. By symmetry, Retailer 2’s optimal choices are determined by

$$
\begin{align*}
\left\{ \left( \frac{\theta M}{2t} + \frac{\theta N}{V} \right) (p_{B2}^{EC} - w_{B2}^{EC}) - s_{B2}^{EC} = 0 \\
Q_B^{EC} = \frac{1}{\theta} s_{B2}^{EC}
\right. 
\end{align*}
$$

Because of the existence of switchers, the total demand of each product is affected by not only the choice of its retailer but also the rival’s decision, the equilibrium retail prices and service levels will be jointly determined by all the four equations in (1.11) and (1.12). Retailers take wholesale prices as given, so the solutions to (1.11) and (1.12) can be represented as functions of wholesale prices. To be precise, denoting $w^{EC} = (w_{A1}^{EC}, w_{B2}^{EC})$ as the vector of wholesale price, the equilibrium retail prices and service levels can be written as $p_{ij}^{EC}(w^{EC})$ and $s_{ij}^{EC}(w^{EC})$ for $i = A, B$ and $j = 1, 2$. Plugging these prices and
service into the demand functions will also make the demand functions of $w_{EC}^E$, i.e.

$Q_i^{EC}(w_{EC}^E)$ for $i = A, B$.

At stage 1, Manufacturer A’s optimization problem is:

$$\max_{(w_A^{EC}, F_A)} \pi_A^{EC} = (w_A^{EC} - c) \cdot Q_A^{EC} + F_A^{EC}$$

s. t. \begin{align*}
Q_A^{EC}(p_{A1}^A - w_A^{EC}) - \frac{1}{2} s_{A1}^{EC^2} - F_A^{EC} \geq 0.
\end{align*}

Since the manufacturer want to maximize its profit, it will set the fixed fee as much as the retailer can afford, which means that the constraint will be binding in equilibrium. Therefore, $F_A^{EC} = Q_A^{EC}(p_{A1}^A - w_A^{EC}) - \frac{1}{2} s_{A1}^{EC^2} = \pi_1^{EC}$. Manufacturer A’s profit function now is:

$$\pi_A^{EC}(w_{EC}) = Q_A^{EC}(w_{EC}) \cdot (w_A^{EC} - c) + \pi_1^{EC}.$$  \hspace{1cm} (1.14)

Equation (1.14) means that the manufacturer will extract all retail profits through the fixed fee. Thus, the retailers will end up with zero profits and become indifferent between accepting and rejecting the contracts. However, a retailer will not reject a wholesale contract as long as he can afford the fixed fee if he wants to maximize his payoff, even if accepting it leads to zero profit. The first order condition of (1.14) is

$$\frac{\partial \pi_A^{EC}}{\partial w_A^{EC}} = Q_A^{EC}(w_{EC}) + (w_A^{EC} - c) \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} + \frac{\partial \pi_1^{EC}}{\partial w_A^{EC}} = 0.$$  \hspace{1cm} (1.15)

We can also obtain the other manufacturer’s first order condition by symmetry:

$$\frac{\partial \pi_B^{EC}}{\partial w_B^{EC}} = Q_B^{EC}(w_{EC}) + (w_B^{EC} - c) \frac{\partial Q_B^{EC}}{\partial w_B^{EC}} + \frac{\partial \pi_1^{EC}}{\partial w_B^{EC}} = 0.$$  \hspace{1cm} (1.16)

Again because of the switchers, the equilibrium level of wholesale prices is determined by the first order conditions of both manufacturers’ profit maximization problems, namely (1.15) and (1.16) together. These wholesale prices and (1.11)-(1.12), in turn, determine the equilibrium retail prices and service levels.

**Proposition 1.1** Suppose at least one manufacturer chooses to require exclusivity at stage 0. In an equilibrium at subsequent stages,

a) each retailer sets the retail price above the respective wholesale price, i.e. $p_i^{EC} > w_i^{EC}$, and offers a positive level of service, i.e. $s_i^{EC} > 0$; and
b) each manufacturer sets its wholesale price above the unit cost of production, \textit{i.e.} \( w_{i}^{EC} > c \), if and only if \( \theta^2 < \frac{1}{\frac{M}{N} - \frac{N}{V}} \).

Proposition 1.1 shows that in the presence of exclusive dealing, retail prices are above wholesale prices. As can be seen in (1.10), this positive retail profit margin is needed to induce the retailers to offer a positive level of service. On the other hand, wholesale prices are above the marginal cost of production if and only if consumers’ marginal valuation of service (\( \theta \)) is not too large. This is because the need to preserve the retailers’ incentives to offer an adequate level of service puts a cap on wholesale prices. This drives the manufacturers to drop their wholesale prices below marginal cost when consumers’ marginal valuation of service is very high. Note that the manufacturers still earn positive profits in this case because they can extract profits from the retailers through the fixed fees.

1.4 Common Agency

Common agency can be viewed as the opposite case of exclusive dealing. It describes one of the relationships between principals and agents where several principals simultaneously affect the agent’s action. In our model, such situation can be formed when neither manufacturer requires exclusivity in the wholesale contract. Then both retailers will accept to carry both brands. We label all variables with superscript “CA” in this section.

We follow the same procedure as in the preceding section by first considering consumer’s choice. In a symmetric equilibrium, both types of consumers are indifferent between the sellers, so half of the total population will go to Retailer 1 and the rest will choose Retailer 2. After determining which retailer he turns to, a switcher \( k \) will then choose between product A and B at the retailer. Suppose that this individual is at retailer 1, he will purchase good A if this decision generates higher utility:

\[
v + \theta s_{A1} - p_{A1} - tz^k \geq v + \theta s_{B1} - p_{B1} - t(1 - z^k). \]  

(1.17)
\[ z^k \leq \frac{\theta(s_{A1} - s_{B1}) - p_{A1} + p_{B1} + t}{2t} = z^*_{CA}. \]  

Switchers whose location \( z^k \in [0, z^*_{CA}] \) will purchase A and the rest choose B. The switchers’ demand at Retailer 1 thus takes the form

\[ Q_{A1}^{S, CA} = \frac{\theta(s_{A1}^{CA} - s_{B1}^{CA}) - p_{A1}^{CA} + p_{B1}^{CA} + t}{2t} \cdot M; \]

\[ Q_{B1}^{S, CA} = \frac{t - [\theta(s_{A1}^{CA} - s_{B1}^{CA}) - p_{A1}^{CA} + p_{B1}^{CA}]}{2t} \cdot M. \]

In terms of the loyals, the analysis follows the same steps as that in exclusive dealing case. The only difference is that there are just half of each brand’s lovers, which has mass equal to \( \frac{N}{2} \), at Retailer 1. The loyals’ demand function at Retailer 1 can then be written as:

\[ Q_{A1}^{L, CA} = \left(1 - \frac{p_{A1}^{CA} - \theta s_{A1}^{CA}}{V}\right) \cdot \frac{N}{2}; \]

\[ Q_{B1}^{L, CA} = \left(1 - \frac{p_{B1}^{CA} - \theta s_{B1}^{CA}}{V}\right) \cdot \frac{N}{2}. \]

Unlike the exclusive dealing case where each retailer carries only one brand, both retailers carry both brands in common agency case, so each retailer must determine the retail prices and service levels for both products. Let \( p_1^{CA} = (p_{A1}^{CA}, p_{B1}^{CA}) \) and \( s_1^{CA} = (s_{A1}^{CA}, s_{B1}^{CA}) \) to be Retailer 1’s retail price vector and service vector respectively and define \( Q_{i1}^{CA} = Q_{i1}^{S, CA} + Q_{i1}^{L, CA} \), for \( i = A, B \) as the total demand of product \( i \) at Retailer 1, we write Retailer 1’s profit function as:

\[ \pi_{1}^{CA}(p_1^{CA}, s_1^{CA}) = Q_{A1}^{CA}(p_{A1}^{CA} - w_A^{CA}) + Q_{B1}^{CA}(p_{B1}^{CA} - w_B^{CA}) - \frac{1}{2} s_{A1}^{CA}^2 - \frac{1}{2} s_{B1}^{CA}^2. \]

In equilibrium, price competition between the two retailers leads to \( p_{ij} = w_i \) for each product \( i \). To see this, suppose that retailer \( j \) prices product \( i \) at \( p_{ij} > w_i \) and the service level in downstream market is fixed at \( s \). Then the other retailer will be able to set the retail price slightly lower than \( p_{ij} \) (and still above \( w_i \)) so that it will capture the whole downstream market of product \( i \). Such price competition will not end until there is no space for a further price cut:

\[ p_{ij} = w_i, \ i = A, B \ \text{and} \ j = 1, 2. \]
In terms of service level, we turn back to the first order conditions of retailer’s optimization problem:

$$\frac{\partial \pi_{1A}}{\partial s_{A1}} = \left( \frac{\theta M}{2t} + \frac{\theta N}{V} \right) (p_{A1}^{CA} - w_{A}^{CA}) - \frac{\theta M}{2t} (p_{B1}^{CA} - w_{B}^{CA}) - s_{A1}^{CA} = 0;$$  \hspace{1cm} (1.24)

$$\frac{\partial \pi_{1A}}{\partial s_{B1}} = -\frac{\theta M}{2t} (p_{A1}^{CA} - w_{A}^{CA}) + \left( \frac{\theta M}{2t} + \frac{\theta N}{V} \right) (p_{B1}^{CA} - w_{B}^{CA}) - s_{B1}^{CA} = 0.$$  \hspace{1cm} (1.25)

When every product’s retail price is equal to the respective wholesale price, (1.24) and (1.25) imply that all service levels drop to zero. Retailers will not offer any service because the marginal profit from an additional unit of service is 0. Setting $p_{ij} = w_i$ and $s_{ij} = 0$ in (1.19) and (1.21), we obtain the quantity of product A sold by Retailer 1:

$$Q_{A1}^{CA} = -\frac{w_{A}^{CA} + w_{B}^{CA} + t}{2t} \cdot \frac{M}{2} + \left( 1 - \frac{w_{A}^{CA}}{V} \right) \cdot \frac{N}{2}.$$  \hspace{1cm} (1.26)

The quantity of product A sold by the other retailer is the same as (1.26) because of symmetry.

Without loss of generality, we only focus on Manufacturer A’s optimization problem. After summing up the quantity of product A sold through both retailers, the total demand facing the manufacturer of good A is:

$$Q_A^{CA}(w^{CA}) = \frac{-w_{A}^{CA} + w_{B}^{CA} + t}{2t} \cdot M + \left( 1 - \frac{w_{A}^{CA}}{V} \right) \cdot N$$  \hspace{1cm} (1.27)

where $w^{CA} = (w_{A}^{CA}, w_{B}^{CA})$ is defined as the vector of wholesale prices in common agency case. Since the equilibrium retail price is equal to the wholesale price, there is no retail profit for the manufacturer to extract through the fixed fee. Hence, Manufacturer A maximizes his profit $\pi_{A}^{CA} = Q_A^{CA} (w_{A}^{CA} - c)$ by choosing $w_{A}$ optimally. The equilibrium level of wholesale prices is again, just like the exclusive dealing case, determined by both manufacturers’ first order conditions:

$$\frac{\partial \pi_{A}^{CA}}{\partial w_{A}^{CA}} = Q_A^{CA}(w^{CA}) + (w_{A}^{CA} - c) \frac{\partial Q_A^{CA}}{\partial w_{A}^{CA}} = 0;$$  \hspace{1cm} (1.28)

$$\frac{\partial \pi_{B}^{CA}}{\partial w_{B}^{CA}} = Q_B^{CA}(w^{CA}) + (w_{B}^{CA} - c) \frac{\partial Q_B^{CA}}{\partial w_{B}^{CA}} = 0.$$  \hspace{1cm} (1.29)
Proposition 1.2 Suppose none of the manufacturers choose to require exclusive at stage 0. In an equilibrium at subsequent stages,

a) each retailer sets its retail price exactly equal to the respective wholesale price and provides no service, i.e. \( p_i^{CA} = w_i^{CA}, s_i^{CA} = 0 \).

b) each manufacturer sets the wholesale price above the unit cost, i.e. \( w_i^{CA} > c \).

1.5 Benchmark: Maximization of Joint Profit

For the purpose of comparing equilibria in previous two sections, we need the assistance of a benchmark case where the industry’s joint profit is maximized. In this case, all firms in the industry behave jointly as a monopolist. The joint profit of the industry is

\[
\Pi = \sum_{i=A,B} (p_i - c)Q_i - \frac{1}{2} s_i^2. \tag{1.30}
\]

The quantity sold \( Q_i \) includes two components: quantity sold to switchers and loyals, which takes the same functional forms as those in previous sections, i.e. (1.6) and (1.9).

The wholesale process is internalized so choice variables are \( p_i \) and \( s_i \) only. In a symmetric equilibrium, \( Q_i \) can be simplified as

\[
Q_i = \frac{M}{2} + N \left( 1 - \frac{p - \theta s}{V} \right). \tag{1.31}
\]

Substituting (1.31) into (1.30), we can write the joint profit in a symmetric equilibrium as

\[
\Pi = 2(p - c) \left[ \frac{M}{2} + N \left( 1 - \frac{p - \theta s}{V} \right) \right] - s^2. \tag{1.32}
\]

The optimal retail price and service level are characterized by their first order conditions:

\[
\frac{M}{2} + \left( 1 - \frac{p^*}{V} \right) \cdot N - (p^* - c) \frac{N}{V} + \frac{N}{V} \theta s^* = 0; \tag{1.33}
\]

\[
(p^* - c) \theta \frac{N}{V} - s^* = 0. \tag{1.34}
\]

Solving (1.33)-(1.34), we obtain the joint-profit maximizing price and service:

\[
p^* = \frac{V^2 \left( \frac{1}{2} M + N \right) + c(VN - \theta^2 N^2)}{2VN - \theta^2 N^2}; \tag{1.35}
\]
\[ s^* = \frac{\theta \cdot \left[ V \left( \frac{1}{2} M + N \right) - Nc \right]}{2V - \theta^2 N}. \] (1.36)

Using (1.33) and (1.34), we can calculate the second-order derivatives of \( \Pi \) and verify that (1.3) is needed to satisfy the second-order conditions of this optimization problem. Moreover, it can be verified that (1.3) and \( V > c \) ensure that \( p^* > c \) and \( s^* > 0 \), that is, the joint-profit maximizing price is greater than the unit cost of production and the joint-profit maximizing level of service is positive.

### 1.6 Comparison of Equilibria

In this section, we will compare the equilibria in all previous sections. Most importantly, we are interested in the levels of equilibrium profit under exclusive contracts and common agency since it directly determines manufacturer’s choice regarding exclusivity. We will also compare the equilibrium values of other variables to determine whether consumers are better or worse off in presence of exclusive dealing.

Since consumer’s welfare are affected by price and service level, it is useful to define \( \tilde{p} = p - \theta s \) as the service-adjusted price. As we can see from consumers’ utility functions in equation (1.1) and (1.2), this adjusted price plays the same role as the price of a good: consumer will be worse off when the adjusted price increases. The only difference is that it additionally takes service level into consideration.

We start with a comparison of service level under exclusive dealing with that under common agency.

**Proposition 1.3** Retailers offer higher level of services under exclusive dealing than under common agency, i.e., \( s^{EC} > s^{CA} = 0 \).

Proposition 1.3 can be understood in terms of the intensity of intra-brand competition. Under common agency, a retailer faces intense intra-brand competition for each good it carries. The resulting low profit margin diminishes the retailer’s incentive to offer
service, driving its level to 0. Exclusive dealing, on the other hand, eliminates the intra-
brand competition and thus restores the retailer’s incentive to offer services. Therefore,
exclusive dealing unambiguously raises the level of retail service.

The impact of exclusive dealing on prices, quantity and profits, however, is less clear-
cut; it depends on the value of $\theta$, consumer’s marginal valuation of services. Specifically,
we need to define another critical value of $\theta$:

$$
\theta^2_b = \frac{\left(\frac{M}{2t} + \frac{N}{V}\right)^2 - \sqrt{\left(\frac{M}{2t}\right)^4 + \left(\frac{M}{2t} + \frac{N}{V}\right)^2 \left[\left(\frac{M}{2t} + \frac{N}{V}\right)^2 - \left(\frac{M}{2t}\right)^2\right]}}{\left(\frac{M}{2t} + \frac{N}{V}\right)^3 - \left(\frac{M}{2t}\right)^2 \left(\frac{M}{2t} + \frac{N}{V}\right)}.
$$

(1.37)

Comparing this critical value of $\theta$ with that defined by (1.3), we find that $\theta_b < \theta_a$.

**Proposition 1.4** Service-adjusted price is higher and total quantity is smaller under exclusive dealing than under common agency, *i.e.*, $\hat{p}^{EC} > \hat{p}^{CA}$ and $Q^{EC} < Q^{CA}$ if and only if $\theta < \theta_b$.

Proposition 1.4 states that if consumers’ marginal valuation for services ($\theta$) is not too large, exclusive dealing enables the retailers to charge higher service-adjusted prices than under common agency, and total quantity falls as a result. But the opposite is true if $\theta$ is relatively large. Intuitively, a larger $\theta$ induces more intense competition in service among retailers under exclusive dealing. This drives down service-adjusted prices and increases the quantity consumed. Consequently, when $\theta$ is sufficiently large, service-adjusted price is lower and total quantity is larger under exclusive dealing than under common agency.

**Proposition 1.5** Suppose $\theta < \theta_b$. Retail prices and the manufacturers’ profits are higher under exclusive dealing than under common agency. Consequently, at least one manufacturer chooses to require exclusivity in equilibrium.

Proposition 1.5 indicates that as long as consumers’ marginal valuation for service is not too large, exclusive dealing enables the retailers to charge higher prices than under
common agency, and a manufacturer will find it profitable to adopt exclusive dealing in equilibrium. Intuitively, the adoption of exclusive dealing has two opposing effects on the firms’ profits: while a higher retail price generates a larger profit margin, a higher service level increases the fixed cost of service provision. Under the condition \( \theta < \theta_b \), the first effect dominates the second effect. Note, however, this condition is sufficient but not necessary for this result to hold. As we can see from the results of numerical simulations below, exclusive dealing may still be more profitable for the firms even if consumers’ marginal valuation for service is higher.

To gain further insight into how \( \theta \) affects the equilibria under exclusive dealing and common agency, particularly regarding retail prices and the manufacturers’ profits, we conduct numerical simulations. Specifically, we fix the value of parameters (including \( M, N, t, V, c \) and \( \theta \))\(^5\) and calculate the equilibrium prices and service levels under exclusive dealing and common agency using equilibrium conditions (1.11), (1.12), (1.28) and (1.29). This enables us to compute the equilibrium values of other variables such as profits and total surplus.

Figures 1.1-1.5 illustrate the results of numerical simulations associated with parameter values \( M = 10, N = 2, t = 1, V = 2 \) and \( c = 1 \). Using these parameter values, we find that \( \theta_b \approx 0.25 \). Condition (1.3) requires the upper bound of \( \theta \) to be approximately 0.48. Furthermore, note that the mass of switchers (\( M \)) is substantially larger than that of the loyals (\( N \)) in this case.

---

\(^5\) The value of \( v \) does not affect the equilibrium as long as it is sufficiently high.
Figure 1.1 Service under exclusive dealing (M=10 N=2)

Figure 1.2 Service adjusted prices (M=10 N=2)

Figure 1.3 Quantities (M=10 N=2)
From Figure 1.1 we see that equilibrium service level in the exclusive dealing case increases as $\theta$ grows. When consumers have a higher valuation of service, the manufacturers will give the retailers a stronger incentive to provide it. Figures 1.2 and 1.3 confirm the results in Proposition 1.4. Moreover, they show that service-adjusted prices and quantities under exclusive dealing change monotonically with the value of $\theta$.

Figure 1.4 illustrates the equilibrium retail prices in the exclusive dealing case and the common agency case as functions of $\theta$. Since $s^{CA} = 0$, a retailer’s decision under common agency is independent of the value of $\theta$ and hence $p^{CA}$ remains constant for different values of $\theta$. The retail prices under exclusive dealing ($p^{EC}$), on the other hand, fall with the value of $\theta$. While $p^{EC}$ is higher than $p^{CA}$ for a wide range of $\theta$ in Figure 1.4, it eventually falls below $p^{CA}$ for $\theta$ close to the upper bound. Intuitively, there are two opposing forces that drive the retail prices under exclusive dealing. On one hand, the retailers want to charge higher prices as they provide a higher level of service in response to a larger $\theta$. On the other hand, the intensity of inter-brand competition increases as $\theta$ rises, which tends to drive the retail prices down. Given that the mass of switchers is substantially larger than that of the loyals, the second force dominates the first force and hence $p^{EC}$ falls with an increase in the value of $\theta$. 
Figure 1.5 shows that equilibrium level of profits under exclusive dealing is higher than that under common agency for some values of $\theta$ above $\theta_b$. This confirms that the condition $\theta < \theta_b$ is sufficient but not necessary for the manufacturers to choose exclusivity in equilibrium. However, if $\theta$ is sufficiently large, service competition becomes so intense that exclusive dealing becomes less profitable than common agency for the manufacturers.

Some of these results will change if we change the relative size of the two types of consumers. In the above example, the mass of switchers is larger than that of the loyals. Now, we examine an opposite case, where $M=2$ and $N=8$. The values of all other parameters are the same as in the previous example. These parameter values imply that the upper bound of $\theta$ is approximately 0.6. To clearly illustrate the difference in equilibrium values under exclusive dealing and common agency, however, Figures 1.6-1.10 are drawn for $\theta$ in the range [0, 0.3].

Figure 1.6 Service under exclusive dealing (M=2 N=8)
Figures 1.6, 1.7 and 1.8 show qualitatively the same pattern as Figures 1.1, 1.2 and 1.3. Specifically, while the level of service and total quantity under exclusive dealing rise with the value of $\theta$, the opposite is true for the service-adjusted prices. On the other hand, the retail prices in Figure 1.9 displays a very different pattern from that in Figure 1.4. Instead of falling, the retail prices under exclusive dealing rise with the value of $\theta$. Intuitively, this result is driven by the two opposing forces identified earlier. Because the mass of switchers is substantially smaller than that of the loyals in the present case, the
second force is now dominated by the first force, resulting in rising retail prices. Finally, we see from Figure 1.10 that the manufacturers’ profits are larger under exclusive dealing than those under common agency for $\theta \in [0, 0.3]$. Not shown in this diagram is that the former falls below the latter as $\theta$ approaches its upper bound. This pattern is qualitatively the same as in Figure 1.5.

