Subcontracting Network Formation among US Airline Carriers

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Abstract

In this paper, we use Bayesian estimation to study subcontracting network formation and pricing decisions in the US airline industry. We find that, a major carrier is more likely to enter a route in subcontracting services if its rivals have already subcontracted while regional carriers prefer to avoid competition. For existing major carriers per-route, self-service and use of subsidiaries are complementary to subcontracting, while code-sharing is a substitute. Carrier similarity and previously formed networks have significant impacts on new network formations. Taking potential endogeneity issues into account, we find that major carriers' subcontracting behaviors decrease ticket prices by 3.4%.

Keywords: Network; Subcontracting; Airline Industry

JEL Classification Codes: L14, L93, D22.

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1 Introduction

Network analysis is a highly popular approach in theoretical and empirical research across the social sciences.[1] In studying industry evolution, it offers an opportunity to treat corporate agreements as links within a network of business relationships over time. This network of relationships creates new opportunities to capture information flows and understand market dynamics including pricing strategies.

We use network analysis to study the underpinnings of competition in the US airline industry with a finer lens: one that provides a sharper image of the strength and persistence of partnerships, and a way of understanding the interdependency among the airline carriers' decision making processes. The airline industry is dominated by a handful of strong contenders, with small competing firms struggling to establish presence. Within this competitive framework, the industry also engages in cooperative relationships, with subcontracting of flight operation being the most popular form. In this paper, we tackle the airline industry evolution from a whole new angle: we evaluate how network opportunities of airline companies are formed through subcontracting engagement. The wealth of information that is captured by the network's links and the computational capacity it takes to chart the dynamics of interdependency offer a chance to zero in on the effects of market penetration and expansion of firms in the industry.

A natural way of applying network analysis to the US airline industry is to investigate factors that affect the evolution of network structure among carriers. While taking into account non-subcontracting agreements, our focus is on networks formed through subcontracting relationships. A network link is formed when a major carrier subcontracts a flight service to a regional carrier. Within this framework, we make two distinct contributions. First, we investigate factors that affect the formation of links among carriers on certain

[1]Network analysis has been used broadly in sociology (Currarini, Jackson and Pin, 2009; Offer and Fischer, 2018; Isakov et al., 2019), in political science (Ward, Stovel and Sacks, 2011), in epidemiology (Barabási, Gulbahce and Loscalzo, 2011), and in communications and psychology (Newman, 2001; Grunspan, Wiggins and Goodreau, 2014) among other fields. Applications can be found in social media, partner choice, trade relations, epidemics, scientific collaborations, board member relations, investor connections, R&D collaborations, job market and natural disaster management. Jackson, Rogers and Zenou (2017) and Jackson (2011) provide excellent reviews.

routes. Second, we derive a causal effect of subcontracting on flight ticket prices.

In order to gain a deeper understanding of the interdependency among airline carriers, we use newly developed approaches in Bayesian estimation methods discussed in Christakis et al. (2010). We incorporate carriers' subcontracting and non-subcontracting decisions into a sequential game, and develop an empirical model of strategic network formation among US airline carriers. Our main findings are as follows. Subcontracting and non-subcontracting decisions made by an airline company as well as its competitors play a crucial role in the carrier's subcontracting network formation and its evolution. Similarities in the routes two carriers serve have a substantial impact on their subcontracting relationship and new link formations. Their subcontracting decisions can also be explained by network characteristics and previous connections. In turn, major carriers' subcontracting behaviors have a significant negative impact on flight ticket prices.

Our work extends existing research and creates a distinct focus: network analysis allows us to incorporate the complexities introduced by contractual relationships formed across different firms in a network, which traditional models are incapable of handling. In the paper, we look at how subcontracting choices are evolving within its network and how competition and expansion of firms are affected by network opportunities subcontracting creates. We link network formation to questions of dynamic evolution of firms and provide opportunities for direct policy evaluation of regulations regarding subcontracting.

We contribute to the literature in many ways. First, we further the study of network formation by developing a framework for subcontracting choices. The paper most closely related to ours methodologically in the literature is Christakis et al. (2010). They consider a sample of 669 high school students and study how the formation of a social network affects class performance. We extend the estimation approach used in their work by incorporating dynamic interactions in multiple concurrent networks in the airline industry. Other related studies focus on network formation in economics and finance, including networks among fine art dealers and sellers (De Silva et al., 2017) and networks of interbank credit relationships (Lux, 2015).[2] By applying recent methodological advances in network formation into the

[2]De Silva et al. (2017) investigate the drivers of strategic network formation between dealers and sellers in a market for fine art as means of information acquisition and transmission impacting the dealers' market

study of the US airline industry, we are able to enhance our understanding of the interdependency among airline carriers' subcontracting relationships and how it shapes market outcomes. Second, this paper contributes to the subcontracting/outsourcing literature in the US airline industry.[3] 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; Rieple and Helm, 2008), risk consideration (Forbes and Lederman, 2009), and market competition (Tan, 2018). All these studies focus on the major carriers' decisions. We close the gap by analyzing both types of carriers, major and regional, and explore the impact of existing networks and the environment in decision making. Third, we take this analysis a step further to study the impact of subcontracting on flight ticket prices.[4] In this field, Tan (2018) shows that major carriers' ticket prices are lower on routes where they subcontract more of their flight services. We advance the discussion by taking into account the route level potential endogeneity issue of carriers' subcontracting decisions in their pricing strategies. Last, we add to the market entry literature in the airline industry. Previous research examines the determinants of carriers' market/route entry decisions, including airport presence (Berry, 1992), demand variation and airlines' flexibility (Claussen, Essling and Peukert, 2018), mergers (Benkard, Bodoh-Creed and Lazarev, 2019), airlines' financial conditions (Liu, 2009), and the size and utilization of airlines' hub-and-spoke system (Sinclair, 1995).[5] In our paper, we study airlines' market entry and subcontracting decisions together shedding new light on the role of interdependency in market entry.

The rest of the paper is organized as follows. Section 2 provides background information

reach. Lux (2015) shows that a learning mechanism affects the link formation in the network of interbank credit relationships.

