Subcontracting Network Formation among US Airline Carriers

Lei He Georgia Kosmopoulou *†

October 27, 2018

Abstract

This paper is applying network analysis to a dataset on the US airline industry to study link formation and pricing decisions among airline carriers. We focus on subcontracting networks formed between major carriers and regional carriers and use Bayesian estimation methods to study the factors that contribute to the formation of carriers' subcontracting relationships. The paper provides evidence that the network structure among carriers plays a significant role in carriers' subcontracting behaviors, new network formation and entry decisions. A major carrier is more likely to enter a route by subcontracting, if its rivals have already formed subcontracting relationships. It is also more likely to form links with regional carriers that serve fewer routes but serve more passengers and have a larger market share per route. We find that carrier similarity in terms of their route service distributions impacts the establishment of subcontracting relationships on a route. Major carriers' self-service and subsidiary relationships are complementary to their subcontracting behaviors, while code-sharing and other types of non-subcontracting relationships are substitutes. Our results show that, regional carriers prefer to avoid direct competition by not serving routes on which there is already another regional carrier. Taking the resulting major carriers' subcontracting behaviors into account and potential endogeneity issues, we find that ticket prices decrease by 3.4% in our sample.

Keywords: Network; Subcontracting; Airline Industry

JEL Classification Codes: L14, L93, D22.

*The authors would like to thank the conference participants at the 2018 Western Economic Association meeting in Vancouver, Canada, and the seminar participants at the University of Oklahoma.

†Department of Economics, Norman, OK 73072. E-mails: lei.he@ou.edu (Lei He) and georgiak@ou.edu (Georgia Kosmopoulou).

1 Introduction

Research in networks is developing quickly in economics and provides an opportunity to study the underpinnings of competition in the US airline industry. The airline industry is dominated by a handful of strong contenders, with small competing firms struggling to establish a presence. In this paper, we tackle industry evolution from a whole new angle: by evaluating how network opportunities of airline companies are forming through subcontracting and how the network structure of unique and common connections is affecting prices. Understanding the mechanics of network formation is instrumental to understanding price dynamics, and how positive spillovers are channeled to enhance participation and survival of firms in the market. The wealth of information that is required to capture the network's links and the computational capacity it takes to chart the dynamics of interdependence offer an opportunity to zero in on the effects of market penetration and expansion.

A natural way of applying network analysis into the US airline industry is to investigate factors that affect the evolution of network structure among carriers. Our focus is on the network formed through subcontracting relationships while we control for other types of agreements among major carriers. A network link is formed when one carrier subcontracts a flight service to another carrier. We investigate factors that affect new or maintained link formation among carriers on certain routes, the impact of this network on prices and carrier expansion at the regional level.

This paper develops a model of strategic network formation among US airline carriers. Relationships among firms can have a significant effect on firms' behaviors, pricing strategies and information flow. The study of firm network formation, and their resulting cooperative market behavior creates exciting new opportunities to understand market dynamics. We contribute to the literature in two respects. First, we contribute to the network formation literature by developing a framework of subcontracting choices. The two papers most closely related to ours in the literature are Christakis et al. (2010) and De Silva et al. (2017). Christakis et al. consider a sample of 669 high school students and study how the formation of a social network affects class performance. De Silva et al. investigate the drivers of strategic network formation between dealers and sellers in a market for fine art as means of information acquisition. They study the effect of network structure on artwork prices and dealer market reach. Proprietary knowledge is shown to improve market outcomes and the length of market presence for dealers. Other studies in economics and finance focus on preferential attachments in a network. Lux (2015) shows that a learning mechanism affects the link formation in the network of interbank credit relationships. Currarini et al. (2009) shows that same-type relationships with respect to demographics contribute to friendship formation. Our study of network formation among US airline carriers will utilize recent methodological advancements in analyzing empirically the formation of networks to enhance our understanding of firm success. Second, this paper contributes to the subcontracting/outsourcing literature in the US airline industry. Many papers have studied why major carriers subcontract part or all of their flight services to regional carriers on a route. The main reasons include cost reduction (Fill and Visser (2000) and Rieple and Helm (2008)), risk consideration (Forbes and Lederman (2009)), and market competition (Tan (2018)). We study airline's subcontracting behavior from a distinct perspective, namely by exploring the network structure and its capabilities within a competitive framework. We focus on major carriers' subcontracting decisions, while taking regional carriers into consideration. The exploration of the network structure is motivated by a need to understand the make-or-buy decisions and has been subject of study in various settings and industries besides the airline, such as entertainment, health care and public service (De Silva et al. (2012), Marion (2009)). In addition, we study the effect of subcontracting on ticket prices. In this field, Tan (2018) is most closely related to our work. We contribute to the literature by taking into account the route level potential endogeneity issue of carriers' subcontracting decisions in their pricing strategies.

We use newly developed approaches in Bayesian estimation methods discussed in Christakis et al. (2010) and find that the network among airline carriers has important impact on their subcontracting behavior and new link formations. This behavior can be explained by network factors such as the number of links for both carriers and the number of common routes carriers served in the last period, as well as other typically used measures including the presence of low-cost carriers on a route and market concentration.

Our work extends existing research and creates a distinct focus: we look at how competition and expansion of firms is affected by the network opportunities subcontracting creates. It links network formation to questions of dynamic evolution of firms and provides opportunities for a direct policy evaluation of regulations regarding subcontracting. While traditional models enable us only to derive relationships between firm specific characteristics and prices, network analysis allow us to incorporate the complexities introduced by interdependencies across different firms in the market. The network structure and connectedness of a network can be critical for understanding ripple effects caused by input price fluctuations and economic downturns.

The rest of the paper is organized as follows. Section 2 provides background information on the relationships among US airline carriers. Section 3 presents our Bayesian estimation method and the model. Section 4 describes how we construct the data and variables. We present the estimation results in Section 5 while in Section 6, the effects of major carriers' subcontracting behaviors on ticket prices are studied. We conclude in Section 7.

2 Background of the US Airline Carriers' Relationships

In the US Airline industry, there are three commonly known types of carriers: major carriers, low-cost carriers and regional carriers. Major carriers are the carriers that sell tickets in a network of routes connecting the majority of the airports in the US. Low-cost carriers are the ones that also serve a network of routes but at a lower cost by not offering some or most of the traditional services major carriers provide, such as seat assignment in advance. We call both major and low-cost carriers as network carriers since both types sell tickets in a network of routes. Regional carriers are the carriers that usually do not sell tickets themselves but operate regional aircrafts for major carriers. Regional carriers have cost advantages in serving routes of small to medium distance, due to the type of aircrafts being used and the lower wages offered to their staff. Table 1 lists the carriers by the type of service they offer in our sample. In total, we have 5 major carriers, 9 low-cost carriers and 22 regional carriers.

Depending on the role that an airline carrier plays in a flight service, we further distinguish between ticketing and operating carriers. Ticketing carriers are the ones that schedule flights, set ticket prices and sell tickets to passengers. In most cases, ticketing carriers are network carriers. Operating carriers are the ones directly providing flight services with their own aircrafts and staff. The same carriers may or may not serve as ticketing and operating carriers. If the ticketing and operating carrier are not the same for a flight service, these two carriers form a relationship to serve the route. This relationship differs depending on the ticketing carrier's and operating carrier's type, namely whether they are major, low-cost or regional carriers.