Next, we discuss the effect of exclusive dealing on social welfare. Propositions 1.4 and 1.5 imply that if $\theta < \theta_b$, exclusive dealing will generate larger profits for the manufacturers but will reduce consumer surplus. This suggests that the overall effect of exclusive dealing on social welfare may be ambiguous. To gain a better understanding about the welfare effect of exclusive dealing, we compare the levels of total surplus under exclusive dealing and common agency using the same sets of parameter values as above. Figures 1.11 and 1.12 illustrate the levels of and the difference in total surplus between exclusive dealing and common agency in the first case where there are substantially more switchers than the loyals. From Figure 1.11 we see that the level of total surplus under exclusive dealing increases monotonically with $\theta$. It rises above the (constant) level of total surplus under common agency for $\theta > 0.17$ (see also Figure 1.12). Recall from Figure 1.5 that the exclusive dealing will be adopted by at least one manufacturer for $\theta < 0.33$. Therefore, the adoption of exclusive dealing improves social welfare if $\theta \in (0.17, 0.33)$, but it reduces social welfare if $\theta < 0.17$.

Figure 1.13 and 1.14 show the welfare comparison in the other case where the mass of loyals is substantially larger than that of switchers. Here we see the same pattern as in Figures 1.11 and 1.12; that is, the level of total surplus under exclusive dealing is lower than that under common agency when $\theta$ is below a certain threshold, but the opposite is true when $\theta$ is above the threshold. Note, however, this pattern is not universally true for all parameter values. Additional numerical simulations show that other patterns are also possible. For example, in the case where $M = 200$ and $N = 2$ (with all other parameter values being the same), the level of total surplus under exclusive dealing is higher for small $\theta$ but lower for large $\theta$ (see Figures 1.15 and 1.16). Therefore, the welfare effect of
exclusive dealing depends on not only the marginal valuation of service, but also the sizes of the loyals and switchers.

Figure 1.11 Total surplus (M=10 N=2)

Figure 1.12 Total surplus differences (M=10 N=2)

Figure 1.13 Total surplus (M=2 N=8)

Figure 1.14 Total surplus differences (M=2 N=8)
In addition, we have also conducted numerical simulations to compare equilibria under different values of marginal mismatch cost $t$. We find that changes in $t$ have the expected impact. That is, since a larger mismatch cost weakens the intensity of competition between the two brands, it leads to higher retail prices and lower service levels, thus reducing consumer welfare. Details of these numerical simulations can be found in the appendix.

Finally, we briefly discuss how the equilibrium under exclusive dealing compares with the joint-profit maximization solution. In particular, it is interesting to find out whether the retail prices and service levels under exclusive dealing are above or below those that maximize the joint profits of the industry.

**Proposition 1.6** Equilibrium retail prices are lower and service levels are higher under exclusive contract than those that maximize the industry joint profits, i.e., $p^{EC} < p^*$ and $s^{EC} > s^*$.

In comparison with the joint-profit maximization solution, the presence of exclusivity increases the intensity of both price and non-price competition, making price drop and
service level rise. Therefore, service adjusted price decreases and consumers are definitely better off.

1.7 Conclusion

In this paper, we have analyzed the incentive to adopt and the effect of exclusive dealing in a model where retailers engage in both price and non-price competition. In particular, we have compared the equilibrium retail prices, service levels, profitability and consumer welfare under exclusive dealing with those under common agency. Our analysis shows that, by eliminating intra-brand competition, the adoption of exclusive contract induces the retailers to raise service level in equilibrium. But the effects of exclusive dealing on retail prices, profitability, consumer welfare depends on the magnitude of consumers’ marginal valuation of service. While retail prices and the manufacturers’ profits are higher under exclusive dealing than under common agency if the marginal valuation of service is below a certain threshold, the opposite may be true if the valuation is too high. Moreover, adoption of exclusive dealing lowers consumer welfare if the marginal valuation of service is below the threshold but raises it otherwise. The effect of exclusive dealing on social welfare, however, is in general ambiguous.

In our model, we have assumed that retailers are homogeneous with regard to their physical locations. This assumption suppresses an additional channel through which exclusive dealing may affect consumer welfare: when retailers are differentiated by their physical locations, adoption of exclusive contracts will increase the transportation cost incurred by consumers, especially the loyals. It is worthwhile to take physical distance into consideration in future research.
Chapter 2: Flight Delay Impact on Airfare and Passenger Volume

2.1 Introduction

Even though people’s travel plans have been severely affected by the COVID-19 pandemic, air traffic still remains traveler’s first choice when traveling long distance, especially overseas. This is because aircraft is so far the only vehicle to travel regardless of the restriction of landforms and it saves such travelling time. The amount of annual passengers on all U.S. scheduled domestic flights has a steady increase of more than twenty million before the outbreak of COVID-19. Airline companies are also increasing flight frequencies every year to meet the requirement of increased demand. However, just like the situation in road traffic that too many cars will cause traffic jam, the problem of air traffic congestion is growing every year. As a result, flight delay has become a serious and universal problem in U.S.. According to a report from U.S. Bureau of Transportation Statistics (BTS), nearly 20% of U.S. domestic flights arrived late for more than 15 minutes (cancelation excluded) in 2018. Only 3.5% of them are caused by weather delay, while the main delay reasons are carrier delay, national aviation system delay and previous flight with same aircraft arriving late (US BTS, 2018).

The consequence of flight delay is much more than just time wasting. On one hand, it decreases passenger’s willingness-to-pay because of lower satisfaction (Suzuki, 1999; Zou and Hansen, 2012). On the other hand, airlines also take heavier burden of the extra costs in fuel, labor and capital (Hansen et al., 2000, 2001). Ball et al (2010) once published a report for The National Center of Excellence for Aviation Operation Research (NEXTOR) about the total delay impact in U.S.. Their estimation results show that flight delay raised cost to airlines by $8.3 billion in 2007. This amount doubles when it comes to excess cost to passengers. Travelers may have to reschedule their travel plans or even suffer business loss due to delay, and, in most cases, they get no compensation from airlines. What made it even worse is that passengers might avoid air travel due to delay, and such decision resulted in additional welfare loss equivalent to $2.2 billion. The overall delay impact has reduced the 2007 U.S. GPD by $4 billion (Ball et al., 2010).
From the perspective of equilibrium theory, the excess delay cost to both airlines and passengers tends to decrease equilibrium quantity. However, the movement of equilibrium price is inconclusive. While firms want to raise price to recover the increased marginal cost, consumers expect airfares to be lower to compensate their loss. This theoretical ambiguity has drawn economist’s attention. Using a multinomial logistic model, Morrison and Winston (1989) estimate that one percent change in airline’s on time performance is valued $1.21 per round trip by travelers. Their finding encourages airlines with better on time performances to charge higher prices. This result is supported by Forbes (2008) in her study of the “LaGuardia experiment”. She makes use of the release of new policy by Federal Aviation Administration (FAA) in 2000 that lifted the flight frequency in New York LaGuardia airport and constructs time dummy as instrument variable to estimate endogenous delay. She finds that airfare of flights involving LaGuardia airport falls in response to longer delay. However, when studying a selected U.S. nationwide sample, Britto et al. (2012), Zou and Hansen (2014) find that airfare and delay are positively related after controlling the endogeneity of passenger demand.

In this paper, we use the regression equations derived from a theoretical model to estimate the delay impact on airfare and passenger volume in U.S. domestic flight market. There are several contributions from our paper. First, we want to shed new light into this topic from equilibrium theory point of view. Second, we will apply more accurate delay data and focus on measuring delay using several approximations. While Britto et al. (2012) is restricted by the sample size and Zou and Hansen (2014) use average delay at airport level, we calculate the delay data for each airline at route level. Third, we investigate whether the difference in market size could offer an explanation for the inconsistent results about the impact of delay in the literature. Thus we manually group routes into different samples and estimate delay impact on different groups. We find that flight delay tends to increase airfares of all flights in metropolitan market. However, when the routes involve airports in secondary cities, delay results in lower airfare of direct flights and does not affect the fare of connecting flights.
We construct the theoretical model and derive the regression equation in section 2.2. The data sources are introduced in section 2.3. In section 2.4 and 2.5, we present and discuss the estimation results regarding to airfare and passenger volume. Finally, we draw conclusion in section 2.6.

2.2 Theoretical Framework

2.2.1 Model Construction

Being different from the pure empirical model constructed by Britto et al. (2012) or Zou and Hansen (2014), we want to derive the regression equation from a theoretical model. The main feature of our regression equation is that, according to the equilibrium theory, passenger demand should not appear on the right hand side of the airfare regression.

We consider an oligopoly airport-pair airline market with $I$ airlines and $J$ routes in total. When there are multiple airlines operating the same route, they are engaged in price competition. Firms set prices and consumers purchase air tickets before the flight departs, so neither airlines nor consumers knows the actual delay information of the corresponding flight at the determination stage. As a result, all decisions are made based on expected delay instead of actual delay. The operating cost of airline $i$ who operates route $j$ over period $t$ is

$$C_{ijt} = c_{0ijt} + c_{1ijt}Q_{ijt}(P_{jt}, D_{ijt}), \quad (2.1)$$

where $c_{0ijt}$ is the firm’s fixed cost and $D_{ijt}$ is each firm’s expected delay in different routes at time $t$. The second term associated with $c_{1ijt}$ represents variable cost, which includes service cost, fuel cost and delay cost. To be precise, we write $c_{1ijt}$ as

$$c_{1ijt} = s_{ijt} + \beta D_{ijt} + p_{Pt} \cdot \frac{\eta}{q} \cdot M_{ij}, \quad (2.2)$$

where $s_{ijt}$ is firm $i$’s per passenger service cost, it is significantly lower when airline $i$ is a low-cost carrier. $\beta$ is constant measuring per unit delay cost. Fuel price in period $t$ is denoted by $p_{Pt}$ and $M_{ij}$ is the miles flown of airline $i$’s flights in route $j$. The constant $\eta$ represents airplane’s average fuel consumption per mile and $q$ is the average capacity per
flight. There are two underlying assumptions: First, we assume here that technology does not improve significantly so that $\eta$ does not change over time. Second, all airlines use airplanes of similar sizes so that $q$ does not vary between different airlines. $Q_{ijt}$ is number of passengers who travel with firm $i$ on route $j$ over period $t$. It is a function of price vector $P_{jt}$, which contains firm $i$'s price and its rivals’ prices, and expected delay $D_{ijt}$.

We assume that $Q_{ijt}$ takes form of a linear function:

$$Q_{ijt} = a_{ijt0} - a_{1} p_{ijt} + \sum_{k=-i} a_{k2} p_{kjt} - a_{3} D_{ijt}.$$  \hspace{1cm} (2.3)

All coefficients in (2.3) are non-negative. The passenger volume of firm $i$ is not only affected by its own price, but also by all rivals’ prices in the same route. Meanwhile, the worse the on-time performance of an airline operating certain route is expected to be, the less passengers who travel that route will choose to fly with the corresponding carrier. Or at least demand of the corresponding airline should not increase as delay grows. $a_{ijt0}$ can be interpreted as a base of passenger volume. It is a positive constant affected by many factors. For example, the vacation factor will significantly enlarge $a_{ijt0}$ if route $j$ is a vacation route in period $t$. Considering the service level, the low-cost carrier (LCC) factor may make $a_{ijt0}$ smaller comparing to legacy airlines if airline $i$ is a low-cost carrier. Moreover, since there will certainly be more local passengers and transferring travelers in a metropolis with large population and high average income, this constant also reflects social information of origin and destination cities.

The profit of airline $i$ in period $t$ is thus

$$\pi_{it} = \sum_{j} (p_{ijt} Q_{ijt} - c_{ijt}).$$ \hspace{1cm} (2.4)

Each airline maximizes the profit in (2.4) by choosing its price for each route. The first order condition associated with route $i$ is

$$\frac{\partial \pi_{it}}{\partial p_{ijt}} = Q_{ijt} + p_{ijt} \frac{\partial Q_{ijt}}{\partial p_{ijt}} - c_{ijt} \frac{\partial Q_{ijt}}{\partial p_{ijt}}$$

$$= a_{ijt0} - 2 \cdot a_{1} p_{ijt} + \sum_{k=-i} a_{k2} p_{kjt} - a_{3} D_{ijt} + \left( s_{ijt} + \beta D_{ijt} + p_{Ft} \cdot \eta \cdot M_{ij} \right) a_{1} = 0.$$

(2.5)

If we denote $n_j$ to be the total number of airlines operating route $j$ and define
\[
A \equiv \begin{bmatrix}
2a_1 & -a_{2j} & -a_{3j} & \cdots & -a_{nj} \\
-a_{1j} & 2a_1 & -a_{3j} & \cdots & -a_{nj} \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
-a_{1j} & -a_{2j} & -a_{3j} & \cdots & 2a_1
\end{bmatrix},
\]
\[
B \equiv \begin{bmatrix}
a_{1jt0} - a_{3j}D_{1jt} + \left(s_{1jt} + \beta D_{1jt} + p_{Ft} \cdot \eta \cdot M_{1j}\right) a_1 \\
a_{2jt0} - a_{3j}D_{2jt} + \left(s_{2jt} + \beta D_{2jt} + p_{Ft} \cdot \eta \cdot M_{2j}\right) a_1 \\
\vdots \\
a_{njjt0} - a_{3j}D_{njjt} + \left(s_{njjt} + \beta D_{njjt} + p_{Ft} \cdot \eta \cdot M_{nj}\right) a_1
\end{bmatrix}
\]
and the price vector \( \mathbf{p} = [p_{1jt}, p_{2jt}, \ldots, p_{njjt}]^{-1} \), we then have
\[
A \cdot \mathbf{p} = B.
\]
Thus the equilibrium prices for route \( j \) in period \( t \) can be solved as:
\[
\mathbf{p} = A^{-1} \cdot B.
\]
Thus airline \( i \)'s equilibrium price is determined by the unique constant \( a_{ijt0} \), its expected delay, the fuel cost and rival firms’ competition in the same route market.

To find out how delay may impact equilibrium airfare, we consider a special case where all airlines are symmetric. Specifically, we assume that all airlines have the same base of passenger volume, same on-time performance, same service cost and fly the same distance in each route, which means that \( a_{ijt0}, D_{ijt}, s_{ijt} \) and \( M_{ij} \) are identical among airlines. Moreover, we assume that the pricing strategy of each rival firm has the same impact on firm \( i \)'s demand quantity, so \( a_{k2} = a_2 \) for all \( k = -i \). In this symmetric case, the equilibrium prices of all airlines are the same and can be solved as:
\[
p_{jt} = \frac{a_{jt0} + (a_1 \beta - a_3)D_{jt} + \left(s_{jt} + p_{Ft} \cdot \eta \cdot M_j\right) a_1}{2a_1 - (n_j - 1)a_2}.
\]
Thus the delay impact on price is simply
\[
\frac{\partial p_{jt}}{\partial D_{jt}} = \frac{a_1 \beta - a_3}{2a_1 - (n_j - 1)a_2}.
\]
Since all parameters are positive, the sign of (2.11) is ambiguous. Theoretically delay impact on airfare is inconclusive.
In the context of airport coordination, a slot is an authorization to either take-off or land at a particular airport on a particular day during a specified time period (FAA, Slot administration website). Unacceptable systemic delay would occur when the slot demand of an airport significantly exceeds its capacity without any control. In order to avoid such situation, the FAA implements slot control on several airports across the country. Throughout the sample period, from the first quarter of 2013 to the second quarter of 2019, New York John F. Kennedy International Airport (JFK), New York LaGuardia Airport (LGA) and Ronald Reagan Washington National Airport (DCA) are consistently slot controlled, while Newark Liberty International Airport (EWR) is no longer one of them but was once a slot controlled airport before the fourth quarter of 2016. If the above airports are involved in sample routes, the maximum of flight frequency is limited to be no greater than a certain level. So there exists a constraint for such routes that

\[
\frac{\sum_i \sum_{j \text{ involves } n} Q_{ijt}}{q} = \sum_i \sum_{j \text{ involves } n} f_{ijt} \leq Z_n, \quad n = JFK, LGA, DCA \tag{2.12}
\]

where \(f_{ijt}\) is airline’s required flight frequency and \(Z_n\) is the maximum flight frequency of each slot controlled airport regulated by FAA. We then set up the Lagrangian for the airline \(i\) to maximize its profit subject to the above constraint:

\[
L_{it} = \pi_{it} + \lambda_{JFK} \left[ \frac{\sum_h \sum_{k \text{ involves } JFK} Q_{hkt}}{q} - Z_{JFK} \right] + \lambda_{LGA} \left[ \frac{\sum_h \sum_{k \text{ involves } LGA} Q_{hkt}}{q} - Z_{LGA} \right] + \lambda_{DCA} \left[ \frac{\sum_h \sum_{k \text{ involves } DCA} Q_{hkt}}{q} - Z_{DCA} \right]. \tag{2.13}
\]

The Kuhn-Tucker conditions of (2.13) are:

\[
\frac{\partial L_{it}}{\partial p_{ijt}} = \frac{\partial \pi_{it}}{\partial p_{ijt}} + \frac{\lambda_{JFK}}{q} \frac{\partial Q_{ijt}}{\partial p_{ijt}} + \frac{\lambda_{LGA}}{q} \frac{\partial Q_{ijt}}{\partial p_{ijt}} + \frac{\lambda_{DCA}}{q} \frac{\partial Q_{ijt}}{\partial p_{ijt}} = a_{ijt0} - 2a_1 p_{ijt} + \sum_{h=-l} a_{hj2} p_{hjt} - a_3 D_{ijt} + \left( s_{ijt} + \beta D_{ijt} + p_{Ft} \cdot \frac{n}{q} \cdot M_{ij} \right) a_1
\]

\[
- \frac{a_1}{q} (\lambda_{JFK} + \lambda_{LGA} + \lambda_{DCA}) = 0 \tag{2.14}
\]

\[
\lambda_n \geq 0 \tag{2.15}
\]

\[
\lambda_n \left[ \frac{\sum_h \sum_{k \text{ involves } n} Q_{hkt}}{q} - Z_n \right] = 0, \quad n = JFK, LGA, DCA \tag{2.16}
\]
The last term $-\frac{a_1}{q} (\lambda_{FK} + \lambda_{LGA} + \lambda_{DCA})$ will not exist if there is no route involving any slot controlled airport, then (2.14) would be just the same as (2.5). Thus we interpret the term related to $\lambda_n$ as the slot control factor.

The construction of regression equation is based on our theoretical model. We will keep delay variable and the fuel cost. The effects of rivals’ pricing strategy and all other factors that may affect market structure is measured by Herfindahl-Hirschman Index (HHI). It is the summation of squared market shares and is commonly accepted as a measure of market concentration. In general, the market is more concentrated when HHI is large and a small HHI means there exist more competitors. One might argue that route HHI is endogenous, since the airfares may in turn affect passengers’ decisions in choosing airlines, consequently the shares of passengers may change. In addition, the rivals’ pricing strategies may also affect airline’s entry and exit decision in a particular route market. Although an airline’s entry and exit decision is commonly acknowledged to be based on its own network considerations rather than rivals’ scheduling or pricing strategy, in order to avoid such arguable endogeneity, we will apply lagged HHI data in our regression. Specifically, we use lag-1 HHI as the measurement of competition intensity. In this case, pricing strategies in current period cannot affect historical market structure, thus we make sure that the market structure variable is exogenous.

The remaining LCC factor, vacation factor, slot control factor, origin and destination fixed effects are represented by the corresponding dummy variables. The LCC dummy equals to one if the flight is operated by a low-cost carrier. The vacation dummy equals to one if the flight was flying from other states to a destination in Florida or California in the first quarter of a year as these two states are popular choices for Americans to spend a warm winter with beach and sunshine. The slot control dummy equals to one if either origin or destination airport is slot controlled. We additionally add year and quarter dummies as fixed effects and write the primary regression equation as following
\[ \ln(\text{Airfare})_{i,j,t} = \beta_0 + \beta_1 \text{HHI}_{i,j,t-1} + \beta_2 \text{Expected Delay}_{i,j,t} \]
\[ + \beta_3 \text{Fuel Price}_t \times \text{Miles Flown}_j + \beta_4 \text{Slot Control}_j + \beta_5 \text{Vacation}_{j,t} \]
\[ + \beta_6 \text{LCC}_{i,j,t} + \sum \beta_n \text{Year} + \sum \beta_n \text{Quarter} \]
\[ + \sum \beta_n \text{Origin} + \sum \beta_n \text{Destination} + \epsilon_{i,j,t}. \] (2.17)

By substituting (2.9) into (2.3), we can write airline \( i \)’s equilibrium quantity in route \( j \) over period \( t \) as a function of the unique constant \( a_{ijt0} \), number of firms in the same route market, the corresponding expected delay and fuel cost. Thus empirically we change the dependent variable in (2.17) and run the following regression on passenger volume per day.

\[ \ln(\text{Passenger per day})_{i,j,t} = \beta_0 + \beta_1 \text{HHI}_{i,j,t-1} + \beta_2 \text{Expected Delay}_{i,j,t} \]
\[ + \beta_3 \text{Fuel Price}_t \times \text{Miles Flown}_j + \beta_4 \text{Slot Control}_j + \beta_5 \text{Vacation}_{j,t} \]
\[ + \beta_6 \text{LCC}_{i,j,t} + \sum \beta_n \text{Year} + \sum \beta_n \text{Quarter} \]
\[ + \sum \beta_n \text{Origin} + \sum \beta_n \text{Destination} + \epsilon_{i,j,t}. \] (2.18)

The standard errors are clustered at route level since the observations within the same route are closely related. First, flights within the same route experience the same air traffic volume. The National Aviation System (NAS) will impose air traffic control when air traffic is heavy. Second, flights within the same route will affected by very similar weather condition at origin, destination and along halfway, which may eventually lead to weather delay.