[3]The exploration of subcontracting/outsourcing is motivated by a need to understand make-or-buy decisions and has been the subject of study in various settings and industries besides the airline industry, such as entertainment, health care and public service (De Silva et al., 2012; Marion, 2009).

[4]De Silva, Kosmopoulou and Lamarche (2012, 2017) study the effect of subcontracting on the survival and business duration of firms in government procurement projects. De Silva, Kosmopoulou and Lamarche (2012) shows that early involvement as a subcontractor increases the chance of survival. De Silva, Kosmopoulou and Lamarche (2017) finds an apparent increase in the business life of firms who subcontract out part of their projects.

[5]Boguslaski, Ito and Lee (2004) study the entry patterns by a specific airline, Southwest.

about 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 Section 6 studies the effects of major carriers' subcontracting behaviors on ticket prices. 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. Table 1 lists the names of the carriers in our sample grouped by their types (consisting of 5 major, 9 low-cost and 22 regional carriers). Major carriers, such as American, Delta and United Airlines, are carriers that sell tickets on routes connecting the majority of airports in the US. Low-cost carriers, such as Southwest, AirTran and Spirit Airlines serve similar routes at a lower cost without offering some or most of the traditional services major carriers provide, such as seat assignments. Both major and low-cost carriers are called network carriers since they both sell tickets in their networks of routes.[6] Regional carriers, like ExpressJet, SkyWest and Endeavor Airlines are less known to passengers as they typically do not sell tickets themselves but operate regional aircrafts for major carriers. Regional carriers have cost advantages in serving routes of short to medium distances, due to the type of aircrafts being used and the lower wages being offered to their staff.

Depending on the roles that airline carriers play in flight services, we distinguish between ticketing and operating carriers. Ticketing carriers schedule flights, set ticket prices and sell tickets to passengers. In most cases, ticketing carriers are network carriers. Operating carriers provide flight services directly with their own aircrafts and staff. The same carrier may or may not serve as both the ticketing and operating carrier. If the ticketing carrier and the operating carrier are not the same for a flight service, they have reached a cooperative

[6] A distinction is made here between a network carrier selling tickets in their network of routes and a network created by a carrier which signifies the connections established across carriers via contractual agreements to serve various routes.

agreement to serve the route, and we define the relationship they form at the route level. This relationship varies depending on the ticketing carrier's and the operating carrier's types, namely whether they are major, low-cost or regional carriers.

Table 2 summarizes the types of cooperative agreements among US airline carriers. If the ticketing carrier and the operating carrier are the same for some flights across a route, we call their service structure, self-service. If the ticketing carrier and the operating carrier are different, four types of relationships can be identified: codesharing, subsidiary, subcontracting, and "other-type". These business relationships are formed by different agreements and may have different underlying rationales. If ticketing carrier A is a network carrier and operating carrier B is another network carrier, their relationship is characterized as "codesharing". In this case, the flight is operated by network carrier B but the tickets are sold by network carriers A and B together in each of their ticket selling systems. In other words, network carrier A helps sell tickets for network carrier B. The other three types of relationships are formed between major carriers and regional carriers.[7] Specifically: 1) If the regional operating carrier is a wholly-owned subsidiary of the major ticketing carrier or shares one parent company with the major ticketing carrier, we label the relationship as 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. It should be noted that, wholly-owned subsidiaries never form subcontracting relationships with any major carrier and thus the regional carrier being subcontracted to can only be an independent regional carrier. 3) When the firms are not forming a subcontracting relationship and the regional carrier is not a subsidiary, we categorize the relationship as "other-type". This category includes three types of uncommon interactions: a) the major ticketing carrier may subcontract indirectly to the regional operating carrier, and in other words, the major ticketing carrier codeshares with another major carrier, which owns or subcontracts to the regional operating carrier;[8] b) the major ticketing carrier may codeshare with the regional operating carrier

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

[8]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 potential intermediary major

and help sell the regional carrier's flight tickets under the major carrier's system; and c) gate switching occurs between carriers.[9] We group these three cases together as "other-type" for simplicity. This allows us to simplify the framework and focus on carriers' subcontracting relationships and the networks created through this activity. In summary, we have in total five types of relationships among airline carriers including self-service.

Since non-subcontracting relationships may have an impact on carriers' subcontracting decisions, we consider and control for the possible non-subcontracting relationships a major carrier or an independent regional carrier may have on a route. For major carriers, the five types of relationships are *not mutually exclusive*. In other words, a major ticketing carrier on a route may have up to four types of non-subcontracting relationships with other carriers while still be involved in subcontracting. Likewise, an independent regional operating carrier may have up to two types of non-subcontracting relationships on a route while engaging in subcontracting. These non-subcontracting relationships further complicate our task of explaining carriers' subcontracting relationships and networks because of the interdependency of carriers' decisions on their subcontracting and non-subcontracting relationships. In the next section, we discuss the model and estimation method which enables us to accomplish this task.

3 The Model and Estimation Method

We analyze carriers' subcontracting networks at route level. The airline route is defined as a non-directional route between two airports in the US. 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.[10] Assume there are I major carriers and J independent

carrier.

[9]In certain situations, the major ticketing carrier actually operates the flight itself 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 lead to a situation where a major carrier is serving as the ticketing carrier and a regional becomes the operating carrier.

[10]Airlines seldom subcontract at only one direction on a route. This is a common definition following the literature in the US airline industry, for example, Borenstein (1989).

regional carriers operating on M routes for T time periods[11]. Since subcontracting is a directional relationship (a major carrier subcontracts to a regional carrier and not vice versa), the subcontracting networks between major and regional carriers are directional as well. We say that a link, $Link^{s}_{ijmt} = 1$ ($i \in \{1, 2, ..., I\}, j \in \{1, 2, ..., J\}, m \in \{1, 2, ..., M\}, t \in \{1, 2, ..., T\}$), forms if the major carrier i subcontracts to the regional carrier j on route m in period t, and otherwise $Link^{s}_{ijmt} = 0$. The superscript s indicates that the link is established through subcontracting. Carriers' non-subcontracting relationships may also impact their subcontracting network formation. As such, we aggregate major carriers' 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 carriers on route m in period t, and otherwise $Link^{ns}_{ilmt} = 0$. The superscript ns indicates that the link is related to non-subcontracting activities. Likewise, we define independent regional carriers' non-subcontracting networks in the same way. $Link^{ns}_{jemt} = 1$, where $e \in$ {Self-Service, Other-Type}, if the regional carrier j has the relationship of e with relevant carriers on route m in period t, and otherwise $Link^{ns}_{jemt} = 0$.