Table 2 summarizes the types of relationships among US airline carriers. If the ticketing and operating carriers are the same for some flights across a route, we call their service structure as self-service. This self-service structure of provision can be thought of as the relationship of the carrier with itself. If the ticketing and operating carriers are different, they may form four types of relationships. First, if the ticketing carrier is a network carrier and the operating carrier is another network carrier, their relationship is characterized as "code sharing". In this case, the flight is operated by one network carrier but the tickets are sold by one or several network carriers in each of their ticket selling systems. In other words, the network ticketing carrier helps sell tickets for another network operating carrier. Second, if the ticketing carrier is a major carrier and the operating carrier is a regional carrier[1], we categorize their relationships into three types, depending on the agreement between these two carriers: 1) If the regional carrier is a wholly owned subsidiary of the major ticketing carrier or the parent company of the major ticketing carrier, we call it subsidiary. 2) If the major ticketing carrier has a long-term contract with the regional operating carrier, we call their contractual relationship subcontracting. In this case, the major carrier subcontracts part or all of its flight services on some routes to the regional carrier. 3) When the major ticketing carrier does not have a long-term contract with the regional operating carrier, and the regional carrier is not a wholly owned subsidiary of the major carrier either, we categorize this relationship as of "other type". This category includes three types of interactions:[2] a) First, the major ticketing carrier may subcontract indirectly to the regional operating carrier. In other words, the major ticketing carrier codeshares with another major carrier, which subcontracts the flight service to the regional operating carrier.[3] b) Second, the major ticketing carrier may codeshare with the regional operating carrier and help sell the flight tickets under the major carrier's system. c) Last, this may also be a result of gate switching behavior of the major ticketing carrier. In certain situation, the major ticketing carrier actually operates the flight itself (is the operating carrier) but has to use a regional carrier's gate at the airport. If this happens, the regional carrier which has contracted the use of the gate will be reported as the operating carrier. Gate switching will thus result to a major carrier serving as the ticketing carrier and a regional being the operating carrier. We group these three cases together as "other type" for simplicity. This allows us to simplify the framework and focus on carrier subcontracting relationships and networks.

These relationships are *not mutually exclusive*, namely, a major ticketing carrier on a route may have more than one type of relationships with other carriers. In extreme cases, a major ticketing carrier may have all four types of relationships with other carriers while also self-serving a route.

3 The Model and Estimation Method

The airline route used in our paper is defined as a non-directional route between two airports in the US, so for example, the route from Chicago O'Hare International Airport to New York John F. Kennedy International Airport and that from New York John F. Kennedy International Airport to Chicago O'Hare International Airport are considered the same. Assume there are I major carriers and J independent regional carriers operating on M routes for T time periods[4]. Since subcontracting is directional behavior

[1]Even though we may observe a relationship formed between a low-cost ticketing carrier and a regional operating carrier, this is rare.

[2]We would like to thank Myongjin Kim for generously sharing with us the information about these three types of interactions.

[3]Unfortunately, we are not able to identify the intermediary major carrier between the major ticketing carrier and the regional operating carrier since there may be more than one possible intermediary major carriers which subcontract to the regional operating carrier.

[4]Since we are focusing on the subcontracting network, we do not model low-cost carriers' and wholly-owned subsidiaries' behaviors. In addition, the regional carriers which do not have subcontracting relationships are not modeled either.

(a major carrier subcontracts to a regional carrier and not vice versa), the network between major and regional carriers is directional, and we analyze the network at route level. We say that a link, $Link^{s}_{ijmt}$ ($i \in \{1,2,...,I\}, j \in \{1,2,...,J\}$), forms if the major carrier i subcontracts to the regional carrier j on route m at time period t, and otherwise $Link^{s}_{ijmt} = 0$. Although we focus on modeling carriers' subcontracting network, we also analyze how major carriers' other non-subcontracting relationships including self-service affect their subcontracting network formation. As such, we aggregate major carriers' other non-subcontracting relationships by category and incorporate them into the network. We define $Link^{ns}_{ilmt} = 1$, where $l \in \{$Self-Service, Subsidiary, Code-Sharing, Other-Type$\}$, if the major carrier i has the relationship of l with relevant agents on route m at period t, and otherwise $Link^{ns}_{ilmt} = 0$.

The link matrix $Link_{mt}$ is combining an $I \times J$ subcontracting adjacency link matrix and an $I \times 4$ aggregated non-subcontracting link matrix to present the entire landscape of relationships within t and m. The ith and jth element of the subcontracting adjacency link matrix $Link^{s}_{ijmt}$ ($i \in \{1,2,...,I\}, j \in \{1,2,...,J\}$) represents all of the subcontracting relationships on route m at period t. The ith and lth element of the non-subcontracting link matrix $Link^{ns}_{ilmt}$ ($i \in \{1,2,...,I\}, l \in \{\text{Self-Service}, \text{Subsidiary}, \text{Code-Sharing}, \text{Other-Type}\}$) represents all of the aggregated non-subcontracting relationships. Table 3 presents a subcontracting adjacency and a non-subcontracting link matrices that could synthesize a potential link matrix $link_{mt}$ in the case of 3 major carriers and 2 regional carriers on route m in period t. The 3×2 matrix to the left has entries indicating whether a major carrier subcontracts to regional carriers and form links in the network. For example, the value 1 in the second row and second column indicates that Major carrier 2 forms a link with and subcontracts to Regional carrier 2. However, Major carrier 2 does not form a link with Regional carrier 1 indicated by the value 0 in the second row and first column. The 3×4 matrix to the right indicates whether major carriers have other non-subcontracting relationships. For example, the value 1 in the second row and third column shows that Major carrier 2 has a code-sharing relationship with other network carriers. Note that, Major carrier 3 subcontracts to both regional carriers and has all four types of other non-subcontracting relationships at the same time. This is possible since these relationships are not mutually exclusive. In addition, all elements for Major carrier 1 are 0, indicating that Major carrier 1 does not operate on route m in period t. [5]

In our paper, we extend the Bayesian estimation method developed in Christakis et al. (2010) in a dynamic framework of multiple concurrent networks. During each period t, carriers may engage in a contractual or non-contractual relationship with other carriers or may self-serve their demand according to some event order (EO_t). The event order is not fixed arbitrarily but determined optimally in the estimation as described later. Those events include meetings between major and regional carriers, in which they decide on which route to establish or maintain a subcontracting relationship (by forming or maintaining a link). We model each period's interaction between a major and a regional carrier as a single meeting occurrence leading to a subcontracting decision. As a result, if all I major carriers and all J regional carriers are active in period t, EO_t will contain in total $I \times J$ meetings between major and regional carriers. Besides those meetings, EO_t also includes events when major carriers can decide whether or not to have other non-subcontracting relationships with relevant carriers. The outcomes of each event in period t are observable to all carriers immediately after the event. Table 4 presents an example of a potential event order in the case of 3 major and 2 regional carriers at period t. The first six events listed in the table are the meetings between major carriers and regional carriers. For example, Event 1 allows Major carrier 1 and Regional carrier 1 to meet

[5] For later reference, we also define $Link_t$ as the aggregation of $Link_{mt}$ across all routes and $Link$ as the aggregation of $Link_t$ across all time periods. Correspondingly, $Link_t$ represents all relationships in period t and $Link$ all relationships.

and decide whether to maintain or establish subcontracting relationships and if so on which routes. In Event 7 to 10, Major carrier 1 decides whether to form other non-subcontracting relationships with relevant agents and if so on which routes. Event 9 allows Major carrier 1 to meet all other network carriers and decide on which routes it will establish or maintain code-sharing relationships[6]. We define EO as the aggregation of EO_t across time and $EventOrder$ as the set which contains all possible EOs.