2.2.2 Delay measurement

When making the purchase decision, the flight has not departed so the consumer does not know the actual delay information. Consumers’ decisions are made based on their own expectations about the delay of their booked flights. In this sub-section, we establish several proximations for the consumer to predict the upcoming delay and form his expectation.
Flight delay information is now more accessible. Passengers can easily track flights and check their recent on-time performance through website like “FlightStats”6 or mobile apps such as “VariFlight”. In most cases, passengers are provided with the delay information of the past month. In order to match the period construction in our model, we use the lag-one average delay of an airline in a certain route to predict the expected delay in current period. It mainly reflects delay caused by recent operating factors like change in airport’s policy or flight rescheduling by particular airline(s). The lagged delay time can be viewed as exogenous variable since it is historical data available at time $t$.

$$Expected Delay_{i,j,t} = \text{Average Delay}_{i,j,t-1}$$

Similarly to Zou and Hansen’s (2014) work, we also apply the lag-four average delay as one of our delay measurements. This average delay of the same season last year mainly reflects delay caused by weather condition. In real life, users have to pay for the data in order to backtrack the on-time performance of a particular flight for such long period, so this information is usually not referred by passengers.

$$Expected Delay_{i,j,t} = \text{Average Delay}_{i,j,t-4}$$

Combining the ideas of the first two proximations together, expected delay may also be predicted by weighted average of historical delays in past four quarters. We also construct an AR(4) model containing average delay time of all quarters in the past year as our third measurement.

$$Expected Delay_{i,j,t} = \alpha_0 + \alpha_1 \text{Average Delay}_{i,j,t-1} + \alpha_2 \text{Average Delay}_{i,j,t-2} + \alpha_3 \text{Average Delay}_{i,j,t-3} + \alpha_4 \text{Average Delay}_{i,j,t-4} + \epsilon_{i,j,t}$$

While the autoregressive model suggests that there is linear relationship between current delay and previous on-time performance, one may also argue that delay is mainly affected by unexpected random shocks. In this case, the moving average model may give a better prediction.

$$Expected Delay_{i,j,t} = \text{Delay Rate}_{i,j,t-1}$$

---

6 Website can be found at www.flightstats.com.
\[ ExpectedDelay_{i,j,t} = DelayRate_{i,j,t-4} \]

From the passengers’ point of view, they may care about how likely the flight is going to be delayed in addition to how long the average delay may take. Accordingly, we use the historical delay rate as an additional proxy for expected delay. A commonly accepted international rule is that flights with delay time longer than 15 minutes are considered as delayed flights. Delay rate is defined as the percentage of delayed flights in the total number of flights. The higher the rate is, the more likely a flight operated by airline \( i \) in route \( j \) is going to arrive after scheduled time.

2.3 Data

In the United States, airlines are required by law to provide all flight’s information to the federal government. All datasets we use in our estimation are from the U.S. Bureau of Transportation Statistics (BTS). Our sample covers the period from the first quarter of 2013 to the second quarter of 2019. During this period, the global economy has recovered from the financial crisis and the market structure of airlines is generally stable. The sample routes are select based on the size of passenger volume from the first table of consumer airfare report titled “Top 1,000 Contiguous State City-Pair Markets”. This table contains 1,000 largest city-pair markets in the 48 contiguous states of U.S.. Considering that the passenger demand is found to have significant impact on airfare by almost all literatures and we do not have it on the right hand side of our regression, we manually group the observations into two samples by their magnitudes of passenger volume and are expecting to find different results in different groups. We pick the top 25% busiest routes with largest passenger volumes per day in the second quarter of year 2016 and consider these routes to be the large market sample. The involved routes in this sample mostly link metropolitan airports or most popular holiday resorts like Tampa and Orlando in Florida. Meanwhile, the bottom 25% routes with smallest passenger volumes are chosen to form the small market sample. The origins and destinations in this sample are mostly secondary airports. The routes not listed in this table do not have large enough passenger volume, their data may fluctuate violently due to unexpected shocks. Thus those routes are not suitable for empirical analysis.
Considering the facts that flights may speed up or, oppositely, take a detour due to unexpected meteorology halfway, we prefer to use arrival delay rather than departure delay in our estimation. There are two versions of the airline on-time performance dataset which provides us the delay information of corresponding flights in the sample routes. One version records delay time to be zero for early arrivals, while the other uses negative numbers to record the accurate minutes for flights that arrive ahead of schedule. Since negative delay time will offset delay impact, we choose the first version of delay data in our estimation. We also ignore the territorial differences in fuel prices and use the U.S. national quarterly average fuel price in our estimation.

The detailed airline market information comes from the Airline Origin and Destination Survey (DB1B) database, a 10% sample of all U.S. domestic itineraries. We directly use the airfare data but eliminate the outliers from the survey: the observations with per passenger airfare lower than $1 or greater than $50,000 are deleted. The former itinerary usually stands for cabin crew repositioning and the later probably results from system error as the most expensive (international) plane ticket in 2020 does not exceed $45,000 per passenger. In our dataset, non-stop miles is the straight-line distance between two airports. Taking detours or connecting halfway will all be recorded into the actual miles flown. If a flight’s miles flown is smaller than the non-stop miles of corresponding route, in most cases it means that the aircraft returned to the origin and the flight is finally cancelled. Since cancellation is not counted in our delay measurements, these observations are deleted. At last, the sample routes’ HHIs are manually calculated based on number of passengers remaining in the sample after the processes described above.
Table 2.1 Descriptive statistics of direct flights in top 25% busiest routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airfare (USD)</td>
<td>240.186</td>
<td>222.5259</td>
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<td>42400</td>
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<tr>
<td>Miles flown (miles)</td>
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<td>153</td>
<td>2804</td>
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<td>Nonstop miles (miles)</td>
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</tr>
<tr>
<td>Fuel price (USD per gallon)</td>
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<td>1.27</td>
<td>3.2</td>
</tr>
<tr>
<td>Lagged HHI</td>
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<td>1115.171</td>
<td>1164.327</td>
<td>9899.817</td>
</tr>
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<td>LCC</td>
<td>0.3325</td>
<td>0.4711</td>
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<td>1</td>
</tr>
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<td>Slot control</td>
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<td>0.4374</td>
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<td>1</td>
</tr>
<tr>
<td>Vacation</td>
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<td>0.2629</td>
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<td>1</td>
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<td></td>
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<td>Variable</td>
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<td>-----------</td>
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<td>Nonstop miles (miles)</td>
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<tr>
<td>Fuel price (USD per gallon)</td>
<td>2.1627</td>
<td>0.6020</td>
<td>1.27</td>
<td>3.2</td>
</tr>
<tr>
<td>Lagged HHI</td>
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<td>1164.327</td>
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<td>LCC</td>
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<td>Slot control</td>
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<td>Vacation</td>
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<td>N</td>
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<td>3,455,885</td>
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Table 2.3 Descriptive statistics of direct flights in bottom 25% busiest routes

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<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>Miles flown (miles)</td>
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<tr>
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<td>3.2</td>
</tr>
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<td>Lagged HHI</td>
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<td>Vacation</td>
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Table 2.4 Descriptive statistics of connecting flights in bottom 25% busiest routes

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<th>Variable</th>
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<th>Max</th>
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<td>Airfare (USD)</td>
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<td>174.6083</td>
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<tr>
<td>Miles flown (miles)</td>
<td>1721.927</td>
<td>666.5324</td>
<td>328</td>
<td>8941</td>
</tr>
<tr>
<td>Nonstop miles (miles)</td>
<td>1404.371</td>
<td>637.1694</td>
<td>175</td>
<td>2700</td>
</tr>
<tr>
<td>Fuel price (USD per gallon)</td>
<td>2.1627</td>
<td>0.6020</td>
<td>1.27</td>
<td>3.2</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>3923.914</td>
<td>2301.333</td>
<td>939.6592</td>
<td>10000</td>
</tr>
<tr>
<td>LCC</td>
<td>0.2275</td>
<td>0.4192</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Slot control</td>
<td>0.0710</td>
<td>0.2568</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0708</td>
<td>0.2565</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>1,472,286</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Miles flown is the recorded actual distance a flight covered in its itinerary. For connecting flights, it includes the distance during landing and taking off at the connecting hub.
- Nonstop miles is the straight line distance between origin and destination airports. For connecting flights, the connecting hub is not relevant in this data.
- Fuel price is the US national quarterly average fuel price per gallon.
- Lagged HHI is the lag-1 Herfindahl-Hirschman Index of each route. It is the summation of squared market shares and values in the range from 0 to 10,000.
- LCC is a dummy variable set to 1 if the operating carrier is a low cost carrier. The list of LCC can be found in Appendix B.1.
- Slot control is a dummy variable set to 1 if either origin or destination airport is a slot controlled airport.
- Vacation is a dummy variable set to 1 if the observation is in the first quarter of a year and the destination of a cross-state flight is California or Florida.
In our estimation, an observation is considered as a connecting flight if the difference between miles flown and nonstop miles is greater than 100 miles. The average lagged HHI of top 25% routes is about 3200, and none of the routes is monopolized by a single firm. The market of bottom 25% routes, especially direct flight market, is more concentrated as the average adjusted HHI increases to more than 3900 and there exists monopolist in some routes. Since connecting flights usually fly longer distance than direct flights, the average fuel cost of connecting flights is much higher than that of direct ones.

**Table 2.5** Descriptive statistics of flights’ on-time performance in top 25% busiest routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Observation</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average lag-1 delay (minutes)</td>
<td>25,734</td>
<td>14.56145</td>
<td>11.80293</td>
<td>0</td>
<td>864</td>
</tr>
<tr>
<td>Lag-1 delay rate</td>
<td>25,747</td>
<td>0.2235879</td>
<td>0.119178</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Average lag-4 delay (minutes)</td>
<td>28,305</td>
<td>14.3011</td>
<td>11.59038</td>
<td>0</td>
<td>864</td>
</tr>
<tr>
<td>Lag-4 delay rate</td>
<td>28,320</td>
<td>0.2203092</td>
<td>0.1187238</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 2.6 Descriptive statistics of flights’ on-time performance in bottom 25% busiest routes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Observation</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average lag-1 delay (minutes)</td>
<td>6,477</td>
<td>13.6026</td>
<td>12.16397</td>
<td>0</td>
<td>240</td>
</tr>
<tr>
<td>Lag-1 delay rate</td>
<td>6,514</td>
<td>0.2133634</td>
<td>.1539329</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Average lag-4 delay (minutes)</td>
<td>7,131</td>
<td>13.38635</td>
<td>12.46017</td>
<td>0</td>
<td>315.5</td>
</tr>
<tr>
<td>Lag-4 delay rate</td>
<td>7,168</td>
<td>0.2094638</td>
<td>.1510051</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Averagely flights in top 25% busiest routes delay for about 14 minutes. Although the average delay is quite close to 15 minutes, only about 22% of direct flights actually arrive more than 15 minutes later than schedule. However, the route with worst on-time performance has the lagged delay rate as high as 100%. The on-time performance slightly improves in bottom 25% busiest routes. The average lagged delay decreases to 13 minutes and the delay rate drops to 0.21 as secondary airports normally have less traffic congestion. But a notable issue is that the standard deviations of this sample is also larger than those of metropolitan sample, which means that the on-time performance in this sample fluctuates more widely than that in metropolitan sample.

Table 2.7 Estimated coefficients in AR(4) model of top 25% busiest routes

<table>
<thead>
<tr>
<th>Variables</th>
<th>Average lag-1 delay</th>
<th>Average lag-2 delay</th>
<th>Average lag-3 delay</th>
<th>Average lag-4 delay</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficients</td>
<td>0.2936*** (0.0071)</td>
<td>0.0780*** (0.0073)</td>
<td>0.1366*** (0.0075)</td>
<td>0.1823*** (0.0072)</td>
<td>4.4913*** (0.1269)</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
As stated in section 2.2.2, we construct an autoregressive model as well as moving average model to estimate the expected delay using time series delay data. When applying time series data, we need the data to be continuous and stable over time. However, the dataset of bottom 25% routes does not meet this requirement. Most airlines did not continuously operate these routes in every quarter during the sample period. Therefore, the AR(4) and MA(4) estimated delay only exist in the top 25% routes sample. The estimated coefficients in Table 2.7 show that, in the AR(4) model, lag-1 data carries the heaviest weight in affecting current on-time performance. Such result is not surprising since the statistics presented by BTS shows that over 90% of delay is caused by all kinds of recent operating factors such as aircraft arriving late, air carrier’s maintenance and intervention from the National Aviation System. In later sections, we will use the estimated coefficients in Table 2.7 to predict expected delay in current periods.

2.4 Delay Impact on Airfare

We believe that the variation of prices caused by flight delay is the final result of the battle between demand and cost effect: airfare will drop if demand effect dominates cost effect and vice versa. In this section, we will run regressions of airfare on the various delay measurements discussed above. As is stated by Ball et al (2010), delay impacts of the same flight may vary depending on passengers’ itineraries. To be more specific, even though all passengers on a delayed flight experience the same delay time, their final arrival delay may have great difference since transferring passengers may miss the connection. Therefore, nonstop passengers and multi-flight-leg ones should be separated. It is also notable that there is another type of flights which land halfway and carry extra passengers with the original passengers remaining onboard throughout the whole trip. Although these flights are not non-stop, passengers do not need to make any transfer during their trips. Thus, for those original passengers, there is no risk of connection failure that caused by delay in the first lag. In aviation industry, this type of flights along with non-stop flights are called direct flights, which stand for flights linking two points with no change in the flight number. We will use (2.17) as our regression equation in this section and run separate regressions for direct and connecting flights. Since all delay
measurements use historical data only, the delay variables can be viewed as exogenous. The application of lagged HHI avoids the potential endogeneity problem of market structure variable. There are two elements in fuel cost: one is fuel price and the other is flight’s miles flown. Since airlines are price takers of the fuel and flight’s miles flown is mainly affected by geographical distance, both elements are exogenous. The remaining dummy variables are all socially or geographically determined.

Table 2.8 Airfare estimation results for direct flights in top 25% busiest routes

<table>
<thead>
<tr>
<th></th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0.0004 (0.0006)</td>
<td>-0.0005 (0.0007)</td>
<td>0.0030 (0.0020)</td>
<td>0.0018 (0.0015)</td>
<td>0.1699*** (0.0487)</td>
<td>0.0610 (0.0518)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>-0.0115 (0.0297)</td>
<td>-0.0298 (0.0303)</td>
<td>-0.0249 (0.0303)</td>
<td>-0.0249 (0.0303)</td>
<td>-0.0109 (0.0298)</td>
<td>-0.0287 (0.0304)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1797*** (0.0073)</td>
<td>0.1793*** (0.0073)</td>
<td>0.1812*** (0.0073)</td>
<td>0.1812*** (0.0073)</td>
<td>0.1801*** (0.0073)</td>
<td>0.1795*** (0.0072)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.5852*** (0.0174)</td>
<td>-0.5741*** (0.0177)</td>
<td>-0.5706*** (0.0175)</td>
<td>-0.5704*** (0.0175)</td>
<td>-0.5904*** (0.0174)</td>
<td>-0.5767*** (0.0176)</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0265** (0.0130)</td>
<td>0.0283** (0.0125)</td>
<td>0.0272** (0.0126)</td>
<td>0.0277** (0.0126)</td>
<td>0.0271** (0.0131)</td>
<td>0.0279** (0.0126)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0916*** (0.0199)</td>
<td>-0.0988*** (0.0199)</td>
<td>-0.0955*** (0.0199)</td>
<td>-0.0959*** (0.0199)</td>
<td>-0.0901*** (0.0198)</td>
<td>-0.0982*** (0.0199)</td>
</tr>
<tr>
<td>Observations</td>
<td>20,922,436</td>
<td>20,128,759</td>
<td>19,812,792</td>
<td>19,812,792</td>
<td>20,922,715</td>
<td>20,129,299</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1064</td>
<td>0.1061</td>
<td>0.1059</td>
<td>0.1059</td>
<td>0.1065</td>
<td>0.1061</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
Tables 2.8 and 2.9 show regression results for metropolitan market sample. Most coefficients have expected signs: fuel cost has positive effect on airfare and existence of LCC will dramatically lower the price level. The delay impact shown by Tables 2.8 and 2.9 seems to tell us that the widely applied lag-4 delay data does not work the same way as the findings in literature. Airlines may not take seasonal weather condition into consideration when determining pricing strategies since it is also not reliable, from the angle of meteorology, to predict extreme weather condition according to historical data of the same season one year ago. Moreover, weather delay only counts a very small fraction of all delay cases (BTS, n.d.), which makes its impact neglectable.
We find that delay time has no significant impact on the airfare of direct flights, yet lag-1 delay rate may affect airline’s pricing strategy. Specifically, the estimated coefficient implies that one more percent of lag-1 delay rate would increase the airfare of direct flights by 0.17%. Considering the fact that each airline has high frequency of direct flights in these routes, such result is reasonable because it is easy for airlines to endorse tickets and reschedule aircrafts for passengers. The additional cost from several exceptional cases might be neglectable to the firm, and the airlines may not want to take the risk of losing customers by raising airfare. However, such tolerance has a limit. Although the increase of delay time of already delayed flights may not affect airline’s pricing strategy, the impact of lag-1 delay rate on airfare is significant. It is more likely that airlines face additional cost, especially cost of aircraft repositioning, when percentage of delayed flights goes up. In this case, firms may choose to pass part of increased cost burden to passengers in the way of adjusting prices in the upcoming period. Such effect does not last long as lag-4 delay rate no longer has significant impact on airfare.

When it comes to connecting flights, while all other delay measurements do not show significant impact on airfare, the delay coefficient is significantly positive when lag-1 average time is applied. Specifically for passengers taking multi-lag flights, delay of first lag flight may result in failure in catching the connection, under which circumstance the delay time will be extremely long. In this case, besides the extra cost of endorsing tickets, airlines usually have to offer compensations, such as free accommodation, meals and air ticket coupons, to passengers who get affected. Thus, when operating connecting flights over routes with longer delay time, airlines tend to price higher. In addition, even though lag-1 average delay time shows significantly positive impact in this regression, the effect of lag-4 average delay remains insignificant. It means that, opposite to recent delay data, the on-time performance more than one quarter ago is less likely to affect airline’s pricing strategy.

If a route’s origin or destination involves a slot controlled airport, the airfare is reduced by nearly 10% for direct flights and about 6% for connecting flights. A possible reason of
such result is that carriers usually pay less than the market clearing price for slots since it is widely believed that the congested airports charge less, but there is indeed the issue of whether they will pass on the savings to consumers. Our results suggest that airlines may choose to share such benefit with consumers when facing rival’s competition in the route market.

Table 2.10 Airfare estimation results for direct flights in bottom 25% busiest routes

<table>
<thead>
<tr>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>−0.0027*** (0.0009)</td>
<td>−0.0005 (0.0005)</td>
<td>−0.1804*** (0.0684)</td>
<td>−0.0258 (0.0555)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>−0.0447 (0.0274)</td>
<td>−0.0961*** (0.0280)</td>
<td>−0.0429 (0.0275)</td>
<td>−0.0957*** (0.0280)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1160*** (0.0188)</td>
<td>0.1001*** (0.0210)</td>
<td>0.1165*** (0.0190)</td>
<td>0.1008*** (0.0211)</td>
</tr>
<tr>
<td>LCC</td>
<td>−0.9110*** (0.0575)</td>
<td>−0.8542*** (0.0689)</td>
<td>−0.9083*** (0.0578)</td>
<td>−0.8546*** (0.0690)</td>
</tr>
<tr>
<td>Vacation</td>
<td>−0.0265 (0.0188)</td>
<td>0.0035 (0.0173)</td>
<td>−0.0269 (0.0186)</td>
<td>−0.0043 (0.0175)</td>
</tr>
<tr>
<td>Slot control</td>
<td>−0.0481 (0.0692)</td>
<td>−0.0307 (0.0766)</td>
<td>−0.0437 (0.0708)</td>
<td>−0.0315 (0.0772)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,293,208</td>
<td>1,144,372</td>
<td>1,293,254</td>
<td>1,144,392</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1432</td>
<td>0.1315</td>
<td>0.1431</td>
<td>0.1315</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
Table 2.11 Airfare estimation results for connecting flights in bottom 25% busiest routes

<table>
<thead>
<tr>
<th>In(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0.0002 (0.0005)</td>
<td>0.0001 (0.0003)</td>
<td>−0.0379 (0.0331)</td>
<td>−0.0282 (0.0330)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.0823*** (0.0279)</td>
<td>0.0754** (0.0294)</td>
<td>0.0838*** (0.0281)</td>
<td>0.0760** (0.0295)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.0666*** (0.0073)</td>
<td>0.0639*** (0.0074)</td>
<td>0.0673*** (0.0073)</td>
<td>0.0637*** (0.0074)</td>
</tr>
<tr>
<td>LCC</td>
<td>−0.5103*** (0.0490)</td>
<td>−0.5024*** (0.0490)</td>
<td>−0.5113*** (0.0484)</td>
<td>−0.5030*** (0.0487)</td>
</tr>
<tr>
<td>Vacation</td>
<td>−0.0168 (0.0279)</td>
<td>−0.0137 (0.0266)</td>
<td>−0.0220 (0.0274)</td>
<td>−0.0141 (0.0265)</td>
</tr>
<tr>
<td>Slot control</td>
<td>−0.0650** (0.0276)</td>
<td>−0.0678** (0.0264)</td>
<td>−0.0646** (0.0275)</td>
<td>−0.0675** (0.0264)</td>
</tr>
<tr>
<td>Observations</td>
<td>152,337</td>
<td>142,329</td>
<td>152,420</td>
<td>142,329</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.0565</td>
<td>0.0565</td>
<td>0.0564</td>
<td>0.0556</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

Tables 2.10 and 2.11 show regression results for small market sample. Since the small markets sample cannot pass the unit root test, we cannot perform AR(4) estimation in this sample. With all the other independent variables showing the same features as large market, delay variables do have different effects as we are expecting. The results in Table 2.10 for direct flights again confirm our argument that lag-4 delay is not a good measurement if we want to study delay impact. However, showing completely different results as Table 2.5, lag-1 delay and airfare are negatively correlated in this sample. We find that one more minute lag-1 delay tends to make airfare of direct flights 0.27% less expensive and unit increase in the percentage of lag-1 delayed flights tends to decrease such airfare by about 0.18%. When the routes do not have as many passengers as those
linking metropolitan airports, every single passenger counts heavier weight in equilibrium passenger volume. Therefore, the impact of losing unit demand on profit loss is expected to be much larger than that in metropolitan sample. The demand effect in this sample is consequently much stronger. It is not surprising that demand effect dominates cost effect in small markets. For connecting flights, cost effect grows stronger comparing with that of direct flights, it offsets the demand effect and makes coefficients of delay insignificant.