The link matrix $Link_{mt}$ is combining an $I \times J$ subcontracting adjacency link matrix, an $I \times 4$ aggregated non-subcontracting link matrix of major carriers and a $J \times 2$ aggregated non-subcontracting link matrix of independent regional carriers to present the entire landscape of relationships within m and t. The distinct pairs of i and j elements of the subcontracting adjacency link matrix $Link^{s}_{ijmt}$ ($i \in \{1, 2, ..., I\}, j \in \{1, 2, ..., J\}$) represent the potential subcontracting relationships on route m in period t. Likewise, the distinct pairs of i and l elements of major carriers' non-subcontracting link matrix $Link^{ns}_{ilmt}$ ($i \in \{1, 2, ..., I\}, l \in \{\text{Self-Service}, \text{Subsidiary}, \text{Code-Sharing}, \text{Other-Type}\}$) represent all of the potential aggregated non-subcontracting relationships of major carriers. The distinct pairs of j and e elements of regional carriers' non-subcontracting link matrix $Link^{ns}_{jemt}$

[11] Since we are focusing on the subcontracting networks between major carriers and independent regional carriers, we mainly consider their behaviors and do not directly model the behaviors of other types of carriers, including low-cost carriers and wholly-owned subsidiaries. For other types of carriers, only their presence on routes is incorporated in the model.

($j \in \{1, 2, ..., J\}, e \in \{\text{Self-Service}, \text{Other-Type}\}$) represent all of the potential aggregated non-subcontracting relationships of independent regional carriers.

Table 3 presents a subcontracting adjacency link matrix, a non-subcontracting link matrix of major carriers and a non-subcontracting link matrix of independent regional carriers that could synthesize a potential link matrix $link_{mt}$ in the case of 3 major carriers and 3 regional carriers on route m in period t. The 3×3 matrix in the first panel has entries indicating whether a major carrier subcontracts to a regional carrier forming a link in the subcontracting network. For example, the entry 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 0 entry in the second row and first column. The 3×2 matrix in the second panel shows whether independent regional carriers form non-subcontracting relationships. The 3×4 matrix in the third panel indicates whether major carriers have non-subcontracting relationships.[12] [13]

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 decide to engage in contractual or non-contractual relationships 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 endogenously within the framework of our Bayesian estimation as described in the Appendix. Those events include what we will call "meetings" between major and regional carriers, where they determine on which routes 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 possible 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 $I \times J$ potential meetings between major and regional carriers. Besides those meetings, EO_t also includes events when

[12]It should be noted that, in this example, Major carrier 3 subcontracts to Regional carrier 1 and 2 and has all four types of non-subcontracting relationships at the same time. This is possible since these relationships are not mutually exclusive for major carriers. In addition, all elements for Major carrier 1 are 0, indicating that Major carrier 1 does not operate on route m in period t.

[13]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.

major carriers or regional carriers can decide whether or not to establish or maintain other non-subcontracting relationships with relevant carriers in each route. In addition, there is an event in EO_t for low-cost carriers to decide which routes to enter.[14] The outcomes of each event in period t are observable to all carriers immediately after the event so carriers make their decisions based upon what already happened in the same period. We define EO as the aggregation of EO_t across time and $EventOrder$ as the set which contains all possible event orders (EO).

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 within 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 observed in the last period, to $Link_{mt}$, the network observed in the current period, with $O_t = \{0, 1, ..., r_t\}$ signifying the number of events taking place within t. We set $TempLink_{mt}^{0} = Link_{m,t-1}$ at the beginning of each period t, and through the event order $TempLink_{mt}^{O_t}$ is transformed taking into account the decisions that are made sequentially within t. In more details, before any event, if any major carrier i or regional carrier j either exits all routes, goes bankrupt or merges with another carrier in the current period t, we set $TempLink_{imt}^{0} = 0$ or $TempLink_{jmt}^{0} = 0$ respectively following the assumption that if any carrier stops operating in period t it is known to all carriers at the beginning of the period. Subsequently, active major carriers and regional carriers make decisions sequentially according to an event order EO_t that will be estimated endogenously. 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 take place within t, $TempLink_{mt}^{O_t}$ evolves to $Link_{mt}$, describing the network that has formed in the current period.[15] 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 subcontracting link formation for major carriers and

[14]Please see the Appendix for an example of a potential event order.

[15]As mentioned earlier, this event order is ultimately determined not randomly but within the framework of the estimation as will be described in the Appendix.

regional carriers. Let k be an indicator of the type of a carrier, major ($k = 1$) or regional ($k = 2$), that could potentially be serving a route. Let U^1 (U^2) represents the functional form identifying the utility of a major (regional) carrier. Major carrier i is willing to form a link with regional carrier j on route m in time t if utility U^1_{ijmt} is greater than or equal to zero. Likewise, regional carrier j will form a link with major carrier i on route m in time t if $U^2_{ijmt} \geq 0$.