After having defined the way in which we record the network and the order in which carriers make decisions, we now describe how the network evolves at period t. We define $TempLink_{mt}^{O_t}$ as the transition link matrix through which the network on route m evolves from $Link_{m,t-1}$, the network of the last period, to $Link_{mt}$, the network of the current period, with $O_t = \{1, ..., r_t\}$ signifying the number of events taking place within t. $TempLink_{mt}^1 = Link_{m,t-1,}$ at the beginning of each period t and through the event order is transformed taking into account the decisions that are made sequentially within t. Before any event, if any major carrier i or regional carrier j either exits, goes bankrupt or merges with an existing carrier in the current period t, we set $TempLink_{imt}^1 = 0$ or $TempLink_{jmt}^1 = 0$ respectively following the assumption that if any carrier stops existing at period t it is known to all carriers at the beginning of the period. Subsequently, active major and regional carriers make decisions sequentially according to the given event order EO_t. After each event, $TempLink_{mt}^{O_t}$ is updated according to the outcome of the event. In the next event in order, carriers make their decisions conditional on the updated $TempLink_{mt}^{O_t}$. After all the events taking place within t, $TempLink_{mt}^{O_t}$ evolves to $Link_{mt}$, describing the network that has formed in the current period.[7] During this process, the event order EO_t determines the way in which $Link_{m,t-1}$ evolves to $Link_{mt}$. For later reference, we define $TempLink_t^{O_t}$ as the aggregation of $TempLink_{mt}^{O_t}$ across all routes.

Next we specify the utility of each link formation for major carriers and regional carriers. We assume the carrier is willing to form the link if the utility U_{ijmt}^k is greater than zero, where $k = 1$ identifies major carriers and $k = 2$ identifies regional carriers, and

$$\begin{aligned} U_{ijmt}^1 &= \alpha_t^1 + \lambda_{1i}^1 + \lambda_{2j}^1 + f^1(Link_{t-1}) + g^1(TempLink_t^{O_t}|EO_t) + h^1(X) + \epsilon_{ijmt}^1 \\ U_{ijmt}^2 &= \alpha_t^2 + \lambda_{1i}^2 + \lambda_{2j}^2 + f^2(Link_{t-1}) + g^2(TempLink_t^{O_t}|EO_t) + h^2(X) + \epsilon_{ijmt}^2. \end{aligned} \tag{1}$$

α_t^k indicates time fixed effects, λ_{1i}^k major carrier fixed effects and λ_{2j}^k regional carrier fixed effects. U_{ijmt}^k is a function of $Link_{t-1}$ the network in the last period, and also a function of the transition network $TempLink_t^{O_t}$ of the current period conditional on the given event order. X are other covariates which may affect the utility gains from link formation. We also assume the error term ϵ_{ijmt}^k follows a type I extreme value distribution. Thus, the probability that the carrier is willing to form the link will be given by the following equation.

$$ln(\frac{Pr(U_{ijmt}^k > 0)}{1 - Pr(U_{ijmt}^k > 0)}) = \alpha_t^k + \lambda_{1i}^k + \lambda_{2j}^k + f^k(Link_{t-1}) + g^k(TempLink_t^{O_t}|EO_t) + h^k(X),\ k \in \{1, 2\}. \tag{2}$$

A link forms when both carriers' utilities are positive, so the probability of a link formation is

$$Pr(Link_{ijmt}^s) = Pr(U_{ijmt}^1 > 0)Pr(U_{ijmt}^2 > 0). \tag{3}$$

[6]In this paper, we focus on the formation of a subcontracting network instead of code-sharing, so we do not model what factors affect major carriers' code-sharing relationship. For simplicity, we aggregate major carriers' code-sharing decisions rather than allowing them to meet with each network carrier separately, and we do not focus on the characteristics of the carrier that the code-sharing relationship is established with.

[7]As mentioned earlier, this event order is ultimately determined not randomly but optimally as will be described shortly.

Define β the parameter vector for functions f_k, g_k, and h_k as well as fixed effect controls α_t^k, λ_{1i}^k, and λ_{2j}^k. The total number of parameters in β is N. Given an event order, the joint likelihood function of a given network is

$$\mathcal{L}(\beta|EO, Link) = \prod_{t\in\{2,...,T\}} \prod_{(i,j)\in(I_t,J_t)|EO_t} \prod_{m\in\{1,...,M\}} Pr(Link_{ijmt}^s)^{Link_{ijmt}^s}(1 - Pr(Link_{ijmt}^s))^{1-Link_{ijmt}^s}. \tag{4}$$

I_t and J_t are the sets of major carriers and regional carriers which are active in period t. The likelihood function is the product of the probabilities of each link formation decision across time, major carriers, regional carriers and routes given a network $Link$ and an event order EO. It describes the probability that a given network forms. EO determines the order in which major and regional carriers meet to decide on subcontracting relationships and major carriers make decisions of other non-subcontracting relationships. We allow major and regional carriers' decisions to be endogenous and focus on modeling what factors determine the subcontracting relationships. However, we do not model what factors affect major carriers' decisions of other non-subcontracting relationships in the joint likelihood function, which is outside the scope of the paper.

By modeling major carriers' subcontracting decisions and other non-subcontracting relationships including self-service we are also modeling in the estimation separately entry and exit decisions linked to those actions. First, we are modeling all major carriers including route existing major carriers and those potential entrants that do not operate on a route. Taking into account existing major carriers' and potential entrants' subcontracting decisions and the establishment or maintenance of non-subcontracting relationships on a route we are no longer keeping the focus on ongoing relationships, but incorporating decisions of route entry. Second, by including major carriers' subcontracting decisions and other non-subcontracting relationships, we are including all forms in which they can exist and operate on a route. As a result, the estimation includes major carriers' entry and exit decisions linked to those actions.

In estimating this model, we use the Markov-Chain-Monte-Carlo method to update β and get a converged posterior distribution after a large number of iteration. At the same time, we update EO. We assume β follows a prior normal distribution $N(0, I)$, where I is the identity matrix, and $\beta_0 = 0$. Letting q denote the iteration number and n the element in the parameter vector, we update β from β_q^n to β_{q+1}^n as follows. We first randomly draw a β^n from $N(\beta_q^n, 1)$. We then calculate the likelihood ratio

$$r = min\{1, \frac{\mathcal{L}(\beta^n|EO^q, Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N)p(\beta^n)}{\mathcal{L}(\beta_q^n|EO^q, Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N)p(\beta_q^n)}\}, \tag{5}$$

where p is the density function of the standard normal distribution. Depending on the likelihood ratio r, β_{q+1}^n will be determined by the following equation.

$$\beta_{q+1}^n = \begin{cases} \beta^n & \text{with probability } r \\ \beta_q^n & \text{with probability } 1 - r. \end{cases} \tag{6}$$

Next, we update EO from EO^q to EO^{q+1}. We assume EO follows a uniform distribution over $EventOrder$. We first draw an EO^{temp} from the distribution, and calculate the likelihood ratio

$$r = min\{1, \frac{\mathcal{L}(\beta_{q+1}|EO^{temp}, Link)}{\mathcal{L}(\beta_{q+1}|EO^{q}, Link)}\}. \tag{7}$$

Depending on the likelihood ratio, we decide whether to update the event order according to the following equations

$$EO^{q+1} = \begin{cases} EO^{temp} & \text{with probability } r \\ EO^{q} & \text{with probability } 1-r. \end{cases} \tag{8}$$

After a large number of iterations, the distribution of the parameters will converge to a posterior distribution. Obtaining the estimates of the parameters from the last 500 iterations, which constitute the posterior distribution, we can calculate the means and standard deviations of the parameters and determine whether they are significant.

4 Data and Variables

The main data we use is the Airline Origin and Destination Survey (DB1B) data, which is a 10% quarterly sample of airline tickets sold. DB1B Coupon Data records flight segment level data, and provides the year, quarter, origin airport, destination airport, route distance, ticketing carrier, operating carrier, and passenger number. We also use the Regional Airline Association (RAA) annual reports to identify subcontracting partnerships between major and regional carriers. As the 2012 annual report is missing from the RAA official website, our data sample covers the periods from the 3rd quarter of 2013 to the 3rd quarter of 2017. Following the literature, we only keep the largest 300 airports in terms of passenger numbers in the lower 48 U.S. states[8]. We aggregate DB1B Coupon data to route-quarter-ticketing carrier-operating carrier level, and drop the observations which have less than 20 passengers.[9]

We identify the five types of relationships (Self-service, Subsidiary, Subcontracting, Code-sharing, and Other-Type) among airline carriers using the DB1B Coupon Data first. The DB1B Coupon Data directly provides information about self-service and code-sharing relationships. We identify relationships between major and regional carriers (Subsidiary, Subcontracting, and Other-Type) as follows. We first collect the information about major carriers' wholly owned subsidiaries. We then use RAA annual reports to distinguish subcontracting relationship from "other types" of relationships. Unfortunately, RAA only provides information for the third quarter each year. For the remaining quarters, we have to extrapolate carriers' subcontracting relationships based upon the available information.[10]

Table 5 lists the subcontracting partnerships between major and regional carriers at the carrier level in quarter 3 of 2014. The regional carriers in bold are the wholly owned subsidiaries of the corresponding major carriers. For each major carrier, there is at least one independent regional carrier being subcontracted to. More than one major carrier may subcontract to the same regional carrier. For example, all five major carriers subcontract to SkyWest. Thus, between major and regional carriers, an interdependent network forms by their subcontracting relationships.