Another notable result is that HHI and airfare of direct flights are not positively correlated, some coefficients are even significantly negative. Normally when HHI is small, the market is more diversified, competition among firms in the same market will lower the price. Thus the coefficient of HHI should be positive theoretically. The negative coefficients imply that airlines who are enjoying lower operation cost when have their exclusive terminals or own boarding gates at dominated hubs may deliberately price direct flight tickets lower to attract more passengers (Zou and Hansen, 2010). Such cost benefit possibly disappears when operating a connecting flight as the airline may no longer have the same priority in connecting airports. Therefore, coefficients of HHI in the connecting flights estimation become positive as they are expected to be based on theory.

<p>| Table 2.12 Airfare estimation results for top 25% busiest routes: pooled sample |
|---------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| ln(Airfare)   | Lag-1 delay     | Lag-4 delay     | AR(4) delay     | MA(4) delay     | Lag-1 delay     | Lag-4 delay     |
|               | average         | average         | estimated       | delay           | rate            | rate            |
| Delay         | 0.0002          | −0.0006         | 0.0025          | 0.0014          | 0.1503***       | 0.0534          |
|               | (0.0006)        | (0.0007)        | (0.0019)        | (0.0014)        | (0.0470)        | (0.0495)        |
| Lagged HHI    | −0.0102         | −0.0072         | −0.0021         | −0.0022         | −0.0107         | −0.0061         |
|               | (0.0291)        | (0.0296)        | (0.0297)        | (0.0297)        | (0.0292)        | (0.0297)        |
| Fuel cost     | 0.1847***       | 0.1841***       | 0.1860***       | 0.1860***       | 0.1849***       | 0.1842***       |
|               | (0.0068)        | (0.0068)        | (0.0068)        | (0.0068)        | (0.0068)        | (0.0068)        |
| LCC           | −0.5670***      | −0.5567***      | −0.5533***      | −0.5531***      | −0.5718***      | −0.5591***      |
|               | (0.0163)        | (0.0165)        | (0.0165)        | (0.0165)        | (0.0163)        | (0.0165)        |</p>
<table>
<thead>
<tr>
<th>Vacation</th>
<th>0.0254** (0.0123)</th>
<th>0.0264** (0.0118)</th>
<th>0.0249** (0.0119)</th>
<th>0.0253** (0.0120)</th>
<th>0.0249** (0.0124)</th>
<th>0.0259** (0.0119)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slot control</td>
<td>-0.0894*** (0.0189)</td>
<td>-0.0964*** (0.0190)</td>
<td>-0.0935*** (0.0191)</td>
<td>-0.0939*** (0.0191)</td>
<td>-0.0880*** (0.0188)</td>
<td>-0.0958*** (0.0190)</td>
</tr>
<tr>
<td>Observations</td>
<td>22,662,089</td>
<td>21,816,734</td>
<td>21,424,515</td>
<td>21,424,515</td>
<td>22,662,608</td>
<td>21,817,464</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1089</td>
<td>0.1087</td>
<td>0.1086</td>
<td>0.1086</td>
<td>0.1090</td>
<td>0.1087</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

**Table 2.13** Airfare estimation results for bottom 25% busiest routes: pooled sample

<table>
<thead>
<tr>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>-0.0025*** (0.0008)</td>
<td>-0.0004 (0.0004)</td>
<td>-0.1824*** (0.0610)</td>
<td>0.0251 (0.0485)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>-0.0259 (0.0265)</td>
<td>-0.0768*** (0.0267)</td>
<td>-0.0241 (0.0266)</td>
<td>-0.0767*** (0.0268)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1591*** (0.0140)</td>
<td>0.1420*** (0.0148)</td>
<td>0.1596*** (0.0141)</td>
<td>0.1423*** (0.0148)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.8703*** (0.0572)</td>
<td>-0.8105*** (0.0676)</td>
<td>-0.8675*** (0.0575)</td>
<td>-0.8107*** (0.0678)</td>
</tr>
<tr>
<td>Vacation</td>
<td>-0.0292 (0.0185)</td>
<td>0.0024 (0.0173)</td>
<td>-0.0295 (0.0183)</td>
<td>-0.0032 (0.0174)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0232 (0.0570)</td>
<td>-0.0063 (0.0572)</td>
<td>-0.0191 (0.0581)</td>
<td>-0.0071 (0.0576)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,445,545</td>
<td>1,286,701</td>
<td>1,445,674</td>
<td>1,286,721</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1342</td>
<td>0.1228</td>
<td>0.1342</td>
<td>0.1228</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
As a robustness check, we have also estimated our model using the pooled samples of both direct and connecting flights. The results of these estimations are presented in Tables 2.12 and 2.13. They are generally consistent with the findings from the baseline specifications. That is, delays have a positive effect on airfare in large markets, but a negative effect in small markets. To be more specific, we see from Table 2.12 that in the metropolitan markets lag-1 delay rate has significantly positive coefficient. In small market sample (Table 2.13), both lag-1 delay rate and lag-1 average delay have a significantly negative effect on prices. Generally, the regression results of the pooled sample is driven by direct flights as their number of observations are much more than connecting flights.

2.5 Delay Impact on Passenger Volume

In this section, we will use equation (2.18) to estimate the delay impact on equilibrium passenger volume. Since the passenger volume data does not distinguish between direct and connecting flights, the regressions are run in a pooled sample of both types of flights.

Table 2.14 Passenger estimation results for top 25% busiest routes

<table>
<thead>
<tr>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>–0.0003 (0.0003)</td>
<td>–0.0007 (0.0005)</td>
<td>–0.0020 (0.0015)</td>
<td>–0.0014 (0.0011)</td>
<td>–0.0559* (0.0335)</td>
<td>–0.1178*** (0.0428)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.1940** (0.0746)</td>
<td>0.1887** (0.0762)</td>
<td>0.1911** (0.0764)</td>
<td>0.1911** (0.0764)</td>
<td>0.1936*** (0.0745)</td>
<td>0.1881** (0.0762)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>–0.1408*** (0.0208)</td>
<td>–0.1440*** (0.0207)</td>
<td>–0.1442*** (0.0208)</td>
<td>–0.1442*** (0.0208)</td>
<td>–0.1409*** (0.0207)</td>
<td>–0.1441*** (0.0207)</td>
</tr>
<tr>
<td>LCC</td>
<td>0.0406*** (0.0102)</td>
<td>0.0420*** (0.0100)</td>
<td>0.0415*** (0.0099)</td>
<td>0.0415*** (0.0099)</td>
<td>0.0420*** (0.0103)</td>
<td>0.0449*** (0.0099)</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0335 (0.0295)</td>
<td>0.0406 (0.0300)</td>
<td>0.0442 (0.0304)</td>
<td>0.0439 (0.0303)</td>
<td>0.0335 (0.0295)</td>
<td>0.0400 (0.0299)</td>
</tr>
<tr>
<td>Slot control</td>
<td>0.3423** (0.3783**)</td>
<td>0.3787** (0.3787**)</td>
<td>0.3787** (0.3787**)</td>
<td>0.3423** (0.3787**)</td>
<td>0.3780** (0.3780**)</td>
<td></td>
</tr>
</tbody>
</table>
Observations | (0.1701) | (0.1828) | (0.1847) | (0.1847) | (0.1700) | (0.1827)
--- | --- | --- | --- | --- | --- | ---
25,515 | 22,494 | 21,861 | 21,861 | 25,528 | 22,499
\(R^2\) | 0.7931 | 0.7947 | 0.7959 | 0.7958 | 0.7931 | 0.7949

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

Table 2.15 Passenger estimation results for bottom 25% busiest routes

<table>
<thead>
<tr>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>-0.0002 (0.0001)</td>
<td>0.0001 (0.0001)</td>
<td>-0.0128 (0.0099)</td>
<td>-0.0001 (0.0143)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.0441** (0.0177)</td>
<td>0.0418** (0.0185)</td>
<td>0.0441** (0.0176)</td>
<td>0.0417** (0.0195)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>-0.0088 (0.0102)</td>
<td>-0.0085 (0.0109)</td>
<td>-0.0088 (0.0102)</td>
<td>-0.0085 (0.0109)</td>
</tr>
<tr>
<td>LCC</td>
<td>0.0156 (0.0096)</td>
<td>0.0150 (0.0194)</td>
<td>0.0157 (0.0096)</td>
<td>0.0150 (0.0094)</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0011 (0.0095)</td>
<td>-0.0094 (0.0102)</td>
<td>0.0014 (0.0095)</td>
<td>-0.0094 (0.0102)</td>
</tr>
<tr>
<td>Slot control</td>
<td>0.0403* (0.0206)</td>
<td>0.0557** (0.0257)</td>
<td>0.0404** (0.0203)</td>
<td>0.0559** (0.0257)</td>
</tr>
<tr>
<td>Observations</td>
<td>6,467</td>
<td>5,029</td>
<td>6,470</td>
<td>5,030</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.6771</td>
<td>0.7008</td>
<td>0.6772</td>
<td>0.7010</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

Tables 2.14 and 2.15 present the estimated coefficients of top 25% and bottom 25% busiest routes. The delay coefficients in Table 2.15 give us two pieces of information. First, the length of delay does not have a significant impact on passenger volume, but the
likelihood of delay does. Second, airlines will probably suffer consumer loss when delay rate increases, as we find that 1% increase in lag-1 and lag-4 delay rate may decrease daily passenger volume by 0.056% and 0.118% respectively. This result is not surprising since the outputs in Table 2.12 show that firms tend to increase airfare or at least offer no discount as delay occurs more frequently. Besides, in metropolitan markets, there are usually enough alternative airlines operating the same route. Passengers have a wide range of choices to fly with the carrier with best on-time performance.

However, the pattern changes in the secondary airport sample. The insignificant coefficients of delay in Table 2.15 indicate that the total passenger volume is not likely to be affected by delay in the least busy routes. There are two possible reasons behind such result. First, as is presented in Table 2.13, airlines tend to offer price cut in this sample when delay occurs. The lower airfare may offset the effect of worse on-time performance. Second, since this sample involves more secondary airports, it is more likely that travelers only have limited choices in flights and carriers. It may be difficult or even cost more to find alternative routes or means of transportation in order to simply avoid delay and save time. Thus, passengers tend to stick to their original choices either actively or passively.

In metropolitan market sample, fuel cost and passenger volume is found to be negatively related with each other. As is presented in Tables 2.12, higher fuel cost may lead to more expensive airfare. As a result, passenger volume tends to decrease. The existence of LCC significantly increases passenger volume as their low airfare are attractive to many travelers. It is notable that, however, neither fuel cost nor the LCC dummy has significant impact on the passenger volume in least busy routes. Such results indicate that passengers in least busy routes behave like loyal customers of certain airlines, but it may just result from lack of alternative choices.

2.6 Conclusion

In this paper, we use the regression equation derived from equilibrium theory to estimate the delay impact on airfare and passenger volume in metropolitan and secondary
airport markets in the United States. Our results show that airfare tends to increase in response to more serious delay in metropolitan markets, but delay tends to decrease prices in small markets. These results indicate that, in large markets, cost effect is likely to dominate the demand effect, while the opposite may be true in small markets. As a result of airfare changes due to delay, we find that flight delay may cause customer loss to the corresponding airlines in metropolitan market, but has little impact on passenger volume in secondary airport market.

To some extent, our findings remain valid even during the COVID-19 pandemic. In the year 2020, the on-time performance of US domestic flights improved greatly as the delay rate decreases from 20% in normal years to 15% (US BTS, 2021). Being consistent with the relationship between airfare and flights’ on-time performance we discover in Table 2.12, the national-level domestic average fare drops about 80 US dollar since the second quarter in 2020 (US BTS, 2020). Although there might be other reasons, we do believe that improvement in flight’s on-time performance partially contribute to such price drop. The actual delay impact during the pandemic requires further study.
Chapter 3: Flight Delay Impact: A Welfare Study

3.1 Introduction

The airline industry is not only a traditional transportation industry, but also can be classified as a service industry. Besides the on board service provided by crew members, the airline service quality is also evaluated by airline safety (Rose, 1990), flights’ on-time performance (Prince and Simon, 2009), number of connecting and the length of layout time (Youssef and Hansen, 1994), etc. While airplanes are overall the safest mode of transportation (BTS, 2020) and consumers are aware of the flight’s itinerary before purchasing the ticket, the on-time performance has drawn our attention because of its unpredictability.

In my second chapter, by running regressions using the reduced forms of airfare and passenger volume, we estimate the effect of flight delay on equilibrium price and quantity. Within certain sample groups, we do discover significant delay impact on either equilibrium price or quantity or both when lag-1 delay data is applied to be the delay measurement. However, the welfare analysis related to flight delay is not covered in the previous chapter. This forms our main purpose of this final chapter.

Researchers showed interests in the delay impact on the consumer side long time ago. Early in 1981, Anderson and Kraus (1981) constructed a model which used not only price but also generalized travel time, including frequency and stochastic delay, to estimate equilibrium number of air travelers. However, they failed to estimate the value of travel time because of insufficient variability of the fare and delay series. Morison and Winston (1989) made a large progress as they managed to estimate the values of flying time, transfer time and delay time using their multinomial logit model. They stated that passengers evaluate 1% point change of carrier’s on-time performance by $1.21 per round trip. Yimga (2017) made a further progress as he pointed out that the welfare cost to consumers due to delay varied by the travel distance. He found that the shorter the distance is, the higher loss passengers have to take when facing same length of delay. Thus, in order to protect consumer’s legal rights, a new policy was released by the U.S.
Department of Transportation in 2008 ruling the tarmac delay to be no longer than three hours. Any violation of the rule would result in fines on airlines.

The tarmac rule is in favor of consumers by posting restrictions on delay, but passengers are not the only ones wishing to avoid delay. According to literatures, delays may also be costly to airlines. In early years, the traditional way to estimate the delay cost was simply calculate the product of a cost factor based on reported values per block hour and the delay time (Geissinger, 1988; Odoni, 1995). However, such estimation, especially the value of the cost factor, was based on strong assumptions which were not reliable. For the very first time, using a statistical cost estimation approach, Hansen et al. (2001) stated that delay reduction could generate billions of dollars airline’s annual cost savings. Zou and Hansen (2012) further encouraged improvement in flight’s on-time performance as they discovered that flight inactivity inside the schedule window did not have significant cost impact, which meant that early arrival had no harm on firms. Yimga (2020) even found that an airline might lose market power if it had poor on-time performance.

Combining the delay impact on both consumer’s and firm’s sides, Britto et al. (2012) carried out a welfare study. They firstly constructed a simultaneous equation system and ran two-stage least squares regression twice to estimate the shift of the demand curve and the fare curve in response to the delay shock. They then made use of the shifts to calculate welfare changes of consumers and airlines in different scenarios where delay is partially or completely removed. Based on the theoretical framework of Britto’s paper in welfare calculation, we will extend their study in several aspects in ours. First, we apply three-stage least squares rather than two-stage least squares to solve simultaneous equations. Second, just like my second chapter, we will use different measurements of delay. According to our findings in the previous chapter, lag-1 delay data rather than lag-4 data will be applied to measure flight’s on-time performance.

Our analysis shows that, in American metropolitan airports, both passengers and airlines benefit from improvement in flights’ on-time performance. When lag-1 delay rate is chosen to be the delay measurement, while each existing customer will gain $1.45 if
delay rate is reduced by 10%, airlines’ gain from cost reduction is as small as $0.24 per passenger. These numbers increase proportionally as further delay reduction takes place. While the additional consumer surplus is mostly gained by existing customers, airlines mainly gain excess welfare from new passengers as we see that airlines consistently gain more than $28 from each new passenger. When lagged average delay minute is applied, except the insignificance of the airline’s gain from cost reduction, there is no other qualitative change in our results. We also notice that in the sample markets, a 10% or 20% reduction in delay minutes or rate may not lead to substantial increase in the equilibrium quantity.

In section 3.2, we construct the theoretical model and illustrate the method to calculate the welfares. The data and descriptive statistics are presented in section 3.3. In section 3.4, we firstly present and discuss the estimation results, then calculate the welfare changes of passengers and airlines. At last, the conclusion is drawn in section 3.5.

### 3.2 Methodology

We start this section by model construction. Suppose that there are $I$ airlines operating $J$ routes compete monopolistically in the market. Both passengers and firms would take the delay factor into consideration when making their choices. On demand side, passenger might be driven away by long-time delay. They may choose other airlines with better on-time performance, alternative routes with less congestion or even another mode of transportation if possible. On supply side, flight delay is highly likely to affect airfare through rising costs including but not limited to maintenance costs and costs of aircraft repositioning. A simultaneous equation system is constructed to estimate the delay impact on both sides. We assume that for an airline $i$ operating route $j$ in period $t$, the model is specified as following:

$$Passenger\ Volume_{i,j,t} = \beta_0 + \beta_1 \text{Airfare}_{i,j,t} + \beta_2 \text{Expected Delay}_{i,j,t} + \beta_3 \text{Nonstop Miles}_j$$

$$+ \beta_4 \text{Population}_{j,t} + \beta_5 \text{Personal Income}_{j,t} + \beta_6 \text{LCC}_i,j,t$$

$$+ \sum \beta_n \text{Year} + \sum \beta_n \text{Quarter} + \sum \beta_n \text{Destination} + \epsilon_{i,j,t}, \quad (3.1)$$
\[
\text{Airfare}_{i,j,t} = \alpha_0 + \alpha_1 \text{Passenger Volume}_{i,j,t} + \alpha_2 \text{Fuel Price}_t + \alpha_3 \text{HHI}_{j,t-1} \\
+ \alpha_4 \text{Expected Delay}_{i,j,t} + \alpha_5 \text{Nonstop Miles}_j + \alpha_6 \text{LCC}_{i,j,t} \\
+ \sum \alpha_n \text{Year} + \sum \alpha_n \text{Quarter} + \sum \alpha_n \text{Destination} + \epsilon_{i,j,t}.
\] (3.2)

Equation (3.1) is the demand function. Besides the price and delay effects, we also believe that the passenger volume will be affected by some social variables. Firstly, a larger population in the origin airport’s metropolitan area will provide larger amounts of potential passengers. In addition, the average personal income reflects how developed the origin city is and how wealthy the citizens are. The higher the personal income is, the more likely citizens will choose to travel by air for the purpose of either business or vacation. The existence of low-cost carrier (LCC) may also lower the threshold of affordable air tickets, so that more consumers would be able to afford air travel.

Equation (3.2), which contains factors that would affect the airfare from the supply side, would be taken as reference when airlines are at the pricing stage. The fuel price and non-stop miles variables mainly capture the fuel cost of the flights. The Herfindahl-Hirschman Index (HHI) is incorporated to describe the competition intensity of the route market; it reflects the impact of competitor airlines operating the same route. At last, the LCC dummy distinguishes between the service costs of legacy carriers and low-cost carriers, as an LCC is expected to have significantly lower service costs.

We estimate the equations (3.1) and (3.2) using three-stage least squares (3SLS), which has been proved to be a more efficient method to deal with simultaneous equation system with two equations (Belsley, 1988). Using the estimated coefficients, we expect to observe shifts of the curves when the magnitude of the delay variable changes. The equilibrium market variables under various circumstances with different levels of flight’s on-time performance are then estimated to calculate welfare changes. The welfare calculation will be based on the following graph:
In Figure 3.1, the downward sloping demand curves are defined by equation (3.1) with different levels of delay. The price curves are defined by equation (3.2). Since the equations are assumed to be log linear in regression, they are not drawn as straight lines in the figure. Subscript “0” stands for the situation with original delay data. When flights’ on-time performance is improved, the corresponding equilibrium values and curves are labelled by subscript “1”. Since delay decreases passengers willingness-to-pay (Suzuki, 1999; Zou and Hansen, 2012), we expect the demand curve to shift to the up right when delay is reduced. The fare curve is expected to shift up when fuel price or non-stop miles increase and shift down if the corresponding airline is an LCC. Since delay brings airlines excess cost, when on-time performance improves, we predict the fare curve to shift down as is shown in the above figure.
According to the prediction discussed in the previous paragraph, several shadowed areas will appear as a result of curves’ shifts in response to a hypothetical delay reduction. These areas are the welfare changes that we are looking for. Area 1 represents the welfare gain of existing passengers when delay is reduced. In the situation shown by the above figure, airline’s marginal cost decreases when flight’s on-time performance improves. In this case, airlines will benefit from cost reduction, which is captured by Area 2. Area 1 and 2 together gives us the total additional welfare brought by existing passengers. Besides, we also expect the equilibrium quantity to be larger with less delay. Area 3 is the gain in consumer surplus associated with new customers and Area 4 is the welfare gain by airlines from these new customers. The total amount of gain in consumer surplus is the summation of Area 1 and 3. The total additional welfare gained by firms is the summation of Area 2 and 4.

The calculation of Areas 1 and 3 are straight-forward:

\[
\text{Area 1} = \int_{0}^{p_0} D_1(p) \, dp - \int_{0}^{p_0} D_0(p) \, dp; \tag{3.3}
\]
\[
\text{Area 3} = \int_{p_0}^{p_1} D_1(p) \, dp - p_1(q_1 - q_0). \tag{3.4}
\]

To calculate Areas 2 and 4, the marginal costs \(MC_0\) and \(MC_1\) are obtained by calculating the corresponding marginal revenues from the equation (1) because marginal revenue equals to marginal cost at the equilibrium in monopolistic competition. The problem is that we cannot evaluate \(MC_2\), which is the predicted marginal cost at original quantity after the improvement of flights’ on-time performance. We follow Britto et al.’s work and assume that the difference between the marginal costs at \(q_0\) is equal to the difference between fare curves at the same quantity. Hence, \((MC_2 - MC_0)\) is approximated by \((p_2 - p_0)\), where \(p_2\) is estimated by inserting \(q_0\) into the function \(P_1\). Areas 2 and 4 are then calculated based on the following equations:

\[
\text{Area 2} = (p_2 - p_0) \cdot q_0; \tag{3.5}
\]
\[
\text{Area 4} = (p_1 - MC_0 + p_2 - p_0 + p_1 - MC_1) \cdot \frac{p_1 - q_0}{2}. \tag{3.6}
\]
3.3 Data

All data related to flight status are downloaded from the U.S. Bureau of Transportation Statistics (BTS). Our sample routes are picked from the “Top 1,000 Contiguous State City-Pair Markets” table and contain top 25% routes with largest passenger volume in the second quarter of 2016. The general information of airline market, such as passenger volume, airfare, nonstop miles and HHI, is directly collected or calculated based on the “Airline Origin and Destination (DB1B) Survey”, which is a 10% sample of all US domestic itineraries. The two measurements of expected delay, namely average lag-1 delay and lag-1 delay rate, are obtained from the Airline On-Time Performance Database. We also collect population and average personal income data from U.S. Census Bureau and U.S. Bureau of Economic Analysis respectively. All continuous variables are logged when running the regressions except the delay variable since delay data contain zero values.