In general terms, we denote the utility function as U^k_{ijmt} for $k = \{1, 2\}$ and let

$$U^k_{ijmt} = \alpha^k_t + \lambda^k_{1i} + \lambda^k_{2j} + f^k(Link_{t-1}) + g^k(TempLink^{O_t}_t|EO_t) + h^k(X) + \epsilon^k_{ijmt}, \quad (1)$$

where α^k_t indicates time fixed effects, λ^k_{1i} major carrier fixed effects and λ^k_{2j} regional carrier fixed effects. U^k_{ijmt} is a function of $Link_{t-1}$ the network in the last period, and also a function of the transition network $TempLink^{O_t}_t$ of the current period conditional on the event order. It should be noted that the event order is exogenous in the reduced form of the utility function, although it will be estimated endogenously within the larger Bayesian estimation framework. We denote by X other covariates which may affect the utility gains from link formation. We also assume the error term ϵ^k_{ijmt} follows a type I extreme value distribution. Thus, after we take the integral of ϵ^k_{ijmt}, the probability that the carrier gains a non-negative utility and is willing to form the link will be given by the following equation for $k \in \{1, 2\}$

$$ln(\frac{Pr(U^k_{ijmt} \geq 0)}{1 - Pr(U^k_{ijmt} \geq 0)}) = \alpha^k_t + \lambda^k_{1i} + \lambda^k_{2j} + f^k(Link_{t-1}) + g^k(TempLink^{O_t}_t|EO_t) + h^k(X). \quad (2)$$

A link forms when both carriers' utilities are non-negative, leading to the following probability of link formation

$$P_{ijmt} = Pr(Link^s_{ijmt} = 1) = Pr(U^1_{ijmt} \geq 0)Pr(U^2_{ijmt} \geq 0). \quad (3)$$

Define β the parameter vector for functions f^k, g^k, and h^k as well as fixed effect controls α^k_t, λ^k_{1i}, and λ^k_{2j} characterizing utilities represented by Equation (1). Given an event order, the joint likelihood function of a given network is

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

I_t and J_t are the sets of major carriers and independent regional carriers that are active in period t. The likelihood function is the product of the probabilities of link formation outcomes across routes, major carriers, regional carriers and time given a network $Link$ and an event order EO. It describes the overall probability that a given network forms. We allow major carriers' and regional carriers' decisions to be determined endogenously and focus on modeling which factors determine their subcontracting relationships. However, we do not model the factors affecting carriers' decisions of non-subcontracting relationships in the joint likelihood function, which is outside the scope of the paper.

Before we explain how we estimate β, the parameter vector characterizing the utility functions, it is worth discussing its interpretation. The dependent variables are the probability/utility gains of major carriers and regional carriers forming a link, and thus β^n (the nth element in β) measures the marginal effect of the independent variable on the probability of link formation. Link formation means the establishment of a subcontracting relationship between a major carrier and a regional carrier on a route. Although this description is encompassing for regional carriers, it is incomplete for major carriers that may or may not currently be serving the route. In that regard, we are comparing the behaviors of major carriers serving the route via subcontracting with that of carriers already operating on the route, offering different services, and those who after exploring all options decide not to enter. For simplicity, we say that a major carrier's link formation decision is its decision of entry in subcontracting services within a route.[16] [17] We call the current model as the model

[16]It should be noted that route entry in subcontracting services and route entry in other services are different decisions and made in separate events. We incorporate major carriers' route entry decisions in all forms in the model, but only focus on explaining major carriers' route entry in subcontracting services.

[17]Through a program called Essential Air Service (EAS), the United States Department of Transportation subsidizes some carriers to provide flight service to eligible small airports/communities otherwise no flight service will be provided. This program may bias our estimation of major carriers' route entry behavior. However, only 6 routes out of almost 4000 are subsidized through major carriers so we do not think this will

of all major carriers.

Although it is important to consider the decision to offer subcontracting services among all potential entrants and existing carriers on a route, it is also important to study the choice to form subcontracting relationships conditional on entry decisions. Our next model is emphasizing the make-or-buy trade-offs in the decision making process. While in the first model, we considered every major carrier on the route including potential entrants, in the second, we look at the choices of service existing major carriers on a route make conditional on route entry. Therefore, we assume major carriers' entry or exit decisions precede service choice decisions in each period.

This assumption changes two components of the model. First, it affects how the network evolves at the beginning of each period t, namely, it impacts the form of $TempLink^0_{mt}$.[18] Second, it changes the joint likelihood function,

$$\mathcal{L}(\beta|EO, Link) = \prod_{t\in\{2,...,T\}} \prod_{(i,j)\in(I_t,J_t)|EO_t} \prod_{m\in M_{it}} (P_{ijmt})^{Link^s_{ijmt}} (1 - P_{ijmt})^{1-Link^s_{ijmt}}, \qquad (5)$$

where M_{it} is the set of routes on which major carrier i operates in period t. The likelihood function in this case is the product of the probabilities of link formation outcomes across only the routes where each major carrier operates rather than all routes. Thus we call this model, the model of route-serving major carriers. As a result, for major carriers, each β now helps capture and isolate the marginal effect only on their subcontracting decisions which are conditional on route presence.

We use a Bayesian estimation method (Markov-Chain-Monte-Carlo) to estimate β and update event order.[19] After a large number of iterations, the distribution of the parameters as well as the event order will converge to a posterior distribution. Obtaining the estimates of the parameters from the last 500 iterations, which constitute the posterior distribution,

be a significant concern.

[18] In the model of all major carriers, after we set $TempLink^0_{mt} = Link_{m,t-1}$ at the beginning of each period t, we set $TempLink^0_{imt} = 0$ if major carrier i exits all routes, goes bankrupt or merges with another carrier. In this model, the condition for setting $TempLink^0_{imt} = 0$ refers to exit decision on the single route m.

[19] Details are relegated to the Appendix.

we calculate the estimated means of the parameters and check from the distribution whether they are significantly different than zero.[20]

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[21] data, and provides the variables including 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 carriers and regional carriers. Our data sample covers the periods from the 3rd quarter of 2013 to the 3rd quarter of 2017. We aggregate DB1B Coupon data to route-quarter-ticketing carrier-operating carrier level and obtain a sample of 5 major carriers, 17 independent regional carriers, 3889 routes and 17 quarters.[22]

Table 4 lists the subcontracting partnerships between major carriers and regional carriers at the carrier level in quarter 3 of 2014 from the RAA annual reports. 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. In addition, 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.

[20]Our identification strategy can be explained as follows. Although we have some exogenous variables, such as population, employment and income around end-point airports, and although we also include time fixed effect, capturing technology growth which makes subcontracting increasingly popular, we are not focusing on studying how these external forces change the networks from one equilibrium to another over time. Instead, we are focusing on how firms interact with each other. By incorporating the latent event order into the model, firms' decisions in previous events become exogenous to firms' decision makings in the current event. As a result, the identification of the estimates capturing firms' interdependency relies on the variations in firms' decisions in previous events.