[8]The passenger numbers used to rank the airports are calculated using 2015 first quarter DB1B Coupon Data.

[9]The data sometimes uses different codes for the same carrier across time, so we match carriers' codes with their names.

[10]For example, if Major carrier 1 does not subcontract to Regional carrier 1 in quarter 3 of 2015, but subcontracts to it in quarter 3 of 2016, and if we observe that Major carrier 1 is the ticketing carrier and Regional carrier 1 is the operating carrier on some routes in quarter 2 of 2016, we consider that they have a subcontracting relationship in this quarter. As airline carriers' subcontracting partnerships are typically formed with long-term contracts and are relatively stable over time without changes within a short time, we consider this is a reasonable extrapolation.

Since we focus on the subcontracting relationships between major carriers and regional carriers, we drop the ticketing carriers which are not major carriers. In addition, wholly owned subsidiaries do not have any subcontracting relationship with other major carriers, thus we do not consider subsidiaries as candidate regional carriers that are entering subcontracting agreements with major carriers. We do not take into account those regional carriers that never form subcontracting relationships. We drop the routes with distance more than 2000 miles, since regional carriers equipped with regional aircrafts are not able to provide flight service on a route with such a long distance. In the end, we have a sample with 5 major carriers, 13 regional carriers, 17 quarters and 2293 routes.

We use the following linear specification for carriers' utilities and estimate the effect of these factors on the link formation of the network

$$\begin{aligned} U^k_{ijmt} =& \alpha^k_t + \lambda^k_{1i} + \lambda^k_{2j} + \gamma^k RouteChar + \theta^k CarrierChar \\ &+ \beta^k Homophily + \phi^k LinkVar_{t-1} + \delta^k TempLinkVar_t + \epsilon^k_{ijmt}, k = 1, 2. \end{aligned} \quad (9)$$

$RouteChar$ are route characteristics that include the following six variables. LCC_{mt} is a low-cost carrier dummy variable indicating whether any low-cost carrier operates on route m at time t. $HHI_{m,t-1}$ is the Herfindahl-Hirschman Index of the last period calculated by major carriers' passenger numbers, capturing the market concentration level. $RouteDistance_m$ and $RouteDistance^2_m$ are the route distance and the square of the route distance respectively. $log(gmean(pop))_m$ is the logarithm of the geometric mean of the population[11] near the two endpoint airports of the route, capturing the size of the demand on the route. $Disparity_m$ is the ratio of the larger population divided by the smaller population of the two endpoint airports, and it captures the relative size of the two airports populations.

$CarrierChar$ are carrier characteristics. We use carriers' features in the last period to measure carriers' characteristics. The variables include the number of routes major and regional carriers serve ($RouteNmbr_{i,t-1}, RouteNmbr_{j,t-1}$), the number of passengers they deliver ($PassengerNmbr_{i,t-1}, PassengerNmbr_{j,t-1}$), the number of passengers they deliver on the route ($PassengerNmbr_{im,t-1}, PassengerNmbr_{jm,t-1}$), and the market share of major and regional carriers in terms of passenger numbers on the route ($MarketShare_{im,t-1}$, $MarketShare_{jm,t-1}$). These variables provide different measures of carrier size, and are introduced to examine whether a carrier's size has any impact on the network link formation.

We also include two $Homophily$ measures to control for the similarity between the major and the regional carriers in terms of the routes they serve. One variable is the number of common routes in which two carriers provide service in the last period ($CommonRtNmbr_{ij,t-1}$). The other variable is the metric distance of the two vectors of passenger shares across routes between the two carriers ($MetricDistance_{ij,t-1}$)[12]. The smaller the $MetricDistance_{ij,t-1}$ is, the more similar these two carriers are considered. We expect that the more similar the carriers are, the more likely they will form and maintain a subcontracting relationship on a route.

From $Link_{t-1}$, we generate some variables ($LinkVar_{t-1}$) characterizing the features of the network of the last period. These variables are the link numbers of the major and the regional carriers ($LinkNmbr_{i,t-1}, LinkNmbr_{j,t-1}$), the link numbers of the major and the regional carriers on the route ($LinkNmbr_{im,t-1}, LinkNmbr_{jm,t-1}$), the number of same pair links they form ($SameLinkNmbr_{ij,t-1}$), and a dummy variable indicating whether they have already established a link in the last period ($Link^s_{ijm,t-1}$).

[11] We use the 2015 annual population estimation of the closest Metropolitan and Micropolitan statistical area to the airport.

[12] $MetricDistance_{ij,t-1} = \sqrt{\sum_{m\in\{1,\ldots,M\}} (\frac{passenger_{im,t-1}}{passenger_{i,t-1}} - \frac{passenger_{jm,t-1}}{passenger_{j,t-1}})^2}$

We include them because we expect that the network formed up until the last period has an impact on the network formation in the current period.

$TempLinkVar_t$ are variables generated from $TempLink_t^{O_t}$, the transition network when the major and the regional carriers make subcontracting decisions. $RivalLink_{imt}$ and $RivalLink_{jmt}$ are dummy variables indicating whether any rival of the major carrier i or the regional carrier j has already formed a link on the route. $OtherLink^i_{ijmt}$ and $OtherLink^j_{ijmt}$ are dummy variables indicating whether major carrier i or regional carrier j has already formed a link with other carriers besides the link being considered between major carrier i and regional carrier j on the route. $SelfService_{imt}$, $Subsidiary_{imt}$, $CodeSharing_{imt}$, and $OtherType_{imt}$ are dummy variables indicating whether major carrier i has already established self-service, subsidiaries, code-sharing or other-type of relationships on the route. One advantage of our estimation method is that it allows us to derive the causal effect of $TempLinkVar_t$ on carriers' subcontracting decisions, which cannot be identified by traditional estimation methods because of the simultaneity issue.

Table 6 shows summary statistics of the variables across time, routes and carrier types. Considering the time route level summary, on average there are 1.07 major carriers, 0.94 regional carriers and 1.01 links on a route. The maximum link number on a route which is observed in our sample is 13. Among non-subcontracting relationships, self-service and subsidiary are more common than code-sharing or other types of relationships for major carriers. Figure 1 plots the average number of major carriers, regional carriers, and link numbers across routes over time. The drop in the major number and link number around 2015 quarter 3 is caused by the merger between American and US Airways, following which US Airways disappeared. We observe that after the 3rd quarter of 2016, although the number of major carriers is nearly constant, the number of regional carriers and the number of links decline. From the table and the figure, we can see that there is a large amount of variations in these variables allowing a more precise estimation of effects.