Unlike the study in my second chapter where two separate samples, one containing busiest routes and the other being routes with least passengers, are constructed, only the busiest routes are picked in this paper. We have also studied the other sample with least busy routes, but our regression cannot pass the strong instrument test. Therefore, the corresponding results are not resented in this paper.

Table 3.1 Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Volume</td>
<td>2851.784</td>
<td>3840.856</td>
<td>1</td>
<td>80684</td>
</tr>
<tr>
<td>Airfare (USD)</td>
<td>212.7151</td>
<td>78.94966</td>
<td>18.5</td>
<td>1476.481</td>
</tr>
<tr>
<td>Average Lag-1 Delay</td>
<td>14.56276</td>
<td>11.7649</td>
<td>0</td>
<td>864</td>
</tr>
<tr>
<td>(minutes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lag-1 Delay Rate</td>
<td>0.22333</td>
<td>0.117537</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Nonstop Miles (miles)</td>
<td>1049.255</td>
<td>624.5329</td>
<td>164.031</td>
<td>2704</td>
</tr>
<tr>
<td>Fuel Price (USD)</td>
<td>2.14236</td>
<td>0.572358</td>
<td>1.27</td>
<td>3.2</td>
</tr>
<tr>
<td>Population (thousand)</td>
<td>6476.252</td>
<td>4710.267</td>
<td>660.197</td>
<td>19336.46</td>
</tr>
<tr>
<td>Income (USD)</td>
<td>55776.25</td>
<td>9601.95</td>
<td>35572</td>
<td>104921</td>
</tr>
<tr>
<td>--------------</td>
<td>----------</td>
<td>---------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td>Lag-1 HHI</td>
<td>2790.138</td>
<td>911.2832</td>
<td>1043.945</td>
<td>8617.425</td>
</tr>
<tr>
<td>LCC</td>
<td>0.40435</td>
<td>0.490776</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td>25,515</td>
<td></td>
</tr>
</tbody>
</table>

- **Passenger Volume** is the counted number of passengers in DB1B survey who travelled along a sample route with a carrier during a sample quarter.
- **Airfare** is the quarterly average airfare of a sample route operated by an airline.
- **Average Lag-1 Delay** is the average delay time of an airline’s flights in a sample route during a quarter. Early arrival is recorded as 0 minute in the data.
- **Lag-1 Delay Rate** is the proportion of an airline’s delayed flights (arrive 15 minutes later than the scheduled time) in a sample route during a quarter.
- **Nonstop Miles** is the straight line distance between origin and destination airports.
- **Population** is the population of the metropolitan area of the origin city.
- **Income** is the per capita yearly personal income in the metropolitan area of the origin city.
- **Fuel Price** is the US nationwide quarterly average fuel price per gallon.
- **HHI** is Herfindahl-Hirschman Index of each route. It is the summation of squared market shares. The larger this index is, the more concentrated the market will be.
- **LCC** is a dummy variable set to 1 if the operating carrier is a low cost carrier. The list of low-cost carriers in America can be found in the appendix.

### 3.4 Results and Discussions

#### 3.4.1 Delay impact on the shifts of curves

There are commonly two ways to estimate a simultaneous equation system: two-stage least squares (2SLS) and three-stage least squares (3SLS). While 2SLS has advantages in computational convenience, 3SLS is asymptotically more efficient especially for large samples. Such efficiency arises from exploiting covariation between equations (Zellner and Theil, 1962). Considering our large sample size, the 3SLS is preferred in this paper.
We cluster the standard errors by routes since we believe that the observations within the same route are highly correlated with each other. In order to eliminate potential endogeneity in delay and market structural variable, we assume that airlines determine the airfares according to their flights’ on-time performance and the market structure in the last quarter, and apply lag-1 data for both delay variable and HHI. Thus, the only two endogenous variables in this system are passenger volume and airfare and the system is just-identified. The regression outputs can be found in the following table:

**Table 3.2** Estimation results of demand and fare equations

<table>
<thead>
<tr>
<th></th>
<th>Average lag-1 delay</th>
<th>Lag-1 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Passengers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airfare</td>
<td>−4.6117***</td>
<td>−4.3445***</td>
</tr>
<tr>
<td></td>
<td>(1.3945)</td>
<td>(1.4198)</td>
</tr>
<tr>
<td>Expected delay</td>
<td>−0.0236***</td>
<td>−1.7622***</td>
</tr>
<tr>
<td></td>
<td>(0.0028)</td>
<td>(0.1662)</td>
</tr>
<tr>
<td>Distance</td>
<td>1.5229***</td>
<td>1.4479***</td>
</tr>
<tr>
<td></td>
<td>(0.4018)</td>
<td>(0.4103)</td>
</tr>
<tr>
<td>Population</td>
<td>0.5664***</td>
<td>0.5671***</td>
</tr>
<tr>
<td></td>
<td>(0.0400)</td>
<td>(0.0398)</td>
</tr>
<tr>
<td>Income</td>
<td>0.6403</td>
<td>0.6218</td>
</tr>
<tr>
<td></td>
<td>(0.4631)</td>
<td>(0.4682)</td>
</tr>
<tr>
<td>LCC</td>
<td>−1.2717**</td>
<td>−1.1275*</td>
</tr>
<tr>
<td></td>
<td>(0.5945)</td>
<td>(0.6047)</td>
</tr>
</tbody>
</table>

Dummy variables included

<table>
<thead>
<tr>
<th></th>
<th>Average lag-1 delay</th>
<th>Lag-1 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airfare</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passengers</td>
<td>0.1151***</td>
<td>0.1121***</td>
</tr>
<tr>
<td></td>
<td>(0.0070)</td>
<td>(0.0068)</td>
</tr>
<tr>
<td>Expected delay</td>
<td>−1.7 * 10⁻⁵</td>
<td>0.0883***</td>
</tr>
<tr>
<td></td>
<td>(0.00019)</td>
<td>(0.0183)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>−0.1173***</td>
<td>−0.1130***</td>
</tr>
</tbody>
</table>
The second and third columns in Table 3.2 are estimation results associated with two different measures of expected delays. The left column presents estimated coefficients when we use lag-1 average delay as the measurement of expected delay and numbers in the right column are estimation results using lag-1 delay rate. Generally the signs of the coefficients are as expected. Our passenger equation is defined as the demand curve, we expect it to be downward sloping in price-quantity space. The negative airfare coefficient meets such requirement. Delay is also negatively correlated with passenger volume, which means that the demand curve will shift to the up right when flight’s on-time performance improves. It is also not surprising that the coefficients of distance and population are both positive. Regarding the positive coefficient of distance, air travel is so far the most convenient transportation method to travel long distance. As distance between origin and destination increases, taking an airplane becomes the priority choice of more passengers. In terms of population, a larger local population provides more potential customers for the airline industry. The interesting results that draw our attention are the coefficient of personal income and low-cost carrier. Intuition suggests that both variables should be positively related with passenger volume because of the restriction of personal economic condition. To be precise, low-income consumers may not be able to afford air travel, or may have to fly with low-cost carriers for lower expenditure. However, our results show that personal income does not have significant impact on the
passenger equation and low-cost carrier will decrease passenger volume. These outputs may indicate that, in American metropolitans, consumers’ choices are not restricted by economic condition. On contrary, passengers in sample origins value on board service provided by airlines, so low-cost carriers with less service may not usually be preferred.

In the airfare equation, just as expected, passengers, distance and fuel price all have positive effect on airfare, while the LCC dummy is negatively related to the price. The negative estimated coefficient of HHI suggests that, in sample routes, dominant airlines who may have their exclusive terminals and enjoy lower operating costs tend to price lower for profit maximization purpose (Zou and Hansen, 2010). When we apply average delay minutes as the delay measurement, its impact on the fare equation is not significant. However, if the delay measurement is the lagged delay rate, we observe, from the right column, positive relationship between the delay variable and airfare. Because the mean value of delay minutes is more likely to be affected by extreme values in the sample data, the difference between estimation outputs suggests that airlines may consider delay rate rather than average delay time when determining their pricing strategies.

3.4.2 Delay impact on welfare

Using the estimated coefficients in Section 3.4.1, we are now able to quantify the welfare impact of delays, as illustrated by the shadowed areas in Figure 3.1. By applying the original delay data, in order to make sure that every observation lies on the corresponding curve so that the functions we use to calculate the areas remain valid for all observations in the sample, the original price $p_0$ and quantity $q_0$ are also re-calculated using the estimated coefficients in Table 3.2. We consider three hypothetical scenarios: a 10% reduction in delays, which quantitatively means the average delay time is about 1.5 minutes shorter or the delay rate decreases by 0.022, a 20% reduction in delays, and complete elimination of delays. The following tables present the estimated results.\footnote{The derivation of formulas used to calculate welfares can be found in the appendix}
### Table 3.3 Estimated welfares using average lag-1 delay

<table>
<thead>
<tr>
<th></th>
<th>10% delay reduction</th>
<th>20% delay reduction</th>
<th>No delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing passenger’s gain (1)</td>
<td>19.09 (1.14)</td>
<td>38.35 (2.30)</td>
<td>199.10 (12.14)</td>
</tr>
<tr>
<td>Firm’s gain from cost reduction (2)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>New passenger’s gain (3)</td>
<td>0.14 (0.29)</td>
<td>0.56 (0.58)</td>
<td>16.70 (2.92)</td>
</tr>
<tr>
<td>Firm’s gain from new passengers (4)</td>
<td>9.95 (26.60)</td>
<td>20.36 (26.79)</td>
<td>123.70 (28.33)</td>
</tr>
<tr>
<td>Total</td>
<td>29.17 (1.70)</td>
<td>59.27 (3.34)</td>
<td>339.49 (15.13)</td>
</tr>
</tbody>
</table>

(In the parenthesis are estimated welfares per capita)

### Table 3.4 Estimated welfares using lag-1 delay rate

<table>
<thead>
<tr>
<th></th>
<th>10% delay reduction</th>
<th>20% delay reduction</th>
<th>No delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing passenger’s gain (1)</td>
<td>24.34 (1.45)</td>
<td>48.94 (2.92)</td>
<td>255.56 (15.29)</td>
</tr>
<tr>
<td>Firm’s gain from cost reduction (2)</td>
<td>4.05 (0.24)</td>
<td>8.10 (0.48)</td>
<td>40.11 (2.39)</td>
</tr>
<tr>
<td>New passenger’s gain (3)</td>
<td>0.30 (0.45)</td>
<td>1.21 (0.91)</td>
<td>36.04 (4.45)</td>
</tr>
<tr>
<td>Firm’s gain from new passengers (4)</td>
<td>15.71 (28.66)</td>
<td>32.37 (28.91)</td>
<td>206.43 (30.86)</td>
</tr>
<tr>
<td>Total</td>
<td>44.40 (2.54)</td>
<td>90.61 (4.99)</td>
<td>538.15 (21.62)</td>
</tr>
</tbody>
</table>

(In the parenthesis are estimated welfares per capita)
For Areas 1 and 2, per capita welfares are calculated by dividing the areas by original quantity $q_0$. For Areas 3 and 4, the denominator used to calculate the per capita welfare is new passengers entering the market, namely $(q_1 - q_0)$. We also divide the total welfare, which is the sum of all four areas, by the estimated equilibrium quantity with improved on-time performance $q_1$ to get the total welfare per capita in the last row of each table. Thus, $p_2$ equals to $p_0$ and all values related to Area 2 will be zeroes in Table 3.3.

We firstly focus on the first two rows in Tables 3.3 and 3.4, they are both related to currently existing passengers in the market. For this group of passengers, we see that consumers gain much more than airlines when flights’ on-time performance improves. Each passenger will gain welfare equivalent to $1$ if delay is reduced by 10%. This amount doubles approximately when delay is reduced by 20%. If delay is completely eliminated, the per passenger welfare gain increases to more than $12$, which counts about 5.7% of the average airfare. Comparing to the increase in the consumer’s surplus, the firm’s gain from cost reduction is paltry. When using delay rate as the delay measurement, only if delay vanishes will the airlines gain $2.39$ per passenger from cost reduction. Otherwise, the per capita Area 2 is only slightly above zero or even equal to if we use lagged delay time.

The pattern is reversed for the group of new passengers. These passengers might be from other competitor airlines or new customers from outside the market. As we can see from the third and fourth rows of the above tables, each new passenger only gains a little if delay is reduced by 10% or 20%. This number may increase to $3$ or more than $4$ depending on the delay measurement we use if there is no delay. Each new passenger’s gain from improvement of flight on-time performance is only about 1/3 of the per capita gain of existing customers. We also observe that delay reduction only has minor impact on per capita Area 4. With lagged average delay time as the delay measurement, airlines consistently gain an additional profit of around $27$ from each new customer. This number increases to around $29$ if lagged delay rate is applied. In addition, by comparing
the areas with the per capita number in the parenthesis, we find that the equilibrium quantities do not increase much if delay is only reduced by 10% or 20%. Only when there is no delay, we observe moderate amount of increase in equilibrium quantity, which means the corresponding airline becomes attractive to new customers.

Generally, we observe that all numbers in Table 3.4 are larger than the corresponding ones in Table 3.3. This suggest that delay rate have greater impact on welfares than delay minutes. Taking the regression outputs, especially those of the fare equation, in Table 3.2 into consideration, the possible reason is that airlines and passengers are less likely to be affected by the flights with delay time less than 15 minutes, which is taken into account in the average delay time but would not be counted as delayed flights when calculating the delay rate. Both parties may have sufficient tolerance in minor delay minutes and care more about the likelihood of (significant) delays.

Comparing our findings with Britto’s (2012), the results on the consumer side are qualitatively the same. Each existing customer benefit several times more than new customer from delay reduction. However, our results show completely different pattern on firm’s side. First, Britto found that airlines gain most welfare from delay reduction. The value of per capita Area 2 in their paper is the largest among all four areas, but in our paper, the corresponding numbers are extremely small or even negligible if average delay time is applied. Considering the substantial welfare gain of existing passengers, our results suggest that airlines tend to pass the burden of extra costs caused by delay on to passengers by the mean of adjusting airfare. Second, Britto et al. find that per capita Area 4 increases proportionally as delay reduces. It means that the better the on-time performance is, the more the airlines would charge from each new passenger. On the other hand, our estimation results show that the airlines’ profits from each additional passenger are relatively stable even when the flights’ on-time performance changes. Accordingly, the size of Area 4 grows proportionally with the increase in the number of new passengers brought about by reduced delays.
The divergence in results stated in the above paragraph mainly results from the differences in sample construction, data processing and regression methodology. Britto et al.’s study is strongly restricted by data availability as they only have about 1500 observations collected from 57 short-haul (less than 500 miles) routes, while our sample coverage is much wider. Besides, we apply three-stage least squares when dealing with the simultaneous equation system. Comparing to the two-stage least squares method used by Britto et al., three-stage least squares is more efficient. All these factors may result in differences in the magnitudes of the curves’ shifts and consequently affect the estimated value of each area.

3.5 Conclusion

This paper estimates the impact of flight delays on the social welfare. Our estimation results show that, using different delay measurements, although the fare equation may not be sensitive to a delay shock, the shift of the demand curve is significant as delay changes. As a result, existing customers would enjoy the benefit from improving flight’s on-time performance. Airlines’ gains are mainly from new customers who are attracted by delay reduction and enter the market. However, it is also notable that slight delay reduction is not substantially attractive to new passengers. Our results indicate that the on-time performance has to be improved by at least 20% in order to gain moderate increase in equilibrium quantity.

Considering the benefit brought by delay reduction, it might be worth for airlines to take steps to improve their on-time performance. We hereby provide several suggestions. First, it is necessary to carry out predictive maintenance in order to avoid technical problems. Second, airlines can also arrange spare aircrafts or standby crews to react quickly when unexpected issues cause delay to happen. These measures are usually
associated with extra costs, so airlines should also consider carefully the trade-off between the extra costs and the benefits of delay reduction.
Appendices

Appendix A

A.1 Proof of Condition (1.3)

This condition is a combination of all second-order conditions of both manufacturer’s and retailer’s profit maximization problems. We firstly derive the retailer’s second-order condition under exclusive dealing. From (1.10) we obtain the following second-order derivatives of retailer 1’s profit function:

\[
\frac{\partial^2 \pi_1}{\partial p_{A1}^2} = -2 \left( \frac{M}{2t} + \frac{N}{V} \right),
\]
(A1)

\[
\frac{\partial^2 \pi_1}{\partial s_{A1}^2} = -1;
\]
(A2)

\[
\frac{\partial^2 \pi_1}{\partial p_{A1} \partial s_{A1}} = \frac{\partial^2 \pi_1}{\partial s_{A1} \partial p_{A1}} = \theta \left( \frac{M}{2t} + \frac{N}{V} \right).
\]
(A3)

So the Hessian matrix of (1.10) is

\[
H = \begin{pmatrix}
-2 \left( \frac{M}{2t} + \frac{N}{V} \right) & \theta \left( \frac{M}{2t} + \frac{N}{V} \right) \\
\theta \left( \frac{M}{2t} + \frac{N}{V} \right) & -1
\end{pmatrix}.
\]
(A4)

It is obvious that all diagonal elements are negative. To satisfy the second-order conditions for a maximum, the determinant of the Hessian matrix has to be positive:

\[
|H| = 2 \left( \frac{M}{2t} + \frac{N}{V} \right) - \theta^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 > 0,
\]
(A5)

\[
\theta^2 < \frac{2}{\left( \frac{M}{2t} + \frac{N}{V} \right)}.
\]
(A6)

Similarly, the second-order condition of the joint-profit maximization problem (1.30) requires \( \theta^2 < 2V/N \), but this condition is implied by (A6). It is also notable that although (1.23) is the profit function in common agency case, the equilibrium prices are not obtained by its derivatives. Instead, they are determined by the Bertrand competition as analyzed in section 1.5. Thus, the Hessian matrix is not applicable in this case.
We then proceed to check the second-order derivatives of manufacturer’s profit functions. They are required to be negative. Under common agency, the second-order derivatives of each manufacturer’s profit can be obtained from (1.28) and (1.29) respectively. Without loss of generality, we still focus on Manufacturer A only. From (1.28), we find that
\[
\frac{\partial^2 \pi_A}{\partial w_A^2} = 2 \cdot \frac{\partial Q_A}{\partial w_A} + \frac{\partial^2 Q_A}{\partial w_A^2} (w_A - c) \frac{\partial^2 Q_A}{\partial w_A^2}.
\] (A7)

The derivatives of total quantity with respect to the corresponding wholesale price can be derived easily from (1.27):
\[
\frac{\partial Q_A}{\partial w_A} = -\left(\frac{M}{2\ell} + \frac{N}{V}\right),
\] (A8)
\[
\frac{\partial^2 Q_A}{\partial w_A^2} = 0.
\] (A9)

Thus \(\frac{\partial^2 \pi_A}{\partial w_A^2} < 0\) is always satisfied.

Manufacturer’s second order condition is more complicated under exclusive dealing. We firstly replace \(\pi^{EC}_1\) on the right-hand side of (1.14) by (1.10) and rewrite \(\pi^{EC}_A\) as
\[
\pi^{EC}_A = (p^{EC}_{A1} - c)Q^{EC}_A - \frac{1}{2} s^{EC}_{A1}.
\] (A10)

Since we observe from (1.11) and (1.12) that \(Q^{EC}_A = \frac{1}{\theta} s^{EC}_{A1}\), by applying the definition of service adjusted price, we can rewrite (A10) as
\[
\pi^{EC}_A = \left(p^{EC}_{A1} - c\right)Q^{EC}_A + \frac{\theta^2}{2} [Q^{EC}_A]^2.
\] (A11)

The second-order condition thus is
\[
\frac{\partial^2 \pi^{EC}_A}{\partial w^{EC}_A} = 2 \cdot \frac{\partial p^{EC}_{A1}}{\partial w^{EC}_A} \cdot \frac{\partial Q^{EC}_A}{\partial w^{EC}_A} + \theta^2 \left(\frac{\partial Q^{EC}_A}{\partial w^{EC}_A}\right)^2 < 0.
\] (A12)

In order to derive the restriction on \(\theta\), we have to solve for the service-adjusted prices from (1.11) and (1.12).