[21]Flight segment means the flight is from airport A to airport B. For some passengers A and B can be their origin and destination. For others the flight is a segment of their connecting flights, and A and B are not their origin and/or destination.

[22]The Appendix describes our data filter and variable construction in detail.

Figure 1 aggregates carriers' subcontracting networks across routes and over time. The nodes marked in green represent major carriers and those in red represent independent regional carriers. The gray arrows, pointing from major carriers to regional carriers, indicate subcontracting relationships, which are also directional links in the networks. The thickness of the arrows measures the number of routes on which two carriers established subcontracting relationships during the period. Panel (a) illustrates the subcontracting network in the third quarter of 2013, from which we can see that some carriers had many links, such as United and SkyWest, while others only had one link, such as Alaska and Compass. Some carriers did not engage in any subcontracting relationship at all. Besides the variation in the number of distinct links within a period, the network evolved over time as can be seen in the series of panels presented in Figure 1. Through market consolidation, US Airways and Chautauqua with their network structure were absorbed by other carriers, and thus disappeared from the network. American and Compass increased their numbers of network connections. Our goal is to measure changes in the network structure over time and understand the consequences of those changes on airline expansion and pricing policy.

Figure 2 plots the average numbers of major carriers, regional carriers, and link numbers across routes over time. In general, the average number of major carriers on each route is less than 1, because some routes are only served by low-cost carriers and some routes are not served by any carrier during certain periods. The drop in the number of major carriers and the number of links around the third quarter of 2015 is caused by the merger between American and US Airways. In addition to the merger, the fluctuation in the average numbers of major carriers is caused by major carriers' route entry and exit decisions. The fluctuation in the numbers of regional carriers, however, is mainly caused by subcontracting, since non-subcontracting relationships only count for a tiny fraction of regional carriers' business. We observe that after the 3rd quarter of 2016, although the average number of major carriers on each route is nearly constant, the average numbers of regional carriers and links on each route decrease.

Figure 3 and 4 present, in more detail, the major carriers' and regional carriers' subcontracting behaviors respectively. Figure 3 plots major carriers' subcontracting route numbers over time. In general, major carriers which subcontract on more routes, such as United and

Delta airlines, decrease their subcontracting route numbers over time, while carriers such as American and Alaska have an increasing trend in their subcontracting route numbers. Figure 4 provides similar data on regional carriers. Since we have too many regional carriers, we only select to graph those whose changes in subcontracting route numbers are the greatest over time. The figure shows that SkyWest, Republic, GoJet and Trans States expand their business through subcontracting while the number of routes ExpressJet served decreases. Figure 5 illustrates the networks of two regional carriers' routes on which they are subcontracted to over time. The panels to the left show the route networks of ExpressJet, which shrink gradually over time. The panels to the right display Skywest's expanding subcontracting business engagement over time. These figures display a large amount of variations in carriers' subcontracting relationships, which further provides us with the incentive to study the causes of carriers' subcontracting.

Based on the modeling framework described in Equation (1) in Section 3 and the variables we have constructed from the data, listed in Table A2, we use the following linear specification for carriers' utilities and estimate the effect of these factors on the formation of the network

$$\begin{aligned} U^k_{ijmt} =& \alpha^k_t + \lambda^k_{1i} + \lambda^k_{2j} + \delta^k TempLinkVar_t + \phi^k LinkVar_{t-1} \\ &+ \beta^k Homophily + \theta^k CarrierChar + \gamma^k RouteChar + \epsilon^k_{ijmt}, k = 1, 2. \end{aligned} \tag{6}$$

$TempLinkVar_t$ are variables generated from $TempLink^{O_t}_t$, the transition network, conditional on which the major carrier and the regional carrier make their subcontracting decisions. 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. We also generate $LinkVar_{t-1}$ from $Link_{t-1}$, the variables characterizing the features of the network in the last period. We expect that the network formed up until the last period has an impact on the network formation in the current period. $Homophily$ represents measures that capture the similarity between the major and the regional carriers in terms of the routes they serve. We expect that the more similar the carriers are, the more likely they will form and maintain a subcontracting relationship on a route. We also control for some carrier and route characteristics

($CarrierChar$ and $RouteChar$). Our focus is on variables $TempLinkVar_t$, $LinkVar_{t-1}$ and $Homophily$. Table A2 provides detailed description of all the variables used in our estimation.[23].

Table 5 presents summary statistics of our sample and the variables used in Equation 6. Considering the time route level summary, we can see that on average there are 0.632 major carriers, 0.556 regional carriers and 0.598 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 and "other-type" of relationships for major carriers. As we stated earlier, regional carriers' non-subcontracting relationships only count for a tiny fraction of their business. A large amount of variation in subcontracting activity is captured in our data and these variables are allowing a more precise estimation of effects. The table also presents the summary statistics of our covariates, including route characteristics, such as route distance, airport precipitation, snow fall, population, income and employment, and carrier characteristics, such as passenger numbers, route numbers and market shares. These variables also indicate substantial variation.

5 Estimation Results

In Section 3, we developed two models of carrier decision making. In the first, we model concurrently their route entry and subcontracting choices. As such, we take into account all major carriers' behaviors including those operating on each route and potential entrants.[24] In the second model of route-serving major carriers, we focus on the decisions of those major carriers that operate on each route ex-post.

In this section, we estimate the two models. For each model, we run the estimation with 1000 iterations to update parameters and the event order. Then, we use the last 500 estimates as the posterior distributions of the parameters following Christakis et al. (2010).

[23]One concern we may have is that carriers' participation in international flight service may affect their subcontracting behaviors in the domestic market. However, since we are already controlling for carriers' past passenger numbers at route level, international passengers connecting to a domestic flight are also controlled.

[24]One should note that here the route entry by a major carrier refers to whether the major carrier sells flight tickets on the route and the subcontracting decision refers to whether the major carrier provides flight service to the route through subcontracting.