5 Estimation Results

In this section, we present the estimation results of the specification in equation (9). We run the estimation method with 1000 iterations to update parameters and the event order. Then we use the last 500 estimates as the posterior distribution of the parameters. Table 7 presents the estimation results. The first and second column are estimated together considering all potential competing major carriers. The dependent variable in the first column is the utility gains translated into the probability for a major carrier to subcontract to a regional carrier on a route. The dependent variable in the second column is representing respective utility gains for a regional carrier.[13]

We first consider the impact of the last set of variables, $TempLinkVar_t$, on link formation of carriers' subcontracting network. It is estimated that the major carrier is more likely to enter a route in the form of subcontracting if its rivals already formed a link, indicated by the positive and significant coefficient of $RivalLink_{imt}$ in the first column. If the major carrier's rivals are already subcontracting on a route, subcontracting helps the major carrier enter the route. The regional carrier, on the other hand, is less likely to establish a subcontracting relationship if its rivals (other regional carriers) have already established persistent subcontracting relationships, indicated by the negative and significant coefficient of $RivalLink_{jmt}$ in the second column. This result implies that if a regional carrier already established its active presence on a route,

[13]Note that the estimated coefficients provide the directions and statistical significance of the effects from the variables, but they are not marginal effect themselves.

other regional carriers will prefer to avoid the direct competition by not serving the route. The estimation result also shows that if the major carrier already subcontracts to other regional carriers on a route it is more likely to subcontract to the regional carrier ($OtherLink^i_{ijmt}$ in the first column). Regional carriers exhibit similar behavior indicated by $OtherLink^j_{ijmt}$ in the second column. In addition, the positive and significant coefficients of non-subcontracting relationship variables ($SelfService_{imt}$, $Subsidiary_{imt}$, $CodeSharing_{imt}$, and $OtherType_{imt}$) indicate that if the major carrier is already serving the route in any of these forms, it is more likely to subcontract to a regional carrier on the same route compared to the routes the major carrier has not established any of these non-subcontracting relationships.

The network of the last period is expected to have impacts on the network formation of the current period, as shown by the set of variables, $LinkVar_{t-1}$, in the table. The positive significant coefficients of $SameLinkNmbr_{ij,t-1}$ and $Link_{ijm,t-1}$ in both the first and second columns indicate that if two carriers had more links or they already formed a link on the route in the last period, it is more likely for both of them to be willing to form a link in the current period. In addition, a major carrier is less likely to enter a route in the form of subcontracting with a regional carrier which had many links in the last period across routes ($LinkNmbr_{j,t-1}$ in the first column), and a regional carrier is also less likely to establish a link with a major carrier that have had many links in the last period across routes ($LinkNmbr_{i,t-1}$ in the second column). Nevertheless, carriers' link numbers on the same route ($LinkNmbr_{im,t-1}$ and $LinkNmbr_{jm,t-1}$) in the last period do not matter in their counterparts' subcontracting decisions in the current period.

It is expected that the more similar the major and the regional carriers are, the more likely they are to form a link. Our estimation results of *Homophily* variables confirm the expectation. We find that the more common routes the major and regional carriers served in the last period, the more likely they are to form a link on a route in the current period ($CommonRtNmbr_{ij,t-1}$). In the same spirit, the larger $MetricDistance_{ij,t-1}$ is, namely, the less similar these two carriers are in terms of their passenger shares across routes in the last period, the less likely they are to form a link in the current period.

Carrier characteristics also play significant roles in the link formation of carriers' subcontracting network. We find that the major carrier is more likely to enter a route in the form of subcontracting with a regional carrier which served fewer routes ($RouteNmbr_{j,t-1}$ in the first column) but delivered more passengers and had more market share on the route ($PassengerNmbr_{jm,t-1}$ and $MarketShare_{jm,t-1}$ in the first column) in the last period. The larger the major carrier's market share ($MarketShare_{im,t-1}$ in the first column) was in the last period, the more likely it is to enter the route by subcontracting to a regional carrier in the current period. On the other hand, the regional carrier is more likely to form a link with a major carrier which served fewer routes or delivered fewer passengers on the route ($RouteNmbr_{i,t-1}$ and $PassengerNmbr_{im,t-1}$ in the second column), but had larger market share ($MarketShare_{im,t-1}$ in the second column) in the last period.

Route characteristics also have impacts on link formations. It is shown in Tan (2018) that major carriers are more likely to subcontract to regional carriers on a route with low-cost carriers. In our paper, we examine this question from a new perspective. Tan (2018) aggregates the major carriers' subcontracting decisions on a route into a single dummy variable capturing whether or not the major carrier has subcontracting behavior. We study the major carrier's subcontracting decisions with each individual regional carrier on each route. As shown by the estimated coefficient of LCC_{mt}, the major carrier is less likely to have many subcontracting relationships on a route where a low cost carrier exists. Market Concentration ($HHI_{m,t-1}$) also has a significant impact on the major carrier's subcontracting decision. The major carrier is estimated to have fewer subcontracting relationships on a more concentrated route. We also expect that it is less likely to form a link on a longer route, since regional carriers operating regional aircrafts are not suited for routes with long distance. The squared term captures whether there is nonlinear relationship between route distance and link formation. We find that the effect of route distance on link formation has an inverse-U shape. The probabilities of forming a link for both major and regional carriers increase with route distance first, but eventually decrease.[14] The coefficients of $log(gmean(pop))_m$ for both the major and regional carriers indicate that they have fewer links on a route with large demand. According to the estimated coefficients of $Disparity_m$, major carriers are willing to enter a route of two different size airports establishing more subcontracting relationships compared to a route of two similar size airports. On the other hand, regional carriers have more subcontracting relationships on a route of two same size airports compared to a route of two different size airports.

So far we have modeled subcontracting behaviors of all major carriers including those operating on a route and potential entrants which do not enter the route. As such, we actually model two effects of subcontracting decisions at the same time. One is the effect on route entry, namely, a major carrier's decision of whether or not to enter a route in the form of subcontracting. The other is the effect on ongoing operation determining major carriers' link formation decisions to regional carriers. However, it would also be interesting to model the behaviors of only the existing major carriers on each route so that we can focus on major carriers' subcontracting decisions conditional on route entry. In other words, it would be interesting to model subcontracting behavior conditional on route entry. In order to do so, we need to make one more assumption about major carriers' route entry decisions. Instead of assuming that major carriers make route entry and service decisions at the same time, we assume all major carriers first make route entry and exit decisions before the event order, and then existing major carriers on a route decide on the services provided in terms of their relationships determined sequentially based on the event order. This assumption changes two parts of the model. First, it affects how the network evolves at the beginning of each period t, namely, $TempLink^1_{mt}$. In the previous model after we set $TempLink^1_{mt} = Link_{m,t-1}$ at the beginning of each period t, we set $TempLink^1_{imt} = 0$ if major carrier i exits all routes, goes bankrupt or merges with an existing carrier. In the current model, the condition for setting $TempLink^1_{imt} = 0$ changes to if major carrier i exits route m. The other part of the model affected by the assumption is the joint likelihood function. The new likelihood function is

$$\mathcal{L}(\beta|EO, Link) = \prod_{t\in\{2,\ldots,T\}} \prod_{(i,j)\in(I_t,J_t)|EO_t} \prod_{m\in M_i} Pr(Link^s_{ijmt})^{Link^s_{ijmt}}(1 - Pr(Link^s_{ijmt}))^{1-Link^s_{ijmt}}. \quad (10)$$

M_i is the set of routes in which major carrier i operates at period t. Now the likelihood function multiplies the probabilities of each link decision across only the routes where each major carrier operates rather than all routes. In other words, for each route we only model route existing major carriers instead of all major carriers including those who could potentially enter the route. The rest of the model and estimation methods are the same as before. Column 3 and 4 in Table 7 report the estimation results, which are derived from the last 500 estimates serving as the parameters' posterior distributions after 1000 iterations of updating parameters and the event order. The difference of these results from those of the first two columns is that we are now focusing on the effect on subcontracting only, excluding major carriers' route entry decisions.