Recall that the demand of product A at Retailer 1 in the exclusive dealing case equals to
\[
\begin{aligned}
Q_{A1}^{EC} &= Q_{A1}^S + Q_{A1}^L \\
&= \frac{\theta(s_{A1}^{EC} - s_{B2}^{EC}) - p_{A1}^{EC} + p_{B2}^{EC} + t}{2t} \cdot M + \left(1 - \frac{p_{A1}^{EC} - \theta s_{A1}^{EC}}{V}\right) \cdot N. 
\end{aligned}
\]  
(A13)

Since \(Q_{A1}^{EC} = \frac{1}{\theta} s_{A1}^{EC}\), we can use (A13) to get an expression for \(s_{A1}^{EC}\):

\[
s_{A1}^{EC} = \frac{M}{2t} \left(-\theta s_{B2}^{EC} + p_{B2}^{EC} + t\right) + N\left(1 - p_{A1}^{EC}\right).
\]  
(A14)

For convenience, we define \(\Omega = 1 - \theta^2 \left(\frac{M}{2t} + \frac{N}{V}\right)\). Under condition (1.3), \(\Omega\) takes the values from -1 to 1. Substituting the above expression into the first equation in (1.11) we obtain

\[
p_{A1}^{EC} = \frac{M}{2t} \left(-\theta s_{B2}^{EC} + p_{B2}^{EC} + t\right) + N + \Omega \left(\frac{M}{2t} + \frac{N}{V}\right) w_{A}^{EC},
\]  
(A15)

and thus

\[
p_{A1}^{EC} - w_{A}^{EC} = \frac{M}{2t} \left(-\theta s_{B2}^{EC} + p_{B2}^{EC} + t\right) + N - \left(\frac{M}{2t} + \frac{N}{V}\right) w_{A}^{EC},
\]  
(A16)

Inserting (A16) into the second equation in (1.11) and replacing all \((p_{ij} - \theta s_{ij})\) terms by the corresponding service-adjusted prices, we can rewrite (1.11) as

\[
\frac{p_{B2}^{EC} - p_{A1}^{EC} + t}{2t} \cdot M + N \left(1 - \frac{p_{A1}^{EC}}{V}\right) = \frac{M}{2t} \left(p_{B2}^{EC} + t\right) + N - \left(\frac{M}{2t} + \frac{N}{V}\right) w_{A}^{EC},
\]  
(A17)

After carrying out the same process on product B and Retailer 2, we can rewrite the equations in (1.12) in a similar form:

\[
\frac{p_{A1}^{EC} - p_{B2}^{EC} + t}{2t} \cdot M + N \left(1 - \frac{p_{B2}^{EC}}{V}\right) = \frac{M}{2t} \left(p_{A1}^{EC} + t\right) + N - \left(\frac{M}{2t} + \frac{N}{V}\right) w_{B}^{EC},
\]  
(A18)

Solving (A17) and (A18) we obtain service adjusted prices as functions of wholesale prices:

\[
p_{A1}^{EC} = \frac{\Omega \frac{M}{2t} \left(\frac{M}{2t} + \frac{N}{V}\right) + \frac{M}{2} + N + \left(\frac{M}{2t} + \frac{N}{V}\right) w_{A}^{EC}}{(1 + \Omega) \left(\frac{M}{2t} + \frac{N}{V}\right)} \cdot (1 + \Omega) \left(\frac{M}{2t} + \frac{N}{V}\right)
\]  
(A19)
Next, we use (A19)-(A20) and the demand functions to obtain:

\[
\frac{\partial p_{B_2}^{EC}}{\partial w_A^{EC}} = \left(1 + \Omega\right) \frac{M}{2t} \left(\frac{M}{2t} + N\right) \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right) \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)
\]

and

\[
\frac{\partial Q_{A_1}^{EC}}{\partial w_A^{EC}} = \frac{\partial p_{B_2}^{EC}}{\partial w_A^{EC}} \frac{\partial p_{B_2}^{EC}}{\partial w_A^{EC}} = \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right) \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right) \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)
\]

Substituting (A21) and (A22) into (A12) gives

\[
2 \cdot \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \cdot \left[\left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^3 \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \right]
\]

\[
+ \theta^2 \left[\left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^3 \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 \right] < 0.
\]

It is obvious that the denominator is positive, so we require the numerator to be negative.

Since \(- \left(\frac{M}{2t} + N\right)^3 (1 + \Omega) + \Omega \cdot \left(\frac{M}{2t} + N\right)^2 \left(\frac{M}{2t} + N\right) < 0\), equivalently we need

\[
2 \cdot \left(1 + \Omega\right) \left(\frac{M}{2t} + N\right)^2 + \theta^2 \left[- \left(\frac{M}{2t} + N\right)^3 (1 + \Omega) + \Omega \cdot \left(\frac{M}{2t} + N\right)^2 \left(\frac{M}{2t} + N\right) \right] > 0.
\]

We use \(\Omega\) to replace \(\theta^2\) in (A24) and write the left hand side as an expression of \(\Omega\)

\[
(1 + \Omega)^2 \left(\frac{M}{2t} + N\right)^2 + \Omega (1 - \Omega) \left(\frac{M}{2t} \right)^2 > 0.
\]

Note that (A6) implies \(\Omega > -1\), which does not always satisfy (A25). Thus the restriction implied by (A25) is the most accurate one. Solving (A25) as an equation gives us:

\[
\Omega_0 = \frac{-2 \left(\frac{M}{2t} + N\right)^2 + \left(\frac{M}{2t} \right)^2 \pm \sqrt{\left(\frac{M}{2t} \right)^4 + 8 \left(\frac{M}{2t} \right)^2 \left(\frac{M}{2t} + N\right)^2}}{2 \left(\frac{M}{2t} + N\right)^2 \left(\frac{M}{2t} \right)^2}
\]
The lower boundary value \( \frac{-2(M_2 + N)^2 + (M_2^2)}{2[(M_2^2 + N_2^2)]} \) is smaller than \(-1\), which contradicts (A6). It can also be shown that the upper boundary value is above \(-1\), so \( \Omega \) should satisfy

\[
\Omega \in \left( \frac{-2(M_2 + N)^2 + (M_2^2)}{2[(M_2^2 + N_2^2)]} + \sqrt{(M_2^4 + 8(M_2^2)} \cdot \left( \frac{M_2 + N_2}{2} \right)^2 \cdot \left( 1 + \frac{1}{\Omega} \right) \cdot \left( M_2^2 + N_2^2 \right)^2 - \frac{(M_2^2 + N_2^2)^2}{\Omega^2} \right), \tag{A27}
\]

which implies (1.3) after writing this interval into \( \theta^2 \).

### A.2 Proof of Proposition 1.1

a) In the exclusive dealing case, (1.11) and (1.12) tell us that \( Q^{EC} = \frac{1}{\theta} s^{EC} \). Since \( Q^{EC} > 0 \) in equilibrium, we have \( s^{EC} > 0 \). Then the first equation in (1.11) (or in (1.12)) entails \( p_1^{EC} > w_1^{EC} \).

b) To see the relationship between \( w_1^{EC} \) and \( c \), we take the first order derivative of (1.10) with respect to \( w_A^{EC} \) and obtain

\[
\frac{\partial \pi_1^{EC}}{\partial w_A^{EC}} = -Q_A^{EC}(w) + \frac{\partial \pi_1^{EC}}{\partial p_A^{EC}} \cdot \frac{\partial p_A^{EC}}{\partial w_A^{EC}} + \frac{\partial \pi_1^{EC}}{\partial p_B^{EC}} \cdot \frac{\partial p_B^{EC}}{\partial w_A^{EC}}. \tag{A28}
\]

Expressing \( Q_A^{EC} \) in terms of service-adjusted price, we can write retailer 1’s profit function as

\[
\pi_1^{EC} = \left( \frac{p_B^{EC} - p_A^{EC} + t}{2t} \right) \cdot M + \left( 1 - \frac{p_A^{EC}}{V} \right) \cdot N \cdot (p_A^{EC} - w_A^{EC}) - \frac{1}{2} s_A^{EC^2}. \tag{A29}
\]

Thus, we have

\[
\frac{\partial \pi_1^{EC}}{\partial p_B^{EC}} = \frac{M}{2t} \left( p_A^{EC} - w_A^{EC} \right), \quad \frac{\partial \pi_1^{EC}}{\partial p_A^{EC}} = \frac{M}{2t} \frac{s_A^{EC}}{\theta \left( \frac{M_2}{2t} + \frac{N_2}{V} \right)} > 0, \tag{A30}
\]

and, from (A20),

\[
\frac{\partial p_B^{EC}}{\partial w_A^{EC}} = \frac{\Omega \cdot \frac{M}{2t} \cdot \left( \frac{M_2}{2t} + \frac{N_2}{V} \right)}{\left( 1 + \Omega \right)^2 \left( \frac{M_2}{2t} + \frac{N_2}{V} \right)^2 - \frac{1}{\Omega}}. \tag{A31}
\]
By substituting (A28) into (1.15) and using the first order condition that \( \frac{\partial \pi_A^{EC}}{\partial p_{A1}^{EC}} = 0 \), we rewrite (1.15) as

\[
\frac{\partial \pi_A^{EC}}{\partial w_A^{EC}} = (w_A^{EC} - c) \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} + \frac{\partial \pi_1^{EC}}{\partial p_{B2}^{EC}} \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} = 0. \tag{A32}
\]

We can now determine the sign of \( (w_A^{EC} - c) \) by considering the signs of various terms in (A32). Note from (A30) that \( \frac{\partial \pi_1^{EC}}{\partial p_{B2}^{EC}} > 0 \). In (A22) and (A31), we see that \( \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} \) and \( \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} \) have the same denominator. While the numerator of \( \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} \) is always negative, the sign of that of \( \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} \) changes as \( \Omega \) changes. When \( \Omega < 0 \), i.e., \( \theta^2 > \frac{1}{\frac{M}{N} \cdot \frac{N}{V}} \), the numerator of both derivatives are negative, so \( \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} \) and \( \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} \) have the same sign. In this case, \( (w_A^{EC} - c) \) must be negative (opposite to the sign of \( \frac{\partial \pi_1^{EC}}{\partial p_{B2}^{EC}} \)) to make (A19) hold. When \( \Omega > 0 \), on the other hand, \( \frac{\partial Q_A^{EC}}{\partial w_A^{EC}} \) is negative but \( \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} \) is positive. Hence, \( (w_A^{EC} - c) \) should be positive in this case. When \( \Omega = 0 \), \( \frac{\partial p_{B2}^{EC}}{\partial w_A^{EC}} = 0 \) makes \( w_A^{EC} = c \).

**A.3 Proof of Proposition 1.2**

a) Omitted. It is explained in main text in section 4

b) We see this from a manufacturer’s first order conditions. Since it is obvious from (1.27) that \( \frac{\partial Q_A^{CA}}{\partial w_i^{CA}} < 0 \), \( w_i^{CA} \) must be greater than \( c \) to make (1.28) and (1.29) hold.

**A.4 Proof of Proposition 1.3**

We have proved in Proposition 1.1a that \( s^{EC} > 0 \), and Proposition 1.2a states that \( s^{CA} = 0 \). Thus, this proposition is easily proved.

**A.5 Proof that \( \theta_b < \theta_a \)**

From conditions (1.3) and (1.37), we obtain

\[
\theta_a^2 - \theta_b^2
\]
\[ 2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 - \sqrt{\left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 + 2 \left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2} \]

\[ = \frac{2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 - \sqrt{\left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 + 2 \left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2}}{2 \left( \frac{M}{2t} + \frac{N}{V} \right) \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2} \]. (A33)

The denominator is positive without doubt, so we focus on numerator only. We can split the numerator into two components: \[ \sqrt{\left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2} \]

and the rest. It is obvious that the first component is positive. The rest component is

\[ 2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 + \left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 - \sqrt{\left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2}. (A34) \]

To determine the sign of (A34), we square the positive part and the negative part separately and calculate the difference of the squared terms:

\[ (2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 + \left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 - \left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2)^2 - \left( \frac{M}{2t} \right)^4 + 8 \left( \frac{M}{2t} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2)^2 \]

\[ = 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2 \]

\[ + 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \sqrt{\left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2} - 8 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} \right)^2. \] (A35)

Note that \( 8 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} \right)^2 \) can be viewed as \( 2 \cdot 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} \right)^2 \), we will then observe that

\[ 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^4 > 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} \right)^2 \] (A36)

and

\[ 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \sqrt{\left( \frac{M}{2t} \right)^4 + \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \left( \frac{M}{2t} \right)^2} > 4 \left( \frac{M}{2t} + \frac{N}{V} \right)^2 \left( \frac{M}{2t} \right)^2. \] (A37)

Thus (A34) > 0 as well. We have shown that both components in the numerator are positive, giving us \( \theta_a^2 - \theta_b^2 > 0 \) and consequently \( \theta_a > \theta_b \).

**A.6 Proof of Proposition 1.4**

In order to look for the relationship between service-adjusted prices under different scenarios, we define a new function:
\[ F(p) = \frac{M}{2} + \left(1 - \frac{p}{V}\right) N - (p - c) \left(\frac{M}{2t} + \frac{N}{V}\right). \]  
(A38)

In a symmetric equilibrium, both (1.28) and (1.29) can be written as:

\[ F(p^{CA}) = 0. \]  
(A39)

Since \( s^{CA} = 0, p^{CA} = \hat{p}^{CA} \). Equation (A31) can then be written in terms of \( \hat{p}^{CA} \):

\[ F(\hat{p}^{CA}) = \frac{M}{2} + N \cdot \left(1 - \hat{p}^{CA}\right) - \left(\hat{p}^{CA} - c\right) \left(\frac{M}{2t} + \frac{N}{V}\right) = 0. \]  
(A40)

For the exclusive dealing case, we reconsider (1.11) and write the first order condition in symmetric equilibrium as

\[ \frac{M}{2} + N \cdot \left(1 - \hat{p}^{EC} - \theta s^{EC}\right) - \left(p^{EC} - w^{EC}\right) \left(\frac{M}{2t} + \frac{N}{V}\right) = 0. \]  
(A41)

We then rewrite (A41) to create the term \( F(\hat{p}^{EC}) \)

\[ F(\hat{p}^{EC}) + (w^{EC} - c - \theta s^{EC}) \left(\frac{M}{2t} + \frac{N}{V}\right) = 0. \]  
(A42)

Since \( F(\cdot) \) is a decreasing function, \( \hat{p}^{EC} \) will be greater than \( \hat{p}^{CA} \) if \( w^{EC} - c - \theta s^{EC} > 0 \).

By substituting (A22), (A30), (A31) into (A32), we get

\[ \frac{\partial \pi_{A}^{EC}}{\partial w_{A}^{EC}} = (w_{A}^{EC} - c) - \frac{(M}{2t} + \frac{N}{V})^3 (1 + \Omega) + \Omega \cdot \left(\frac{M}{2t}\right)^2 \left(\frac{M}{2t} + \frac{N}{V}\right) 
\quad \left(1 + \Omega\right)^2 \left(\frac{M}{2t} + \frac{N}{V}\right)^2 - \left(\frac{M}{2t}\right)^2 \Omega^2 
\quad + \frac{M}{2t} \cdot \frac{s_{A1}^{EC}}{\theta} \cdot \frac{\Omega \cdot \left(\frac{M}{2t}\right)^2}{(1 + \Omega)^2 \left(\frac{M}{2t} + \frac{N}{V}\right)^2 - \left(\frac{M}{2t}\right)^2 \Omega^2} = 0. \]  
(A43)

We then rearrange it to obtain:

\[ w_{A}^{EC} - c - \theta s_{A1}^{EC} = \frac{\Omega \cdot \left(\frac{M}{2t}\right)^2 - \theta^2 \left[\left(\frac{M}{2t} + \frac{N}{V}\right)^3 (1 + \Omega) - \Omega \cdot \left(\frac{M}{2t}\right)^2 \left(\frac{M}{2t} + \frac{N}{V}\right) \right]}{\theta \left[\left(\frac{M}{2t} + \frac{N}{V}\right)^3 (1 + \Omega) - \Omega \cdot \left(\frac{M}{2t}\right)^2 \left(\frac{M}{2t} + \frac{N}{V}\right) \right]} \cdot s_{A1}^{EC}. \]  
(A44)

Recall that \( \Omega \in (-1,1) \). Thus, the denominator in (A44) is always positive. We can write the numerator as a function of \( \Omega \)

\[ g(\Omega) = \left(\frac{M}{2t}\right)^2 (2\Omega - \Omega^2) - \left(\frac{M}{2t} + \frac{N}{V}\right)^2 (1 - \Omega^2). \]  
(A45)
The positive interval of the solution to $g(\Omega) > 0$ gives us exactly condition (1.37).
Therefore, We have proved that $(w^E_A - c - \theta s^E_A)$ will be positive if and only if $\theta < \theta_b$, resulting in $p^E > p^C$.

From (1.6), (1.9) and (1.19)-(1.22), we observe that all quantities are inversely related to the service-adjusted prices of the corresponding products. Once we have proved that $p^E > p^C$ under condition (1.37), it is straightforward to conclude that $Q^E < Q^C$.

A.7 Proof of Proposition 1.5

Firstly, we are able to determine the relationship between $p^E$ and $p^C$ using the results from previous propositions. We have proved so far that, in exclusive dealing, both service level and service-adjusted price are higher than those in common agency case. Hence, the retail price, which can be expressed as $(\hat{p} + \theta s)$, has to be higher as well.

In order to compare equilibrium profits, we will compare $p^E$ and $s^E$ with $p^*$ and $s^*$ respectively and then use the benchmark equilibrium as a reference to obtain the results.

Starting by comparing $p^E$ with $p^*$, we substitute (1.34) into (1.33) to get an equation with $p^*$ being its only variable:

$$G(p^*) = \frac{M}{2} + \left(1 - \frac{p^*}{V}\right) \cdot N + \left(p^* - c\right) \frac{N}{V} \left(\frac{\theta^2}{2} \cdot \frac{N}{V} - 1\right) = 0. \tag{A46}$$

Next, we consider the two first order conditions in (1.11). In a symmetric equilibrium, we express $Q^E$ in terms of $p^E$ and $s^E$, and rewrite (1.11) as

$$\frac{M}{2} + N \cdot \left(1 - \frac{p^E - \theta s^E}{V}\right) - (p^E - w^E) \left(\frac{M}{2t} + \frac{N}{V}\right) = 0. \tag{A47}$$

After substituting $s^E$ away by applying the first equation in (1.11), we obtain an equation that determines the value of $p^E$:

$$\frac{M}{2} + \left(1 - \frac{p^E}{V}\right) \cdot N + (p^E - w^E) \left(\frac{M}{2t} + \frac{N}{V}\right) \left(\frac{\theta^2}{2} \cdot \frac{N}{V} - 1\right) = 0. \tag{A48}$$

We rearrange the terms in (A48) to include $G(\cdot)$:
\[ G(p^{EC}) + (p^{EC} - c) \frac{M}{2t} \left( \frac{\theta^2}{2} \cdot \frac{N}{V} - 1 \right) - (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) \left( \frac{\theta^2}{2} \cdot \frac{N}{V} - 1 \right) = 0. \] (A49)

Condition (1.3) implies that \( G(\cdot) \) is decreasing in \( p \). Therefore, if the sign of the extra terms other than \( G(p^{EC}) \) in (A49) can be determined, we will be able to compare \( p^{EC} \) and \( p^* \). To see this, we must get back to (A43).

We drop the subscripts based on symmetry and substitute (1.11) for \( s_{A1}^{EC} \) in (A43) to obtain:

\[
(w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) - \left( \frac{M}{2t} + \frac{N}{V} \right)^3 \left( 1 + \Omega \right) + \frac{\Omega (M/2t)^2}{(M/2t)^3} + \frac{\Omega}{(M/2t)^2} \cdot \frac{M}{2t} (p^{EC} - w^{EC}) \left( \frac{M}{2t} + \frac{N}{V} \right) = 0, \quad (A50)
\]

which can be written as

\[
(w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) = \frac{\frac{M}{2t} (p^{EC} - w^{EC}) \cdot \frac{\Omega (M/2t)^2}{(M/2t)^3} + \frac{\Omega}{(M/2t)^2}}{1 + \frac{\Omega (M/2t)^2}{(M/2t)^3}}. \quad (A51)
\]

Creating a term with \( (p^{EC} - c) \) on the right-hand side of (A51) gives

\[
(w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) = \frac{\frac{M}{2t} (p^{EC} - w^{EC}) \cdot \frac{\Omega (M/2t)^2}{(M/2t)^3} + \frac{\Omega}{(M/2t)^2}}{1 + \frac{\Omega (M/2t)^2}{(M/2t)^3}} \left( \frac{M}{2t} + \frac{N}{V} \right) \left( 1 + \Omega \right) \left( \frac{M}{2t} + \frac{N}{V} \right) - \Omega \left( \frac{M}{2t} \right)^2. \quad (A52)
\]

Rearranging the above equation gives us

\[
\left[ \left( 1 + \Omega \right) \left( \frac{M}{2t} + \frac{N}{V} \right) \right] \cdot (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) = \Omega \left( \frac{M}{2t} \right) \cdot (p^{EC} - c) \left( \frac{M}{2t} \right). \quad (A53)
\]

Comparing the terms on the left- and right-hand side of (A53), we see that as long as \( \Omega > 0 \), \( (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) \) must be smaller than \( (p^{EC} - c) \left( \frac{M}{2t} \right) \) for the equation to hold.

Moreover, recall from Proposition 1b that \( (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) < 0 \) when \( \Omega < 0 \). Hence, \( (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) < (p^{EC} - c) \left( \frac{M}{2t} \right) \) in both instances. Additionally, condition (1.3) implies that \( \left( \frac{\theta^2}{2} \cdot \frac{N}{V} - 1 \right) < 0 \). Therefore,
\[
(p^{EC} - c) \frac{M}{2t} \left( \frac{\theta^2 \cdot N}{2V} - 1 \right) - (w^{EC} - c) \left( \frac{M}{2t} + \frac{N}{V} \right) \left( \frac{\theta^2 \cdot N}{2V} - 1 \right) < 0. \tag{A54}
\]

Since \( G(p) \) is decreasing in \( p \), we conclude that \( p^{EC} < p^* \).

Using a similar procedure, we can compare \( s^* \) with \( s^{EC} \). Solving (1.34) for \( p^* \) and substituting it into (1.33), we obtain:

\[
H(s^*) = \frac{M}{2} + \left( 1 - \frac{c}{V} \right) N + s^* \cdot \left( \frac{\theta N}{V} - \frac{4}{\theta} \right) = 0 \tag{A55}
\]

Condition (1.3) implies that \( H(s) \) is decreasing in \( s \). Equations in (1.11) and (1.12) imply that, in a symmetric equilibrium, \( Q^{EC} = \frac{M}{2} + N \cdot \left( 1 - \frac{p^{EC} - \theta s^{EC}}{\theta} \right) = \frac{1}{\theta} s^{EC} \). We now substitute the first equation in (1.11) for \( p^{EC} \) to get an equation containing \( H(s) \) in exclusive dealing case:

\[
H(s^{EC}) - \frac{N}{V} \left( w^{EC} - c \right) + s^{EC} \cdot \left( \frac{3}{\theta} - \frac{N}{\theta \left( \frac{M}{2t} + \frac{N}{V} \right)} \right) = 0 \tag{A56}
\]

Rewriting (A51) by using (1.11) again to replace \( p^{EC} - w^{EC} \), we obtain an equation in terms of \( \frac{N}{V} \left( w^{EC} - c \right) \) and \( s^{EC} \):

\[
\frac{N}{V} \left( w^{EC} - c \right) = \frac{s^{EC}}{\theta} \cdot \frac{\Omega \left( \frac{M}{2t} \right)^2}{\left( 1 + \Omega \right) \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \Omega \left( \frac{M}{2t} \right)^2} \cdot \frac{N}{V}. \tag{A57}
\]

Since \( \Omega < 1 \), \( \left( \frac{M}{2t} + \frac{N}{V} \right)^2 - \Omega \left( \frac{M}{2t} \right)^2 > \left( \frac{M}{2t} \right)^2 > \Omega \left( \frac{M}{2t} \right)^2 \). Thus,

\[
\frac{N}{V} \left( w^{EC} - c \right) < \frac{s^{EC}}{\theta} \cdot 2 = s^{EC} \cdot \left( 3 - \frac{\frac{M}{2t} + \frac{N}{V}}{\theta \left( \frac{M}{2t} + \frac{N}{V} \right)} \right) < s^{EC} \cdot \left( 3 - \frac{\frac{N}{V}}{\theta \left( \frac{M}{2t} + \frac{N}{V} \right)} \right). \tag{A58}
\]

Therefore, \( H(s^{EC}) < H(s^*) \) and the monotonicity of \( H(s) \) implies \( s^{EC} > s^* \). Combining this result with \( p^{EC} < p^* \), we find that \( p^{EC} < p^* \).