In each model, we control for carrier fixed effect, time fixed effect, carrier characteristics and route characteristics in both major carrier's and regional carrier's utility functions.[25] Table 6 presents results consisting of the estimated means of the coefficients from the posterior distribution and in parentheses the probabilities that the parameters have the opposite sign of their reported means.[26] The first two columns report the estimation results from the model of all major carriers and the last two columns those from the model of route-serving major carriers. The coefficients in the first column capture a major carrier's utility gains translated into the probabilities for the major carrier to enter a route in subcontracting services with a regional carrier, while those in the second column capture a regional carrier's utility gains/probabilities of helping a major carrier enter a route in a subcontracting relationship.[27] The third and fourth columns provide coefficients on the probabilities respectively that a major carrier and a regional carrier will form a subcontracting relationship conditional on the major carrier's route presence. Figures A1-A4 in the Appendix provide plots of the kernel densities of the posterior distributions of the parameters specified in each of the four columns of Table 6 separately.

We first consider the impact of the first set of variables, $TempLinkVar_t$, on link formation of carriers' subcontracting networks. Our interest in this set of variables stems from the fact that they help explain the interdependency among airline carriers in decision making. The estimated coefficient of $RivalLink_{imt}$ in the first column, for example, indicates that a major carrier is more likely to enter a route in subcontracting services if its rivals have already formed a link. The corresponding coefficient in the third column indicates that an existing major carrier on a route is also more likely to subcontract to a regional carrier if its rivals are already doing so. The intuition is straightforward. Subcontracting allows major carriers to create a cost advantage, so if one major carrier subcontracts, it will be easier for other major carriers to compete on the route if they subcontract as well. The regional carrier, on the other hand, is less likely to establish a subcontracting relationship if its rivals (other

[25]Carrier characteristics and route characteristics are listed and explained as in Table A2. Estimates of these covariates are available upon request.

[26]The smaller the probability is, the more likely that the coefficient is significantly different from 0.

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

regional carriers) have already established persistent subcontracting relationships, indicated by the negative coefficient of $RivalLink_{jmt}$ in the second and fourth columns. It implies that if a regional carrier already established its active presence on a route, other regional carriers will prefer to avoid direct competition. Why do major carriers prefer competing while regional carriers do not? One explanation could be that the passenger market is more competitive than the subcontracting market. It is well known that airline carriers could enter the passenger market freely after the Airline Deregulation Act in 1978. Unlike the passenger market which has many buyers, the subcontracting market only involves few buyers (major carriers), so market incumbency, reputation and installed capacity may play a more important role for regional carriers in attracting business from major carriers, which could lead to a higher barrier to entry in the subcontracting market. In addition, regional carriers may already face great pressure from bargaining with major carriers so they tend to avoid competition among themselves in order to survive.

The variables identifying the impact of a major carrier's remaining types of business contact on network formation reveal the interdependency among a major carrier's own decisions. The first column shows the estimation results of the effects on the major carriers' route entry in subcontracting services. The estimation results show that if a major carrier is already serving the route via either subcontracting ($OtherLink^{i}_{ijmt}$), self-service ($SelfService_{imt}$), the use of subsidiaries ($Subsidiary_{imt}$), codesharing ($CodeSharing_{imt}$) or "other-type" of contractual agreements ($OtherType_{imt}$), it is more likely to enter the route in subcontracting services with another regional carrier. Intuitively we are comparing a major carrier's subcontracting decision when it already serves a route with its decision when it has not yet entered a route, with the major carrier's route presence leading to an increase in the probability to subcontract to a regional carrier. The same variables in the third column explain the interdependency among a major carrier's own decisions from another perspective, offering the tradeoffs in engaging in one versus another form of contractual relationship. The estimation results show that if an existing major carrier on a route already subcontracts to a regional carrier, codeshares with a major carrier or has an "other-type" relationship, it is less likely to subcontract to another regional carrier. On the other hand, if a major carrier already serves the route by itself or uses a wholly-owned subsidiary, it is more likely to subcontract out part of its service. In other words, for existing major carriers on a route, self-service and use of subsidiaries are complementary to their subcontracting behaviors, while subcontracting itself, code-sharing and "other-type" relationships are substitutes to other subcontracting activity. Those findings suggest that a major airline's subcontracting choices across regional carriers within a market are substitute services since the regionals practically sell the same services with quality variations. At the same time, accommodating frequent flight changes within a route may necessitate a major carrier's subcontracting behaviors to complement the use of its own flights or wholly-owned subsidiary companies. When major carriers' flight needs cannot be satisfied by their own or subsidiaries' services, they will seek outside options. Subcontracting, code-sharing and "other-type" are all major carriers' outside options, and thus are substitutes to each other.

The variables $OtherLink^{j}_{ijmt}$, $SelfService_{jmt}$, and $OtherType_{jmt}$ reveal the interdependency among a regional carrier's own decisions. The positive coefficients on these variables in the second and fourth columns imply that if the regional carrier is already serving the route via subcontracting, self-service or "other-type" relationships, it is more likely to help a major carrier enter the route in subcontracting services or establish a subcontracting relationship with an existing major carrier on the route. In other words, a regional carrier's route presence increases its probability of forming a link on the route.

The next category of variables in the table uses the carriers' route structures to measure their similarities represented in $Homophily$ measures. One of the two variables constructed, measures the number of common routes for two carriers in the last period. The other is the metric distance (difference) between two carriers' passenger distributions across all routes. It is expected that, the more similar the major carrier and the regional carrier are, the more likely they will be to form a link. Our estimation results confirm this expectation. We find that the more common routes the major carrier and regional carrier 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 the $MetricDistance_{ij,t-1}$ is, the less likely they will be to form a link in the current period.