We first consider the set of variables, $TempLinkVar_t$. For route existing major carriers, whether their rivals have subcontracting relationships on the route does not matter in their subcontracting decisions any

[14] The turn-around point is at 0.488 thousand miles.

more. They are more likely to have additional subcontracting relationships on a route with a history of subcontracting. From the estimation results of $selfService_{imt}$, $Subsidiary_{imt}$, $CodeSharing_{imt}$, and $OtherType_{imt}$, we can see that major carriers' self-service and subsidiaries are complementary to their subcontracting behaviors, while code-sharing and "other type" relationships are substitutes. The behavior of Regional carriers' does not change much in general compared with the estimation in column 2.

Among the variables of the network in the last period, only one variable $LinkNmbr_{j,t-1}$ changes its sign from the estimation in column 1. Route existing major carriers are more likely to subcontract to a regional carrier with more links rather than fewer links in the last period. The change is caused by excluding the effect on route entry decisions. In column 1, the effect on route entry dominates the effect on subcontracting so the sign of the effect is negative. After the effect on route entry is excluded in column 3, the effect on subcontracting becomes positive. The regional carrier's link number in the last period decreases the probability a major carrier enters a route by subcontracting to the regional carrier, but increases the probability that existing major carriers on a route will subcontract to the regional carrier.

For both $Homophily$ measures, the estimation results remain consistent. In other words, the more similar the major and the regional carriers are, the more likely they are to form a link.

The impact of some carrier characteristics change after we restrict our attention only on route existing major carriers. Passenger numbers ($PassengerNmbr_{i,t-1}$ and $PassengerNmbr_{j,t-1}$) become significant, and $MarketShare_{im,t-1}$ changes from positive to negative. The estimation results show that existing major carriers are more likely to subcontract to a regional carrier which serves fewer routes, delivers more passengers on the route and across all routes, and has a higher market share on the route in the last period. In other words, route existing major carriers are more likely to subcontract to a regional carrier specialized on fewer routes rather than the ones serving multiple routes. In addition, if the major carrier has a higher market share, it is less likely to subcontract its flight service. On the other hand, regional carriers are more likely to be subcontracted to by a major carrier which serves fewer routes, delivers fewer passengers on the route and across all routes, and has smaller market share on the route in the last period. In other words, the regional carrier is more willing to be subcontracted to by an existing major carrier with less market power in terms of the major carrier's route numbers, capacities and market shares, so that the regional carrier may have larger bargaining power against the major carrier. The regional carrier's market share in the last period also increases the probability that the regional carrier accepts a subcontracting relationship in the current period.

Most of the estimated effects of route characteristics remain the same after we only consider route existing major carriers. Route existing major carriers have fewer subcontracting relationships on the route which has low-cost carriers or has a higher market concentration level. The effect of route distance follows the same pattern as that in column 1 and 2. The coefficients of $log(gmean(pop))_m$ for both the major and regional carriers become insignificant, indicating that the size of demand does not matter in route existing major carriers' subcontracting decisions or regional carriers' subcontracting decisions with route existing major carriers. Route existing carriers are estimated to have more subcontracting relationships on a route of two same size airports than that of two different size airports.

6 Effects on Ticket Prices

In this section, we investigate another important question: the effects of major carriers' subcontracting behaviors on ticket prices. Tan (2018) shows that major carriers' ticket prices are lower on routes where they subcontract more of their flight services. In our paper, we further take into account the interactions among major carriers on a route, which leads to the issue of major carriers' endogenous subcontracting decisions, that has not been studied. A major carrier's subcontracting decisions are endogenous not only in that the major carrier makes the subcontracting and pricing decisions simultaneously but also in the way that the major carrier's rivals' behaviors affect its subcontracting decisions, which in return affect the rivals' pricing strategy.

In order to address the endogeneity issue, we use as an instrumental variable, the major carriers' probabilities of subcontracting. This IV is constructed based on the estimation in the last section. Given the estimated means of the parameters and the last used event order in the estimation in which all major carriers are considered, we can calculate all the predicted probabilities that each major carrier subcontracts to each regional carrier on route m in period t, $\hat{Pr_{ijmt}}$. The constructed IV, IV_{mt}, is the predicted probability that there is subcontracting behavior on route m in period t.

$$IV_{mt} = 1 - \prod_{i \in I_t, j \in J_t} (1 - \hat{Pr_{ijmt}}). \tag{11}$$

Ticket price information is obtained from DB1B Market Data. We filter the dataset in the following way. We only keep non-stop ticket prices. Following the literature, we drop the ticket prices smaller than \$10 and the highest 2% ticket prices for each route-quarter-ticketing carrier-operating carrier, and aggregate the data into route-quarter-ticketing carrier level. Table 8 presents the summary statistics of the ticket price data being used. $Subcontracting_{mt}$ is a dummy variable indicating whether there is any subcontracting behavior by major carriers on route m in period t, and is the variable we are interested in. 60% of the observations are on a route where major carriers subcontract to regional carriers. 54% of the observations are on a route where low-cost carriers operate. IV_{mt} is the predicted probability and the instrumental variable for $Subcontracting_{mt}$. From the summary statistics we can see that IV_{mt} has similar mean and standard deviation as $Subcontracting_{mt}$, although IV_{mt} is a continuous variable over $[0, 1]$ interval. The weak identification test and under identification test are passed with very high significance level.[15] $MktHHI_{mt}$ captures the market concentration level calculated based upon passenger numbers of non-stop flights. $Fare_{imt}$ is the average ticket price for ticketing carrier i on route m in period t.[16] The mean of the ticket prices is \$205 for a non-stop one way trip with the standard deviation of \$74. The smallest and largest fares are \$10 and \$932 respectively.

Based on this dataset, we run the following linear regression

$$log(fare)_{imt} = \alpha_{im} + \gamma_t + \beta_1 MktHHI_{mt} + \beta_2 Subcontracting_{mt} + \beta_3 LCC_{mt} + \epsilon_{imt}. \tag{12}$$

The dependent variable is the log of average ticket prices. Route-carrier fixed effects and time fixed effects are controlled. We report the estimation results in Table 9. We use no IV in the first column as the reference regression but instrument $Subcontracting_{mt}$ in the second column. In both regressions the estimated signs of $MktHHI_{mt}$ and LCC_{mt} are consistent with our expectations. A lower market concentration level or the

[15] As we only have one IV, we cannot perform an over identification test.

[16] The ticketing carrier includes all types of carriers, not only major carrier.

presence of a low-cost carrier is associated with lower ticket prices. Their coefficients are similar in column 1 and 2 in terms of the magnitude and significance level. However, the coefficients of $Subcontracting_{mt}$ are different. In the first column, $Subcontracting_{mt}$ is only significant at 10% level and the magnitude is relatively small. After being instrumented, $Subcontracting_{mt}$ becomes very significant (1% level), and the magnitude increases by more than 6 times. As a result, we can claim a causal effect that major carriers' subcontracting behavior is estimated to decrease ticket prices by 3.4%.

7 Conclusion

In this paper, we study the network formation among US airline carriers. We focus on the network formation related to subcontracting between major carriers and regional carriers, and use a Bayesian estimation method to study the factors that contribute to the formation of carriers' subcontracting relationships. Besides some traditional factors such as market concentration level and the presence of low-cost carrier, we consider carrier network effects by introducing network measures. We find that not only the traditional factors considered in the literature but also the previous and existing networks among carriers play a significant role in carriers' subcontracting behavior and new network formation decisions. In the end, we use the constructed IV from the network formation estimation to instrument for major carriers' subcontracting behavior, and find that major carriers' subcontracting behavior has a statistically significant impact on ticket prices.

References

Christakis, Nicholas A, James H Fowler, Guido W Imbens, and Karthik Kalyanaraman (2010) "An empirical model for strategic network formation," working paper.

Currarini, Sergio, Matthew O Jackson, and Paolo Pin (2009) "An economic model of friendship: Homophily, minorities, and segregation," *Econometrica*, Vol. 77, pp. 1003–1045.

De Silva, Dakshina G, Timothy Dunne, Georgia Kosmopoulou, and Carlos Lamarche (2012) "Disadvantaged Business Enterprise goals in government procurement contracting: an analysis of bidding behavior and costs," *International Journal of Industrial Organization*, Vol. 30, pp. 377–388.