To compare profit levels, we divide equation (1.32) by 2 to get the profit for each manufacturer:

\[
\Pi_i = (p - c) \left[ \frac{M}{2} + N \left( 1 - \frac{p - \theta s}{V} \right) \right] - \frac{1}{2} s^2 \tag{A59}
\]
Substituting (1.10) for \(\pi_1^{EC}\) in (1.14), we find that a manufacturer’s profit in the exclusive dealing case is the same as (A59). In the common agency case, since all service levels are equal to 0 and retail prices are the same as wholesale prices, (A59) is also applicable. We apply the first order conditions (1.11) and (1.12) under exclusive dealing that \(Q = \frac{1}{\theta} s\) and rewrite it as a function of \(\hat{\rho}\):

\[
\pi(\hat{\rho}) = (\hat{\rho} - c)Q(\hat{\rho}) + \frac{1}{2} \theta^2 Q(\hat{\rho})^2
\]  

(A60)

Note that \(\pi(\hat{\rho})\) reaches a maximum at \(\hat{\rho}^* = p^* - \theta s^*\). Based on the above discussion, \(\pi(\hat{\rho}^{EC})\) is still the manufacturer’s profit in the exclusive dealing case. However, because \(Q = \frac{1}{\theta} s\) is not applicable in the common agency case, \(\pi(\hat{\rho}^{CA})\) is not equal to \(\pi^{CA}\) (a manufacturer’s equilibrium profit under common agency). To be precise, since \(s^{CA} = 0\) and \(p^{CA} = \hat{\rho}^{CA}\), \(\pi^{CA} = (\hat{\rho}^{CA} - c)Q(\hat{\rho}^{CA}) < \pi(\hat{\rho}^{CA})\). Since we have proved that \(\hat{\rho}^{CA} < \hat{\rho}^{EC} < \hat{\rho}^*\) holds under condition (37), \(\pi_{max} = \pi(\hat{\rho}^*) > \pi(\hat{\rho}^{EC}) = \pi^{EC} > \pi(\hat{\rho}^{CA}) > \pi^{CA}\).

**A.8 Proof of Proposition 1.6**

Omitted. This is proved in the proof of Proposition 1.5.

**A.9 Numerical analysis of marginal mismatch cost \(t\)**

Here we present a numerical example of comparative statics with respect to the mismatch cost \(t\). In this example, we fix \(\theta\) at 0.2 and keep other parameters the same as the first numerical simulation example in section 1.6: \(M = 10, N = 2, V = 2\) and \(c = 1\). The parameter values entail that \(t\) should be no smaller than 0.15 to satisfy (1.3).

Increasing the value of \(t\) weakens the intensity of inter-brand competition. In particular, Figure A1 shows that service level under exclusive dealing decreases slowly as \(t\) increases, and Figure A4 shows that equilibrium retail prices tend to be higher with larger \(t\) values. As a result, shown by Figure A2 and A3, service adjusted prices increase and equilibrium quantities decrease. While consumers are worse off with the increase of \(t\), Figure A5 implies that the manufacturers are expected to earn more profits. However,
in terms of total surplus, the manufacturers’ gain is for the most part dominated by the loss in consumer’s surplus. As can be seen in Figure A6, while total surplus rises for some small values of $t$, it falls monotonically once $t$ exceeds a certain threshold.

While retailers face both intra and inter-brand competition in common agency case, there only exists inter-brand competition under exclusive dealing. Thus, enlarging $t$ has greater anti-competitive effects on exclusive dealing equilibria than on those in common agency case. This leads to the fact that, graphically, all slopes of EC curves in Figure A2-A6 are steeper than those of CA curves.

**Figure A1** Service under exclusive dealing  
**Figure A2** Service adjusted prices

![Figure A1](image1.png)  
![Figure A2](image2.png)
Figure A5 Profits

Figure A6 Total surplus
Appendix B

B.1 Low-cost carrier

**Table B1** List of low-cost carriers (LCC)

<table>
<thead>
<tr>
<th>Name</th>
<th>Airline code</th>
</tr>
</thead>
<tbody>
<tr>
<td>JetBlue Airways</td>
<td>B6</td>
</tr>
<tr>
<td>Frontier Airlines</td>
<td>F9</td>
</tr>
<tr>
<td>Allegiant Air</td>
<td>G4</td>
</tr>
<tr>
<td>Lynx Aviation d/b/a Frontier Airlines</td>
<td>L3</td>
</tr>
<tr>
<td>Spirit Air Lines</td>
<td>NK</td>
</tr>
<tr>
<td>Sun Country Airlines d/b/a MN Airlines</td>
<td>SY</td>
</tr>
<tr>
<td>Southwest Airlines Co.</td>
<td>WN</td>
</tr>
<tr>
<td>Virgin America</td>
<td>VX</td>
</tr>
</tbody>
</table>
### B.2 Airfare estimation with connect dummy for pooled sample

**Table B2** Airfare estimation results for top 25% busiest routes pooled sample with connect dummy

<table>
<thead>
<tr>
<th>In(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delay</strong></td>
<td>0.0003 (0.0006)</td>
<td>−0.0006 (0.0007)</td>
<td>0.0026 (0.0019)</td>
<td>0.0015 (0.0014)</td>
<td>0.1537*** (0.0468)</td>
<td>0.0512 (0.0495)</td>
</tr>
<tr>
<td><strong>Lagged HHI</strong></td>
<td>−0.0014 (0.0297)</td>
<td>−0.0189 (0.0302)</td>
<td>−0.0133 (0.0304)</td>
<td>−0.0133 (0.0304)</td>
<td>−0.0008 (0.0298)</td>
<td>−0.0179 (0.0303)</td>
</tr>
<tr>
<td><strong>Fuel cost</strong></td>
<td>0.1715*** (0.0068)</td>
<td>0.1712*** (0.0068)</td>
<td>0.1732*** (0.0068)</td>
<td>0.1731*** (0.0068)</td>
<td>0.1718*** (0.0068)</td>
<td>0.1714*** (0.0068)</td>
</tr>
<tr>
<td><strong>LCC</strong></td>
<td>−0.5678*** (0.0168)</td>
<td>−0.5574*** (0.0171)</td>
<td>−0.5547*** (0.0170)</td>
<td>−0.5544*** (0.0170)</td>
<td>−0.5726*** (0.0169)</td>
<td>−0.5597*** (0.0171)</td>
</tr>
<tr>
<td><strong>Vacation</strong></td>
<td>0.0252* (0.0129)</td>
<td>0.0257** (0.0124)</td>
<td>0.0245* (0.0126)</td>
<td>0.0249** (0.0126)</td>
<td>0.0248* (0.0130)</td>
<td>0.0252** (0.0125)</td>
</tr>
<tr>
<td><strong>Slot control</strong></td>
<td>−0.0895*** (0.0185)</td>
<td>−0.0968*** (0.0186)</td>
<td>−0.0940*** (0.0187)</td>
<td>−0.0943*** (0.0187)</td>
<td>−0.0881*** (0.0185)</td>
<td>−0.0961*** (0.0186)</td>
</tr>
<tr>
<td><strong>Connect</strong></td>
<td>0.2372*** (0.0203)</td>
<td>0.2317*** (0.0205)</td>
<td>0.2368*** (0.0212)</td>
<td>0.2367*** (0.0212)</td>
<td>0.2374*** (0.0203)</td>
<td>0.2316*** (0.0205)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>22,662,089</td>
<td>21,816,734</td>
<td>21,424,515</td>
<td>21,424,515</td>
<td>22,662,608</td>
<td>21,817,464</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.1109</td>
<td>0.1107</td>
<td>0.1107</td>
<td>0.1106</td>
<td>0.1110</td>
<td>0.1107</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
**Table B3** Airfare estimation results for top 25% busiest routes pooled sample with connect dummy

<table>
<thead>
<tr>
<th>In(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>−0.0025***</td>
<td>0.0005</td>
<td>−0.1773***</td>
<td>−0.0010</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
<td>(0.0005)</td>
<td>(0.0600)</td>
<td>(0.0494)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>−0.0314</td>
<td>−0.0767***</td>
<td>−0.0296</td>
<td>−0.0766***</td>
</tr>
<tr>
<td></td>
<td>(0.0322)</td>
<td>(0.0262)</td>
<td>(0.0259)</td>
<td>(0.0262)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1001***</td>
<td>0.0854***</td>
<td>0.1006***</td>
<td>0.0855***</td>
</tr>
<tr>
<td></td>
<td>(0.0151)</td>
<td>(0.0163)</td>
<td>(0.0152)</td>
<td>(0.0164)</td>
</tr>
<tr>
<td>LCC</td>
<td>−0.8737***</td>
<td>−0.8184***</td>
<td>−0.8710***</td>
<td>−0.8183***</td>
</tr>
<tr>
<td></td>
<td>(0.0563)</td>
<td>(0.0666)</td>
<td>(0.0566)</td>
<td>(0.0668)</td>
</tr>
<tr>
<td>Vacation</td>
<td>−0.0265</td>
<td>0.0039</td>
<td>−0.0271</td>
<td>0.0041</td>
</tr>
<tr>
<td></td>
<td>(0.0175)</td>
<td>(0.0163)</td>
<td>(0.0173)</td>
<td>(0.0164)</td>
</tr>
<tr>
<td>Slot control</td>
<td>−0.0366</td>
<td>−0.0351</td>
<td>−0.0328</td>
<td>−0.0352</td>
</tr>
<tr>
<td></td>
<td>(0.0547)</td>
<td>(0.0546)</td>
<td>(0.0558)</td>
<td>(0.059)</td>
</tr>
<tr>
<td>Connect</td>
<td>0.2688***</td>
<td>0.2523***</td>
<td>0.2685***</td>
<td>0.2520***</td>
</tr>
<tr>
<td></td>
<td>(0.0180)</td>
<td>(0.0192)</td>
<td>(0.0180)</td>
<td>(0.0192)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,445,545</td>
<td>1,286,701</td>
<td>1,445,674</td>
<td>1,286,721</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1375</td>
<td>0.1258</td>
<td>0.1374</td>
<td>0.1258</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.

As an additional robustness check, we treat direct flights and connecting flights as differentiated products in the same market and additionally include a connect dummy in the original regression equation to distinguish between the two types of flights. The connect dummy equals to 1 if the observation took a connecting flight and equals to 0 otherwise. Tables B2 and B3 present the regression results of the pooled sample. Comparing to Tables 2.12 and 2.13, the coefficients of original variables does not have any notable changes, but connecting flights are over 23% more expensive than direct
flights. This is because for all domestic flights, landing halfway usually leads to additional costs especially in terms of slot charge and maintenance. With all other interpretations same as those in Section 2.4, the results in this appendix demonstrates the robustness of our findings in the main text.

B.3 Regressions using contemporaneous HHI

In the main text, although the application of lagged HHI data eliminates the potential endogeneity in the market structure variable, the delayed effect of changes in market structure may also be problematic. To be specific, using lagged HHI means that new entry will not take effect until next period, while the incumbents may react immediately to new entries in the real world. Therefore, we run the same regressions with contemporaneous HHI in this section as an additional robustness check. As we can see from Tables B4-B9, the results from these additional regressions are consistent with our findings in Sections 2.4 and 2.5. This is not surprising since the market structure during our sample period is stable over time.
Table B4  Airfare estimation results for direct flights in top 25% busiest routes using contemporaneous HHI

<table>
<thead>
<tr>
<th>In(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0.0004 (0.0006)</td>
<td>-0.0005 (0.0007)</td>
<td>0.0030 (0.0020)</td>
<td>0.0018 (0.0015)</td>
<td>0.1691*** (0.0487)</td>
<td>0.0602 (0.0518)</td>
</tr>
<tr>
<td>HHI</td>
<td>-0.0264 (0.0303)</td>
<td>-0.0417 (0.0308)</td>
<td>-0.0409 (0.0308)</td>
<td>-0.0411 (0.0308)</td>
<td>-0.0255 (0.0304)</td>
<td>-0.0406 (0.0309)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1790*** (0.0073)</td>
<td>0.1788*** (0.0073)</td>
<td>0.1805*** (0.0073)</td>
<td>0.1804*** (0.0073)</td>
<td>0.1794*** (0.0073)</td>
<td>0.1790*** (0.0072)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.5849*** (0.0174)</td>
<td>-0.5740*** (0.0177)</td>
<td>-0.5704*** (0.0175)</td>
<td>-0.5702*** (0.0175)</td>
<td>-0.5902*** (0.0174)</td>
<td>-0.5765*** (0.0176)</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0274** (0.0129)</td>
<td>0.0283** (0.0124)</td>
<td>0.0271** (0.0125)</td>
<td>0.0276** (0.0125)</td>
<td>0.0269** (0.0130)</td>
<td>0.0279** (0.0125)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0916*** (0.0234)</td>
<td>-0.0988*** (0.0199)</td>
<td>-0.0955*** (0.0199)</td>
<td>-0.0959*** (0.0200)</td>
<td>-0.0901*** (0.0198)</td>
<td>-0.0981*** (0.0200)</td>
</tr>
<tr>
<td>Observations</td>
<td>20,923,436</td>
<td>20,128,759</td>
<td>19,812,792</td>
<td>19,812,792</td>
<td>20,922,715</td>
<td>20,129,299</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1064</td>
<td>0.1061</td>
<td>0.1059</td>
<td>0.1059</td>
<td>0.1065</td>
<td>0.1061</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
### Table B5: Airfare estimation results for connecting flights in top 25% busiest routes using contemporaneous HHI

<table>
<thead>
<tr>
<th></th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delay</strong></td>
<td>0.0009** (0.0004)</td>
<td>0.0003 (0.0006)</td>
<td>0.0032 (0.0021)</td>
<td>0.0019 (0.0016)</td>
<td>0.0545 (0.0361)</td>
<td>0.0080 (0.0424)</td>
</tr>
<tr>
<td><strong>HHI</strong></td>
<td>0.1403*** (0.0260)</td>
<td>0.1278*** (0.0272)</td>
<td>0.1444*** (0.0278)</td>
<td>0.1444*** (0.0278)</td>
<td>0.1404*** (0.0260)</td>
<td>0.1276*** (0.0272)</td>
</tr>
<tr>
<td><strong>Fuel cost</strong></td>
<td>0.1043*** (0.0049)</td>
<td>0.1044*** (0.0051)</td>
<td>0.1050*** (0.0051)</td>
<td>0.1050*** (0.0051)</td>
<td>0.1042*** (0.0049)</td>
<td>0.1045*** (0.0051)</td>
</tr>
<tr>
<td><strong>LCC</strong></td>
<td>-0.4352*** (0.0152)</td>
<td>-0.4367*** (0.0153)</td>
<td>-0.4378*** (0.0166)</td>
<td>-0.4377*** (0.0165)</td>
<td>-0.4365*** (0.0151)</td>
<td>-0.4368*** (0.0152)</td>
</tr>
<tr>
<td><strong>Vacation</strong></td>
<td>-0.0155 (0.0115)</td>
<td>-0.0184 (0.0114)</td>
<td>-0.0234** (0.0112)</td>
<td>-0.0226* (0.0116)</td>
<td>-0.0154 (0.0115)</td>
<td>-0.0179 (0.0114)</td>
</tr>
<tr>
<td><strong>Slot control</strong></td>
<td>-0.0580*** (0.0171)</td>
<td>-0.0628*** (0.0176)</td>
<td>-0.0614*** (0.0187)</td>
<td>-0.0617*** (0.0188)</td>
<td>-0.0583*** (0.0172)</td>
<td>-0.0625*** (0.0176)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>1,739,653</td>
<td>1,687,975</td>
<td>1,611,723</td>
<td>1,611,723</td>
<td>1,739,893</td>
<td>1,688,165</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.0664</td>
<td>0.0671</td>
<td>0.0679</td>
<td>0.0679</td>
<td>0.0664</td>
<td>0.0671</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
**Table B6** Airfare estimation results for direct flights in bottom 25% busiest routes using contemporaneous HHI

<table>
<thead>
<tr>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>-0.0027***</td>
<td>-0.0005</td>
<td>-0.1804***</td>
<td>-0.0258</td>
</tr>
<tr>
<td></td>
<td>(0.0009)</td>
<td>(0.0005)</td>
<td>(0.0684)</td>
<td>(0.0555)</td>
</tr>
<tr>
<td>HHI</td>
<td>-0.0447</td>
<td>-0.0961***</td>
<td>-0.0429</td>
<td>-0.0957***</td>
</tr>
<tr>
<td></td>
<td>(0.0274)</td>
<td>(0.0280)</td>
<td>(0.0275)</td>
<td>(0.0280)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1160***</td>
<td>0.1001***</td>
<td>0.1165***</td>
<td>0.1008***</td>
</tr>
<tr>
<td></td>
<td>(0.0188)</td>
<td>(0.0210)</td>
<td>(0.0190)</td>
<td>(0.0211)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.9110***</td>
<td>-0.8543***</td>
<td>-0.9083***</td>
<td>-0.8546***</td>
</tr>
<tr>
<td></td>
<td>(0.0575)</td>
<td>(0.0689)</td>
<td>(0.0578)</td>
<td>(0.0690)</td>
</tr>
<tr>
<td>Vacation</td>
<td>-0.0265</td>
<td>0.0035</td>
<td>-0.0269</td>
<td>0.0043</td>
</tr>
<tr>
<td></td>
<td>(0.0188)</td>
<td>(0.0173)</td>
<td>(0.0186)</td>
<td>(0.0175)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0481</td>
<td>-0.0307</td>
<td>-0.0437</td>
<td>-0.0315***</td>
</tr>
<tr>
<td></td>
<td>(0.0692)</td>
<td>(0.0766)</td>
<td>(0.0708)</td>
<td>(0.0772)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,293,208</td>
<td>1,144,372</td>
<td>1,293,354</td>
<td>1,144,392</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.1432</td>
<td>0.1315</td>
<td>0.1431</td>
<td>0.1315</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
<table>
<thead>
<tr>
<th>In(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0.0002</td>
<td>-0.0001</td>
<td>-0.0379</td>
<td>-0.0282</td>
</tr>
<tr>
<td></td>
<td>(0.0005)</td>
<td>(0.0003)</td>
<td>(0.0331)</td>
<td>(0.0330)</td>
</tr>
<tr>
<td>HHI</td>
<td>0.0823***</td>
<td>0.0755**</td>
<td>0.0838***</td>
<td>0.0760**</td>
</tr>
<tr>
<td></td>
<td>(0.0279)</td>
<td>(0.0294)</td>
<td>(0.0281)</td>
<td>(0.0295)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.0666***</td>
<td>0.0639***</td>
<td>0.0673***</td>
<td>0.0637***</td>
</tr>
<tr>
<td></td>
<td>(0.0073)</td>
<td>(0.0074)</td>
<td>(0.0073)</td>
<td>(0.0074)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.5103***</td>
<td>-0.5024***</td>
<td>-0.5113***</td>
<td>-0.5030***</td>
</tr>
<tr>
<td></td>
<td>(0.0490)</td>
<td>(0.0490)</td>
<td>(0.0484)</td>
<td>(0.0487)</td>
</tr>
<tr>
<td>Vacation</td>
<td>-0.0168</td>
<td>-0.0137</td>
<td>-0.0220</td>
<td>-0.0141</td>
</tr>
<tr>
<td></td>
<td>(0.0279)</td>
<td>(0.0266)</td>
<td>(0.0274)</td>
<td>(0.0265)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0650**</td>
<td>-0.0678**</td>
<td>-0.0646**</td>
<td>-0.0675**</td>
</tr>
<tr>
<td></td>
<td>(0.0276)</td>
<td>(0.0264)</td>
<td>(0.0275)</td>
<td>(0.0264)</td>
</tr>
<tr>
<td>Observations</td>
<td>152,337</td>
<td>142,329</td>
<td>152,420</td>
<td>142,329</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.0565</td>
<td>0.0556</td>
<td>0.0564</td>
<td>0.0556</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
Table B8 Passenger estimation results for top 25% busiest routes using contemporaneous HHI

<table>
<thead>
<tr>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>-0.0003 (0.0003)</td>
<td>-0.0007 (0.0005)</td>
<td>-0.0020 (0.0015)</td>
<td>-0.0014 (0.0011)</td>
<td>-0.0549 (0.0335)</td>
<td>-0.1181** (0.0429)</td>
</tr>
<tr>
<td>HHI</td>
<td>0.1908** (0.0747)</td>
<td>0.1837** (0.0761)</td>
<td>0.1875** (0.0764)</td>
<td>0.1875** (0.0764)</td>
<td>0.1904** (0.0747)</td>
<td>0.1831** (0.0761)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>-0.1413** (0.0207)</td>
<td>-0.1445** (0.0207)</td>
<td>-0.1447** (0.0208)</td>
<td>-0.1446** (0.0208)</td>
<td>-0.1414** (0.0207)</td>
<td>-0.1446** (0.0207)</td>
</tr>
<tr>
<td>LCC</td>
<td>0.0403*** (0.0102)</td>
<td>0.0421*** (0.0100)</td>
<td>0.0418*** (0.0100)</td>
<td>0.0418*** (0.0100)</td>
<td>0.0417*** (0.0103)</td>
<td>0.0449*** (0.0100)</td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0332 (0.0296)</td>
<td>0.0402 (0.0301)</td>
<td>0.0432 (0.0304)</td>
<td>0.0429 (0.0304)</td>
<td>0.0332 (0.0296)</td>
<td>0.0396 (0.0300)</td>
</tr>
<tr>
<td>Slot control</td>
<td>0.3437** (0.1708)</td>
<td>0.3802** (0.1837)</td>
<td>0.3807** (0.1855)</td>
<td>0.3807** (0.1856)</td>
<td>0.3437** (0.1706)</td>
<td>0.3800** (0.1836)</td>
</tr>
<tr>
<td>Observations</td>
<td>25,515</td>
<td>22,494</td>
<td>21,861</td>
<td>21,861</td>
<td>25,528</td>
<td>22,499</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.7929</td>
<td>0.7945</td>
<td>0.7957</td>
<td>0.7957</td>
<td>0.7929</td>
<td>0.7947</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
Table B9 Passenger estimation results for bottom 25% busiest routes using contemporaneous HHI

<table>
<thead>
<tr>
<th></th>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>−0.0002 (0.0001)</td>
<td>0.0001 (0.0001)</td>
<td>−0.0128 (0.0099)</td>
<td>−0.0001 (0.0143)</td>
<td></td>
</tr>
<tr>
<td>HHI</td>
<td>0.0441** (0.0177)</td>
<td>0.0418** (0.0185)</td>
<td>0.0441** (0.0176)</td>
<td>0.0417** (0.0185)</td>
<td></td>
</tr>
<tr>
<td>Fuel cost</td>
<td>−0.0088 (0.0102)</td>
<td>−0.0085 (0.0109)</td>
<td>−0.0088 (0.0102)</td>
<td>−0.0085 (0.0109)</td>
<td></td>
</tr>
<tr>
<td>LCC</td>
<td>0.0156 (0.0096)</td>
<td>0.0150 (0.0094)</td>
<td>0.0157 (0.0096)</td>
<td>0.0150 (0.0094)</td>
<td></td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0011 (0.0095)</td>
<td>−0.0094 (0.0102)</td>
<td>0.0014 (0.0095)</td>
<td>−0.0094 (0.0102)</td>
<td></td>
</tr>
<tr>
<td>Slot control</td>
<td>0.0403 (0.0206)</td>
<td>0.0557** (0.0257)</td>
<td>0.0405 (0.0203)</td>
<td>0.0559** (0.0257)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>6,467</td>
<td>5,029</td>
<td>6,470</td>
<td>5,030</td>
<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.6771</td>
<td>0.7008</td>
<td>0.6772</td>
<td>0.7010</td>
<td></td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
B.4 Regressions with standard errors double clustered at route and operating carrier level

In the main text, we cluster the standard errors at route level since it is with high probability that national aviation system delay and weather delay will affect the on-time performance of flights within the same route. According to statistics from BTS, another main reason of delay is called air carrier delay, which is defined as delay due to circumstances within airline’s control. Therefore, there is evidence to believe that the on-time performances of flights belonging to the same airline may be also closely related. In this appendix, as an additional robustness check, we run the same regressions with respect to airfare and passenger volume, but double cluster the standard errors at route and operating carrier level.