The variables grouped as $TempLinkVar_t$ explore choices and tradeoffs and the evolution of the subcontracting network within a period. The set of variables $LinkVar_{t-1}$, which are generated from the network of the last period, helps us understand the impact of the networks in the last period on the network formations in the current period and the dynamics of network formations. The most informative constructs revealing the structure and strength of the subcontracting network are in the carriers' centrality measures. They capture the role of a carrier in establishing, maintaining and expanding a network of subcontracting activities both at the carrier level and the route-carrier level. In our estimation, we include two main centrality measures, namely, hub centrality and authority centrality. Hub and authority centralities, normalized to $[0, 1]$, measure a carrier's subcontracting links, and assign different weights to those links according to their importance (measured by the number of subcontracting connections) of the carriers it's been linked to. A high hub node points to many significant subcontracting partners with critical value to the subcontracting network. A high authority node signifies that a regional airline is subcontracted to by many major airlines with a large number of established links. Due to the directional nature of subcontracting agreements, hub centrality is only meaningful for major airlines and authority centrality for regional airlines. In our particular case, a carrier's centrality essentially measures the position of a carrier in the subcontracting network through its links to other well-connected carriers. As a result, it captures how much market power a carrier has in the imperfectly competitive subcontracting market.

Centralities at carrier subcontracting network level in general, display negative coefficients. The table shows that if a carrier was relatively more important in the carrier level networks in the last period, it is less likely to form a link and other carriers are also less likely to form a link with this carrier in the current period (indicated by the coefficients of $HubCentrality_{i,t-1}$ and $AuthCentrality_{j,t-1}$). In other words, a carrier's overall subcontracting market power in the last period decreases both its own and its counterpart's chances for link formation.

One should note that a carrier's centrality at carrier network level mentioned above measures the carrier's overall subcontracting market power while the centrality at route-carrier network level captures the carrier's subcontracting market power on a particular route. A carrier may have significant subcontracting market power overall but little power on a particular route, and vice versa. The estimation results of $HubCentrality_{im,t-1}$ and

$AuthCentrality_{jm,t-1}$ in the first column show that both centralities of major carrier and regional carrier have negative impacts on a major carrier's route presence in subcontracting services, while those in the third column indicate that both centralities increase the probability of a route-serving major carriers' link formation. For a regional carrier, it is more likely to form a link if the regional carrier has a smaller centrality or the major carrier has a larger centrality as reported by the estimation results of those variables in the second and fourth columns.

In the set of $LinkVar_{t-1}$, we also include two variables to describe the connections between a major carrier and regional carrier in the subcontracting network of the last period. The positive significant coefficients of $SameLinkNmbr_{ij,t-1}$ and $Link_{ijm,t-1}$ in all columns indicate that the stronger the established connections of two carriers are, the more likely it is for them to maintain their connections and form new links.

6 Effects on Ticket Prices

In this section, we investigate another important question: the effects of major carriers' subcontracting behaviors on their ticket prices. Theoretically the answer to the questions is unclear. On the one hand, the lower operating cost from regional carriers should decrease ticket prices. On the other hand, limiting direct market competition in these markets may lead to higher prices and profits. 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 within a route, which leads to the issue of endogenous subcontracting decisions in a linear regression, that has not been studied before. A major carrier's subcontracting decisions are endogenous in a linear regression not only because the major carrier makes subcontracting and pricing decisions simultaneously but also because the major carrier's rivals' behaviors affect its subcontracting decisions, which in turn affect the rivals' pricing strategy.

In order to address the endogeneity issue, we use 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 model of all major carriers, we calculate predicted probabilities that each major carrier subcontracts to each regional carrier on route m in period t, $\hat{P_{ijmt}}$. The constructed IV, IV_{mt}, is the predicted probability that there is any subcontracting behavior on route m in period t

$$IV_{mt} = 1 - \prod_{i \in I_t, j \in J_t} (1 - \hat{P_{ijmt}}). \tag{7}$$

This instrument satisfies the following three conditions. First, it is exogenous to airline ticket prices since in our structural model, airline carriers make subcontracting decisions before they make their pricing decisions. As a result, the predicted probabilities of subcontracting are generated before airlines set their ticket prices. Second, the predicted probability of subcontracting is highly correlated with carriers' actual subcontracting decisions, with a correlation coefficient of 0.8942. Finally, the probability of subcontracting should affect ticket prices only through carriers' actual subcontracting and should not be used to explain ticket prices directly.

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 7 presents summary statistics of the ticket price data being used. We focus our interest on $Subcontracting_{mt}$, a dummy variable indicating whether there is any subcontracting behavior by major carriers on route m in period t. Based on this table, 47.4% of the observations are on a route where major carriers subcontract to regional carriers and 63.7% of the observations are on a route where low-cost carriers operate. The predicted probability IV_{mt} is the instrumental variable for $Subcontracting_{mt}$. We capture the market concentration level by HHI_{mt}, which is calculated based upon passenger numbers of non-stop flights. The average ticket price of ticketing carrier i on route m in period t is represented by $Fare_{imt}$.[28] The mean of ticket prices is \$196 for a non-stop one way trip with the standard deviation of \$74.5. The smallest and largest fares are \$10 and \$932 respectively.

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

Based on this dataset, we run the following linear regression

$$log(fare)_{imt} = \alpha_{im} + \gamma_t + \beta_1 HHI_{mt} + \beta_2 Subcontracting_{mt} + \beta_3 LCC_{mt} + \epsilon_{imt}. \quad (8)$$

The dependent variable is the log of average ticket prices. Route-carrier fixed effects and time fixed effects are controlled for. It should be noted that the error term mainly captures the unexpected supply and demand shock affecting prices and is not related to the variables we used to explain subcontracting network formation. We report the estimation results in Table 8. In the first column, we use no IV. This serves as a reference regression. We instrument for $Subcontracting_{mt}$ in the second column. Both the weak identification test and the under identification test for the IV are passed.[29] In both columns, standard errors are robust and clustered at route level. In both regressions the estimated signs of HHI_{mt} and LCC_{mt} are consistent with our expectations. A lower market concentration level or the 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 not significant and the magnitude is relatively small. After being instrumented for, $Subcontracting_{mt}$ becomes very significant (5% significance level), and the magnitude increases by more than 6 times. As a causal effect, it indicates that major carriers' subcontracting behavior is estimated to decrease ticket prices by 3.4%.