De Silva, Dakshina G, Marina Gertsberg, Georgia Kosmopoulou, and Rachel AJ Pownall (2017) "Dealer Networks in the World of Art," working paper.

Fill, Chris and Elke Visser (2000) "The outsourcing dilemma: a composite approach to the make or buy decision," *Management decision*, Vol. 38, pp. 43–50.

Forbes, Silke and Mara Lederman (2009) "Adaptation and Vertical Integration in the Airline Industry," *American Economic Review*, Vol. 99, pp. 1831–49.

Lux, Thomas (2015) "Emergence of a core-periphery structure in a simple dynamic model of the interbank market," *Journal of Economic Dynamics and Control*, Vol. 52, pp. A11–A23.

Marion, Justin (2009) "How costly is affirmative action? Government contracting and California's Proposition 209," *The Review of Economics and Statistics*, Vol. 91, pp. 503–522.

Rieple, Alison and Clive Helm (2008) “Outsourcing for competitive advantage: An examination of seven legacy airlines,” *Journal of Air Transport Management*, Vol. 14, pp. 280–285.

Tan, Kerry M (2018) “Outsourcing and price competition: An empirical analysis of the partnerships between legacy carriers and regional airlines,” *Review of Industrial Organization*, Vol. 53, pp. 275–294.

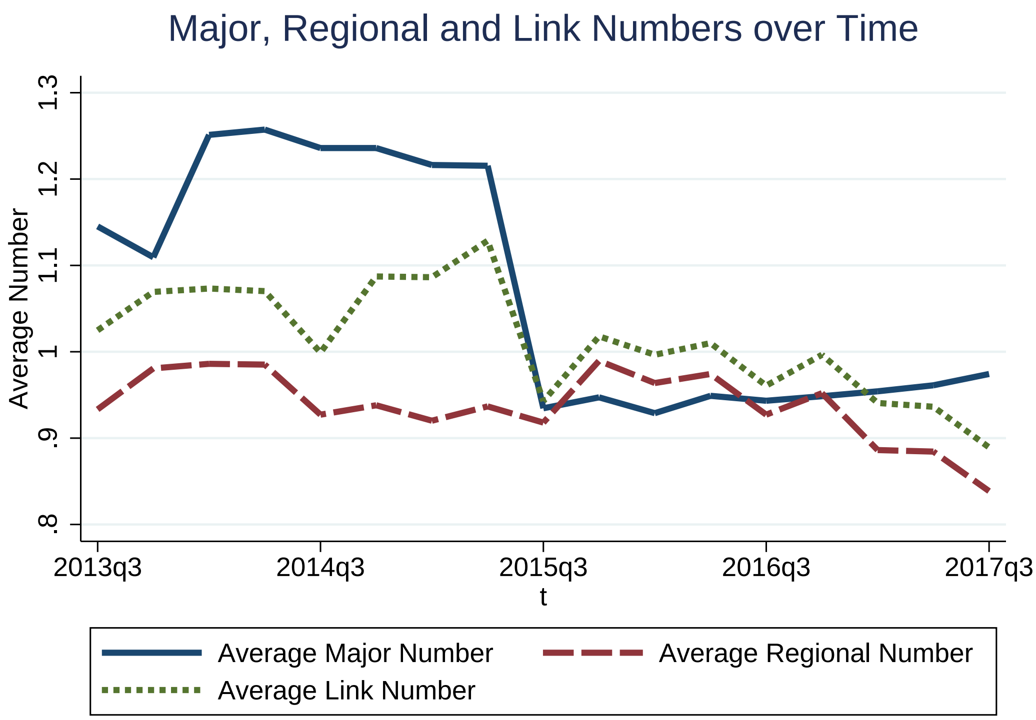

Figure 1: Major, Regional and Link Numbers over Time

Table 1: Carriers List

Network Carriers			
Major Carriers	Alaska	Regional Carriers	Air Wisconsin
	American		Cape Air
	Delta		Chautauqua
	US Airways		CommutAir
	United		Compass
			Endeavor
Low-Cost Carriers	AirTran		Envoy
	Allegiant		ExpressJet
	Frontier		GoJet
	Hawaiian		Great Lakes
	JetBlue		Horizon
	Southwest		Mesa
	Spirit		Mokulele
	Sun Country		PSA
	Virgin America		Pacific Wings
			Peninsula
			Piedmont
			Republic
			Shuttle America
			Silver
			SkyWest
			Trans States

Notes: The table lists the carrier names by type in our sample.

Table 2: Types of Relationships among Airline Carriers

Carrier Role in Flight Service		Same Operating/ Ticketing Carrier	Relationship	Agreement Type
Ticketing Carrier	Operating Carrier			
Any Carrier	Any Carrier	Yes	Self-Service	
Network Carrier	Network Carrier	No	Code-Sharing	Code-sharing Agreement
Major Carrier	Regional Carrier	No	Subsidiary	Wholly Owned Subsidiary
Major Carrier	Regional Carrier	No	Subcontracting	Long-Term Contract Indirect Subcontracting
Major Carrier	Regional Carrier	No	Other-Type	Code-sharing Agreement Gate Switching

Table 3: A Possible Link Matrix on a Route in a Period

Subcontracting Relationships

	Regional 1	Regional 2
Major 1	0	0
Major 2	0	1
Major 3	1	1

Non Subcontracting Relationships

	Self-Service	Subsidiary	Code-Sharing	Other-Type
Major 1	0	0	0	0
Major 2	0	1	1	0
Major 3	1	1	1	1

Notes: The table shows a possible $Link_{mt}$ in the case of 3 major and 2 regional carriers on route m in the end of period t.

Table 4: A Possible Event Order at Period t

Event 1	Major 1 sub. Regional 1
Event 2	Major 1 sub. Regional 2
Event 3	Major 2 sub. Regional 1
Event 4	Major 2 sub. Regional 2
Event 5	Major 3 sub. Regional 1
Event 6	Major 3 sub. Regional 2
Event 7	Major 1: Self-Service
Event 8	Major 1: Subsidiary
Event 9	Major 1: Code-Sharing
Event 10	Major 1: Other-Type
Event 11	Major 2: Self-Service
Event 12	Major 2: Subsidiary
Event 13	Major 2: Code-Sharing
Event 14	Major 2: Other-Type
Event 15	Major 3: Self-Service
Event 16	Major 3: Subsidiary
Event 17	Major 3: Code-Sharing
Event 18	Major 3: Other-Type

Notes: The table shows a possible event order in the case of 3 major and 2 regional carriers in period t.

Table 5: Subcontracting Partnerships among Airline Carriers in the Third Quarter of 2014

Major Carrier	Regional Carrier
Alaska	**Horizon**
	SkyWest
American	**Envoy**
	Chautauqua
	ExpressJet
	Republic
	SkyWest
Delta	Chautauqua
	Compass
	Endeavor
	ExpressJet
	GoJet
	Shuttle America
	SkyWest
United	Cape Air
	CommutAir
	ExpressJet
	GoJet
	Mesa
	Republic
	Shuttle America
	SkyWest
	Trans States
US Airways	Air Wisconsin
	Mesa
	Piedmont
	PSA
	Republic
	SkyWest
	Trans States

Notes: The table shows the subcontracting partnerships among US airline carriers in the third quarter of 2014. The regional carriers in bold are the wholly owned subsidiaries.