Comparing with the estimation results presented in Sections 2.4 and 2.5, although the significance of some control variables have changed due to new standard errors, the significance of delay impact remains qualitatively the same. Generally, the results presented in this appendix do not conflict with our findings in Sections 2.4 and 2.5.
### Table B10: Airfare estimation results for direct flights in top 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th></th>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delay</td>
<td></td>
<td>0.0004 (0.0006)</td>
<td>0.0005 (0.0007)</td>
<td>0.0030 (0.0021)</td>
<td>0.0018 (0.0016)</td>
<td>0.1699*** (0.0529)</td>
<td>0.0610 (0.0542)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td></td>
<td>−0.0115 (0.0283)</td>
<td>−0.0298 (0.0288)</td>
<td>−0.0249 (0.0289)</td>
<td>−0.0249 (0.0289)</td>
<td>−0.0109 (0.0283)</td>
<td>−0.0287 (0.0287)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td></td>
<td>0.1797*** (0.0059)</td>
<td>0.1793*** (0.0060)</td>
<td>0.1812*** (0.0060)</td>
<td>0.1812*** (0.0060)</td>
<td>0.1800*** (0.0059)</td>
<td>0.1795*** (0.0060)</td>
</tr>
<tr>
<td>LCC</td>
<td></td>
<td>−0.5851*** (0.0177)</td>
<td>−0.5741*** (0.0175)</td>
<td>−0.5706*** (0.0174)</td>
<td>−0.5704*** (0.0174)</td>
<td>−0.5904*** (0.0176)</td>
<td>−0.5767*** (0.0173)</td>
</tr>
<tr>
<td>Vacation</td>
<td></td>
<td>0.0275*** (0.0094)</td>
<td>0.0283*** (0.0095)</td>
<td>0.0272*** (0.0095)</td>
<td>0.0277*** (0.0096)</td>
<td>0.0271*** (0.0095)</td>
<td>0.0279*** (0.0096)</td>
</tr>
<tr>
<td>Slot control</td>
<td></td>
<td>−0.0916*** (0.0178)</td>
<td>−0.0988*** (0.0180)</td>
<td>−0.0955*** (0.0180)</td>
<td>−0.0959*** (0.0180)</td>
<td>−0.0901*** (0.0178)</td>
<td>−0.0982*** (0.0180)</td>
</tr>
<tr>
<td>Observations</td>
<td></td>
<td>20,922,436</td>
<td>20,128,759</td>
<td>19,812,792</td>
<td>19,812,792</td>
<td>20,922,715</td>
<td>20,129,299</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td>0.1064</td>
<td>0.1061</td>
<td>0.1059</td>
<td>0.1059</td>
<td>0.1065</td>
<td>0.1061</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
Table B11  Airfare estimation results for connecting flights in top 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th></th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>0.0009*</td>
<td>0.0003</td>
<td>0.0032</td>
<td>0.0020</td>
<td>0.0535</td>
<td>0.0076</td>
</tr>
<tr>
<td></td>
<td>(0.0004)</td>
<td>(0.0005)</td>
<td>(0.0020)</td>
<td>(0.0015)</td>
<td>(0.0382)</td>
<td>(0.0429)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.1473***</td>
<td>0.1327***</td>
<td>0.1515***</td>
<td>0.1516***</td>
<td>0.1474***</td>
<td>0.1326***</td>
</tr>
<tr>
<td></td>
<td>(0.0310)</td>
<td>(0.0319)</td>
<td>(0.0334)</td>
<td>(0.0335)</td>
<td>(0.0310)</td>
<td>(0.0319)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1045***</td>
<td>0.1046***</td>
<td>0.1052***</td>
<td>0.1052***</td>
<td>0.1045***</td>
<td>0.1046***</td>
</tr>
<tr>
<td></td>
<td>(0.0048)</td>
<td>(0.0048)</td>
<td>(0.0049)</td>
<td>(0.0049)</td>
<td>(0.0048)</td>
<td>(0.0048)</td>
</tr>
<tr>
<td>LCC</td>
<td>-0.4352***</td>
<td>-0.4370***</td>
<td>-0.4382***</td>
<td>-0.4381***</td>
<td>-0.4365***</td>
<td>-0.4370***</td>
</tr>
<tr>
<td></td>
<td>(0.0153)</td>
<td>(0.0155)</td>
<td>(0.0161)</td>
<td>(0.0161)</td>
<td>(0.0153)</td>
<td>(0.0155)</td>
</tr>
<tr>
<td>Vacation</td>
<td>-0.0143</td>
<td>-0.0173*</td>
<td>-0.0216**</td>
<td>-0.0208**</td>
<td>-0.0142</td>
<td>-0.0168*</td>
</tr>
<tr>
<td></td>
<td>(0.0100)</td>
<td>(0.0102)</td>
<td>(0.0104)</td>
<td>(0.0103)</td>
<td>(0.0100)</td>
<td>(0.0102)</td>
</tr>
<tr>
<td>Slot control</td>
<td>-0.0582***</td>
<td>-0.0629***</td>
<td>-0.0615***</td>
<td>-0.0618***</td>
<td>-0.0585***</td>
<td>-0.0627***</td>
</tr>
<tr>
<td></td>
<td>(0.0200)</td>
<td>(0.0206)</td>
<td>(0.0215)</td>
<td>(0.0215)</td>
<td>(0.0200)</td>
<td>(0.0205)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,739,653</td>
<td>1,687,975</td>
<td>1,611,723</td>
<td>1,611,723</td>
<td>1,739,893</td>
<td>1,688,165</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.0665</td>
<td>0.0671</td>
<td>0.0679</td>
<td>0.0679</td>
<td>0.0666</td>
<td>0.0671</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
### Table B12 Airfare estimation results for direct flights in bottom 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>−0.0027***</td>
<td>−0.0005</td>
<td>−0.1804***</td>
<td>0.0258</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
<td>(0.0005)</td>
<td>(0.0614)</td>
<td>(0.0509)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>−0.0447</td>
<td>−0.0961***</td>
<td>−0.0429</td>
<td>−0.0957***</td>
</tr>
<tr>
<td></td>
<td>(0.0276)</td>
<td>(0.0276)</td>
<td>(0.0276)</td>
<td>(0.0277)</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>0.1160***</td>
<td>0.1001***</td>
<td>0.1165***</td>
<td>0.1008***</td>
</tr>
<tr>
<td></td>
<td>(0.0214)</td>
<td>(0.0227)</td>
<td>(0.0216)</td>
<td>(0.0229)</td>
</tr>
<tr>
<td>LCC</td>
<td>−0.9110***</td>
<td>−0.8543***</td>
<td>−0.9083***</td>
<td>−0.8546***</td>
</tr>
<tr>
<td></td>
<td>(0.0453)</td>
<td>(0.0508)</td>
<td>(0.0454)</td>
<td>(0.0509)</td>
</tr>
<tr>
<td>Vacation</td>
<td>−0.0265</td>
<td>0.0035</td>
<td>−0.0269</td>
<td>0.0043</td>
</tr>
<tr>
<td></td>
<td>(0.0208)</td>
<td>(0.0190)</td>
<td>(0.0206)</td>
<td>(0.0190)</td>
</tr>
<tr>
<td>Slot control</td>
<td>−0.0481</td>
<td>−0.0307</td>
<td>−0.0437</td>
<td>−0.0315</td>
</tr>
<tr>
<td></td>
<td>(0.0539)</td>
<td>(0.0638)</td>
<td>(0.0551)</td>
<td>(0.0639)</td>
</tr>
<tr>
<td>Observations</td>
<td>1,293,208</td>
<td>1,144,372</td>
<td>1,293,254</td>
<td>1,144,392</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.1432</td>
<td>0.1315</td>
<td>0.1431</td>
<td>0.1315</td>
</tr>
</tbody>
</table>

**Significant at the 1% level.**

**Significant at the 5% level.**

*Significant at the 10% level.*
### Table B13

Airfare estimation results for connecting flights in bottom 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th>ln(Airfare)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delay</strong></td>
<td>0.0002 (0.0005)</td>
<td>0.0001 (0.0003)</td>
<td>−0.0379 (0.0354)</td>
<td>−0.0282 (0.0343)</td>
</tr>
<tr>
<td><strong>Lagged HHI</strong></td>
<td>0.0823*** (0.0267)</td>
<td>0.0755*** (0.0287)</td>
<td>0.0838*** (0.0269)</td>
<td>0.0760*** (0.0288)</td>
</tr>
<tr>
<td><strong>Fuel cost</strong></td>
<td>0.0666*** (0.0073)</td>
<td>0.0639*** (0.0074)</td>
<td>0.0673*** (0.0073)</td>
<td>0.0637*** (0.0073)</td>
</tr>
<tr>
<td><strong>LCC</strong></td>
<td>−0.5103*** (0.0381)</td>
<td>−0.5024*** (0.0382)</td>
<td>−0.5113*** (0.0378)</td>
<td>−0.5030*** (0.0380)</td>
</tr>
<tr>
<td><strong>Vacation</strong></td>
<td>−0.0168 (0.0285)</td>
<td>−0.0137 (0.0274)</td>
<td>0.0220 (0.0281)</td>
<td>−0.0141 (0.0273)</td>
</tr>
<tr>
<td><strong>Slot control</strong></td>
<td>−0.0650 (0.0393)</td>
<td>−0.0678** (0.0289)</td>
<td>−0.0646 (0.0394)</td>
<td>−0.0675** (0.0290)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>152,337</td>
<td>142,329</td>
<td>152,420</td>
<td>142,329</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.0565</td>
<td>0.0556</td>
<td>0.0564</td>
<td>0.0556</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
### Table B14 Passenger estimation results for top 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>AR(4) estimated delay</th>
<th>MA(4) delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delay</strong></td>
<td>−0.0003 (0.0003)</td>
<td>−0.0007 (0.0005)</td>
<td>−0.0020 (0.0016)</td>
<td>−0.0014 (0.0012)</td>
<td>−0.0559* (0.0324)</td>
<td>−0.1178*** (0.0430)</td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.1940*** (0.0341)</td>
<td>0.1887*** (0.0368)</td>
<td>0.1911*** (0.0374)</td>
<td>0.1911*** (0.0374)</td>
<td>0.1936*** (0.0340)</td>
<td>0.1881*** (0.0368)</td>
</tr>
<tr>
<td><strong>Fuel cost</strong></td>
<td>−0.1408*** (0.0086)</td>
<td>−0.1440*** (0.0091)</td>
<td>−0.1442*** (0.0092)</td>
<td>−0.1442*** (0.0092)</td>
<td>−0.1409*** (0.0085)</td>
<td>−0.1441*** (0.0091)</td>
</tr>
<tr>
<td>LCC</td>
<td>0.0406** (0.0176)</td>
<td>0.0420** (0.0186)</td>
<td>0.0415** (0.0188)</td>
<td>0.0415** (0.0188)</td>
<td>0.0420** (0.0175)</td>
<td>0.0449** (0.0186)</td>
</tr>
<tr>
<td><strong>Vacation</strong></td>
<td>0.0335** (0.0135)</td>
<td>0.0406*** (0.0144)</td>
<td>0.0442*** (0.0145)</td>
<td>0.0439*** (0.0145)</td>
<td>0.0335** (0.0135)</td>
<td>0.0400*** (0.0144)</td>
</tr>
<tr>
<td>Slot control</td>
<td>0.3423*** (0.0675)</td>
<td>0.3783*** (0.0782)</td>
<td>0.3787*** (0.0808)</td>
<td>0.3787*** (0.0808)</td>
<td>0.3423*** (0.0675)</td>
<td>0.3780*** (0.0783)</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td>25,515</td>
<td>22,494</td>
<td>21,861</td>
<td>21,861</td>
<td>25,528</td>
<td>22,499</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.7931</td>
<td>0.7947</td>
<td>0.7959</td>
<td>0.7958</td>
<td>0.7931</td>
<td>0.7949</td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.

** Significant at the 5% level.

* Significant at the 10% level.
Table B15 Passenger estimation results for bottom 25% busiest routes with double clustered standard error

<table>
<thead>
<tr>
<th></th>
<th>Ln (Daily Passengers)</th>
<th>Lag-1 average delay</th>
<th>Lag-4 average delay</th>
<th>Lag-1 delay rate</th>
<th>Lag-4 delay rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>−0.0002 (0.0002)</td>
<td>0.0001 (0.0002)</td>
<td>−0.0128 (0.0143)</td>
<td>−0.0001 (0.0177)</td>
<td></td>
</tr>
<tr>
<td>Lagged HHI</td>
<td>0.0441*** (0.0142)</td>
<td>0.0418*** (0.0158)</td>
<td>0.0441*** (0.0143)</td>
<td>0.0417*** (0.0159)</td>
<td></td>
</tr>
<tr>
<td>Fuel cost</td>
<td>−0.0088 (0.0081)</td>
<td>−0.0085 (0.0097)</td>
<td>−0.0088 (0.0081)</td>
<td>−0.0085 (0.0097)</td>
<td></td>
</tr>
<tr>
<td>LCC</td>
<td>0.0156 (0.0115)</td>
<td>0.0150 (0.0121)</td>
<td>0.0157 (0.0115)</td>
<td>0.0150 (0.0121)</td>
<td></td>
</tr>
<tr>
<td>Vacation</td>
<td>0.0011 (0.0101)</td>
<td>−0.0094 (0.0104)</td>
<td>0.0014 (0.0101)</td>
<td>−0.0094 (0.0104)</td>
<td></td>
</tr>
<tr>
<td>Slot control</td>
<td>0.0403 (0.0255)</td>
<td>0.0557** (0.0262)</td>
<td>0.0405 (0.0253)</td>
<td>0.0559** (0.0262)</td>
<td></td>
</tr>
<tr>
<td>Observation</td>
<td>6,467 5,029 6,470 5,030</td>
<td>0.6771 0.7008 0.6772 0.7010</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** Significant at the 1% level.
** Significant at the 5% level.
* Significant at the 10% level.
Appendix C

C.1 Area Calculation

In this section, we derive the formula used to calculate the areas in Section 3.2. Equations (3.1) and (3.2) are assumed to be log linear in regression, so the demand curve and fare curve are actually:

\[
\text{Passenger Volume}_{i,j,t} = \exp[\beta_0 + \beta_1 \ln(Airfare_{i,j,t}) + \beta_2 \ln(\text{NonstopMiles}_j) + \beta_3 \ln(Population_{j,t}) + \beta_4 \ln(\text{Income}_{j,t}) \\
+ \beta_5 \ln(\text{Population}_{j,t}) + \beta_6 \ln(\text{Income}_{j,t}) + \sum \beta_n \text{Year} + \sum \beta_n \text{Quarter} \\
+ \sum \beta_n \text{Destination} + \epsilon_{i,j,t}] \tag{C1}
\]

\[
\text{Airfare}_{i,j,t} = \exp[\alpha_0 + \alpha_1 \ln(\text{Passenger Volume}_{i,j,t}) + \alpha_2 \ln(Fuel Price_t) \\
+ \alpha_3 \ln(HHI_{i,j,t-1}) + \alpha_4 \ln(\text{NonstopMiles}_j) \\
+ \alpha_5 \ln(\text{Population}_{j,t}) + \alpha_6 \ln(\text{Income}_{j,t}) + \sum \alpha_n \text{Year} \\
+ \sum \alpha_n \text{Quarter} + \sum \alpha_n \text{Destination} + \epsilon_{i,j,t}] \tag{C2}
\]

Equation (C1) is the demand function we use in the integrals in Equations (3.3) and (3.4). Solving the above system for Passenger Volume and Airfare, we get:

\[
\text{Passenger Volume}_{i,j,t} = \exp[(\beta_0 + \beta_1 \alpha_0 + \beta_1 \alpha_2 \ln(Fuel Price_t) + \beta_1 \alpha_3 \ln(HHI_{i,j,t-1}) \\
+ (\beta_2 + \beta_1 \alpha_4) \ln(\text{NonstopMiles}_j) + (\beta_3 + \beta_1 \alpha_5) \ln(\text{Population}_{j,t}) + \beta_5 \ln(\text{Income}_{j,t}) \\
+ \sum (\beta_n + \beta_1 \alpha_n) \text{Year} + \sum (\beta_n + \beta_1 \alpha_n) \text{Quarter} \\
+ \sum (\beta_n + \beta_1 \alpha_n) \text{Destination} + \epsilon_{i,j,t} \\
+ \beta_1 \epsilon_{i,j,t})/(1 - \alpha_1 \beta_1)] \tag{C3}
\]
Airfare\textsubscript{i,j,t} = \exp[(\alpha_0 + \alpha_1 \beta_0 + \alpha_2 \ln(Fuel \ Price_\textsubscript{t}) + \alpha_3 \ln(HHI_{i,j,t-1})
+ (\alpha_4 + \alpha_1 \beta_2)\text{Expected \ Delay}_{i,j,t} + (\alpha_5 + \alpha_1 \beta_3) \ln(NonstopMiles_j)
+ (\alpha_6 + \alpha_1 \beta_6)LCC_{i,j,t} + \alpha_1 \beta_4 \ln(Population_{j,t}) + \alpha_1 \beta_5 \ln(Income_{j,t})
+ \sum (\alpha_n + \alpha_1 \beta_n)\text{Year} + \sum (\alpha_n + \alpha_1 \beta_n)\text{Quarter}
+ \sum (\alpha_n + \alpha_1 \beta_n)\text{Destination} + \alpha_1 \varepsilon_{i,j,t} + \varepsilon_{i,j,t})/(1 - \alpha_1 \beta_1)]. \hspace{1cm} (C4)

Equations (C3) and (C4) are used to calculate the market equilibrium prices and quantities.

The marginal revenue, which is supposed to be equal to the marginal cost, is calculated from the demand function. We can rewrite equation (C1) in the form of reversed demand:

\[
Airfare_{i,j,t} = \frac{\text{Passenger Volume}_{i,j,t}^{\frac{1}{\beta_1}}}{\Omega_{i,j,t}} \hspace{1cm} (C5)
\]

where

\[
\Omega_{i,j,t} = \exp[(\beta_0 + \beta_2 Delay_{i,j,t} + \beta_3 \ln(NonstopMiles_j) + \beta_4 \ln(Population_{j,t})
+ \beta_5 \ln(Income_{j,t}) + \beta_6 LCC_{i,j,t} + \sum \beta_n \text{Year} + \sum \beta_n \text{Quarter}
+ \sum \beta_n \text{Destination})/\beta_1] \hspace{1cm} (C6)
\]

Then by using (C5) to derive Airfare's first order derivative with respect to Passenger Volume, the marginal revenue/cost is:

\[
MR_{i,j,t} = MC_{i,j,t} = \frac{\partial(Airfare \ast \text{Passenger Volume})}{\partial(\text{Passenger Volume})} = \frac{1}{\beta_1 \Omega_{i,j,t}^{\frac{1}{\beta_1}}} q_{i,j,t}^{\frac{1}{\beta_1}} + p_{i,j,t}, \hspace{1cm} (C7)
\]

where \(q_{i,j,t}\) and \(p_{i,j,t}\) are equilibrium quantity and price respectively calculated using Equations (C3) and (C4).
References


The Economist (1998), The Science of Alliance, 4 April, pp. 73–74.