Table 6: Summary Statistics

	Observations	Mean	Standard Deviation	Minimum	Maximum
$SmallerPop_m$ (in million)	2293	1.347	1.487	0.024	9.533
$LargerPop_m$ (in million)	2293	6.712	5.297	0.049	20.118
$Disparity_m$	2293	20.073	50.414	1.000	827.053
$RouteDistance_m$ (in mile)	2293	753.683	467.334	55.000	1999.000
LCC_{mt}	38981	0.239	0.426	0.000	1.000
HHI_{mt}	38981	0.635	0.405	0.000	1.000
$MajorNmbr_{mt}$	38981	1.071	0.862	0.000	5.000
$RegionalNmbr_{mt}$	38981	0.938	1.211	0.000	8.000
$LinkNmbr_{mt}$	38981	1.014	1.358	0.000	13.000
$SelfServiceMajorNmbr_{mt}$	38981	0.707	0.753	0.000	5.000
$SubsidiaryMajorNmbr_{mt}$	38981	0.307	0.505	0.000	3.000
$CodeSharingMajorNmbr_{mt}$	38981	0.086	0.321	0.000	3.000
$OtherTypeMajorNmbr_{mt}$	38981	0.072	0.284	0.000	3.000
$CommonRtNmbr_{ijt}$	930	60.399	72.418	0.000	344.000
$MetricDistance_{ijt}$	930	0.156	0.085	0.056	1.010
$SameLinkNmbr_{ijt}$	930	42.482	71.208	0.000	338.000
$RouteNmbr_{it}$	76	549.355	208.905	167.000	778.000
$PassengerNmbr_{it}$(in million)	76	2.055	1.062	0.368	3.652
$LinkNmbr_{it}$	76	519.842	365.074	17.000	1107.000
$RouteNmbr_{jt}$	207	176.589	166.360	0.000	598.000
$PassengerNmbr_{jt}$(in million)	207	0.176	0.197	0.000	0.804
$LinkNmbr_{jt}$	207	190.860	181.159	0.000	682.000
$PassengerNmbr_{imt}$ (in thousand)	174268	0.896	2.975	0.000	47.203
$MarketShare_{imt}$	174268	0.171	0.358	0.000	1.000
$LinkNmbr_{imt}$	174268	0.227	0.678	0.000	8.000
$PassengerNmbr_{jmt}$ (in thousand)	474651	0.077	0.414	0.000	13.948
$MarketShare_{jmt}$	474651	0.043	0.183	0.000	1.000
$LinkNmbr_{jmt}$	474651	0.083	0.300	0.000	5.000

Notes: The table shows the summary statistics of variables at various levels. *Nmbr* means Number.

Table 7: Estimation Results

		All Major Carriers		Route Existing Major Carriers	
		Major	Regional	Major	Regional
$TempLinkVar_t$	$RivalLink_{imt}$	0.1111***		-0.0534	
		(3.3739)		(-1.1253)	
	$RivalLink_{jmt}$		-0.2709***		-0.2529***
			(-5.2139)		(-8.0890)
	$OtherLink^i_{ijmt}$	0.9341***		0.1357**	
		(21.0204)		(2.1913)	
	$OtherLink^j_{ijmt}$		1.6876***		0.9998***
			(22.6515)		(21.6828)
	$SelfService_{imt}$	0.8829***		0.0718***	
		(36.2864)		(3.1868)	
	$Subsidiary_{imt}$	0.7083***		0.5468***	
		(19.3083)		(20.4795)	
	$CodeSharing_{imt}$	0.8439***		-1.0186***	
		(8.5744)		(-9.0690)	
	$OtherType_{imt}$	2.0670***		-1.8705***	
		(24.0835)		(-17.1589)	
$LinkVar_{t-1}$	$LinkNmbr_{j,t-1}$	-0.6430***		0.2918**	
		(-4.5375)		(2.0323)	
	$LinkNmbr_{i,t-1}$		-1.2271***		-0.1820***
			(-4.7302)		(-6.3213)
	$LinkNmbr_{jm,t-1}$	-0.2283		-0.1094	
		(-0.2350)		(-0.1155)	
	$LinkNmbr_{im,t-1}$		0.5254		0.8184
			(0.5005)		(0.7733)
	$SameLinkNmbr_{ij,t-1}$	2.1601***	12.9610***	2.4888***	5.0826***
		(11.6907)	(14.0662)	(7.2105)	(13.2536)
	$Link_{ijm,t-1}$	4.3468***	4.8630***	3.1166***	5.2447***
		(117.7507)	(20.7645)	(43.8287)	(72.7173)

T-statistics in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$

Table 7: Estimation Results (Continued)

		All Major Carriers		Route Existing Major Carriers	
		Major	Regional	Major	Regional
Homophily	$CommonRtNmbr_{ij,t-1}$	0.6826***	14.1661***	6.4981***	0.0236
		(6.2009)	(16.8397)	(39.9677)	(0.0616)
	$MetricDistance_{ij,t-1}$	-2.4701***	-1.1996**	-1.0884***	-3.5244***
		(-7.7579)	(-2.0739)	(-4.6115)	(-4.8756)
CarrierChar	$RouteNmbr_{j,t-1}$	-1.4089***		-1.7552***	
		(-19.5639)		(-12.4166)	
	$RouteNmbr_{i,t-1}$		-0.9079***		-0.7845***
			(-4.2282)		(-7.1768)
	$PassengerNmbr_{j,t-1}$	-0.1218		0.2102***	
		(-0.7273)		(2.7750)	
	$PassengerNmbr_{i,t-1}$		-0.0676		-0.0699***
			(-1.3333)		(-35.7550)
	$PassengerNmbr_{jm,t-1}$	14.4171***		9.4450***	
		(17.9159)		(10.2410)	
	$PassengerNmbr_{im,t-1}$		-4.0305***		-2.8936***
			(-7.4528)		(-4.8822)
	$MarketShare_{im,t-1}$	1.3606***	0.8469***	-0.3714***	-0.4091***
		(21.0170)	(14.9511)	(-22.1983)	(-8.4538)
	$MarketShare_{jm,t-1}$	1.5946***	0.1584	1.8932***	1.4157***
		(31.2182)	(1.1347)	(50.9399)	(37.6025)
RouteChar	LCC_{mt}	-0.1006***		-0.2302***	
		(-2.7361)		(-11.3924)	
	$HHI_{m,t-1}$	-1.1549***		-0.3978***	
		(-17.0417)		(-4.7063)	
	$RouteDistance_m$	0.7346***	0.0865	0.3995***	0.5598***
		(10.8303)	(0.8651)	(16.4630)	(2.9157)
	$RouteDistance^2_m$	-0.7524***	-0.2929**	-0.8046***	-0.6604***
		(-62.5864)	(-2.5333)	(-24.7183)	(-3.9001)
	$log(gmean(pop))_m$	-0.2526***	-0.3838***	0.0157	0.0024
		(-51.2336)	(-14.5355)	(0.8688)	(0.2426)
	$Disparity_m$	0.9036***	-1.8053***	-1.9302***	0.4354
		(2.6710)	(-2.5885)	(-4.0798)	(1.0441)

T-statistics in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$

Table 8: Summary Statistics: Ticket Prices

	Mean	Standard Deviation	Minimum	Maximum
$Distance_m$	797.804	465.813	55.000	1999.000
$Fare_{imt}$	205.136	73.587	10.000	931.854
$MktHHI_{mt}$	0.723	0.258	0.191	1.000
LCC_{mt}	0.540	0.498	0.000	1.000
$Subcontracting_{mt}$	0.602	0.490	0.000	1.000
IV_{mt}	0.593	0.432	0.004	1.000
Observations	52823			

Table 9: The Impact of Subcontracting on Ticket Prices

	(1)	(2)
	$log(fare)_{imt}$	$log(fare)_{imt}$
$MktHHI_{mt}$	0.165***	0.158***
	(0.00874)	(0.00892)
$Subcontracting_{mt}$	-0.00509*	-0.0336***
	(0.00309)	(0.00760)
LCC_{mt}	-0.0346***	-0.0354***
	(0.00465)	(0.00466)
Observations	52823	52167

Standard errors in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Route-Carrier fixed effects and time fixed effects are controlled. No IV is used in the first column. In the second column, IV is used for $Subcontracting_{mt}$.