7 Conclusion

In this paper, we study subcontracting network formations among US airline carriers. The links in the network are subcontracting relationships between major carriers and regional carriers. We use a Bayesian estimation method to study the factors that contribute to the formation of a link in the network of carriers' subcontracting relationships. We build two models in which carriers make sequential decisions about not only their subcontracting but also non-subcontracting relationships, enabling us to understand the interdependency among airline carriers and decisions. In one model, we focus our attention on route entry

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

in subcontracting services, while in the other, we consider decision making among existing major carriers on each route.

Our estimation results confirm the interdependency among carriers' subcontracting and non-subcontracting decisions. First, route presence, in every form, in the current period significantly increase major carriers' and regional carriers' probabilities of subcontracting. Second, for existing major carriers on a route in the current period, self-service and use of subsidiaries are complementary to their subcontracting behaviors, while subcontracting itself, code-sharing and "other-type" relationships are substitutes to other subcontracting activity. Third, a major carrier is more likely to enter a route in subcontracting services or subcontract to a regional carrier conditional on its route presence if its rivals have already formed subcontracting relationships in the current period while regional carriers prefer to avoid competition. In addition, we find that homophily and previously formed networks have a significant impact on carriers' current subcontracting network formations. Using the IV constructed from the network formation estimation, we instrument for major carriers' subcontracting behaviors, and find that major carriers' subcontracting decrease ticket prices by 3.4%.

Finally, the paper highlights potential policy implications. Since subcontracting is related to lower operation cost and decreases flight ticket prices, the formation of subcontracting relationships could be facilitated and supported as a way to promote competition.

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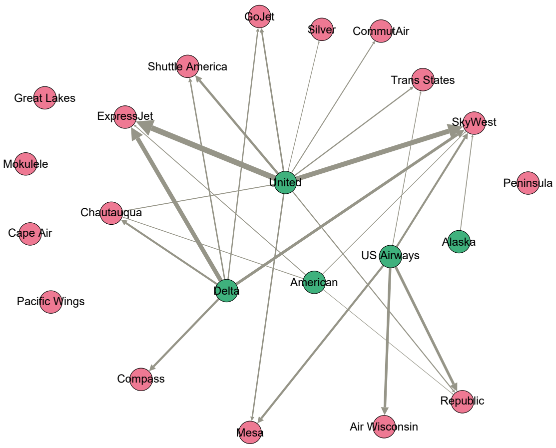
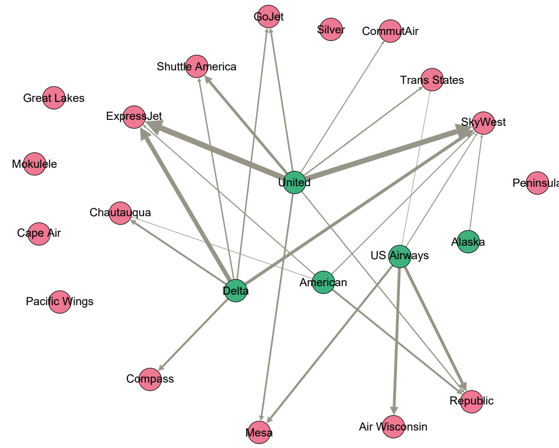
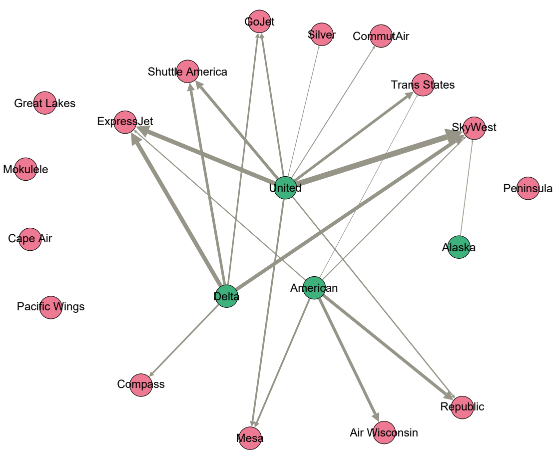
Figure 1: Subcontracting Networks over Time



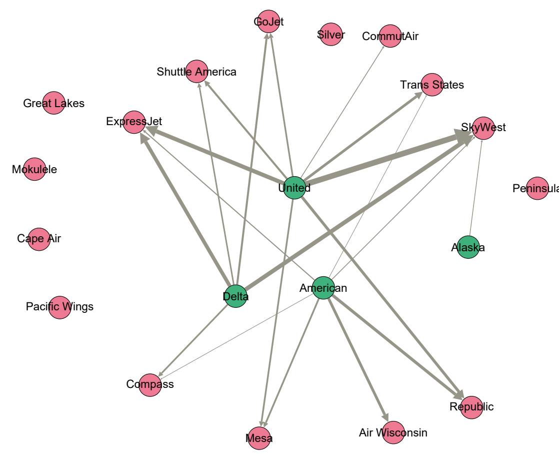
(a) Subcontracting Network in 2013q3



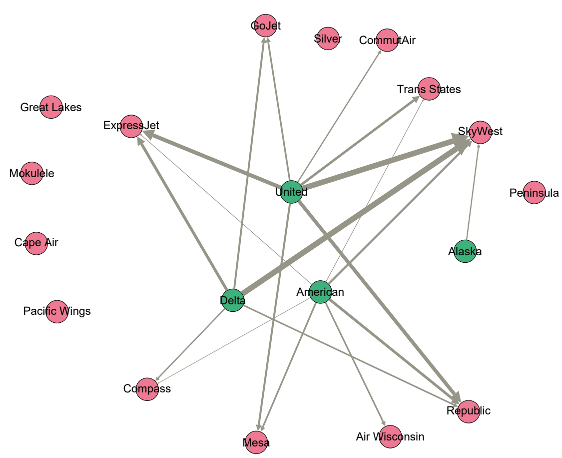
(b) Subcontracting Network in 2014q3



(c) Subcontracting Network in 2015q3



(d) Subcontracting Network in 2016q3



(e) Subcontracting Network in 2017q3

Figure 2: Major, Regional and Link Numbers over Time

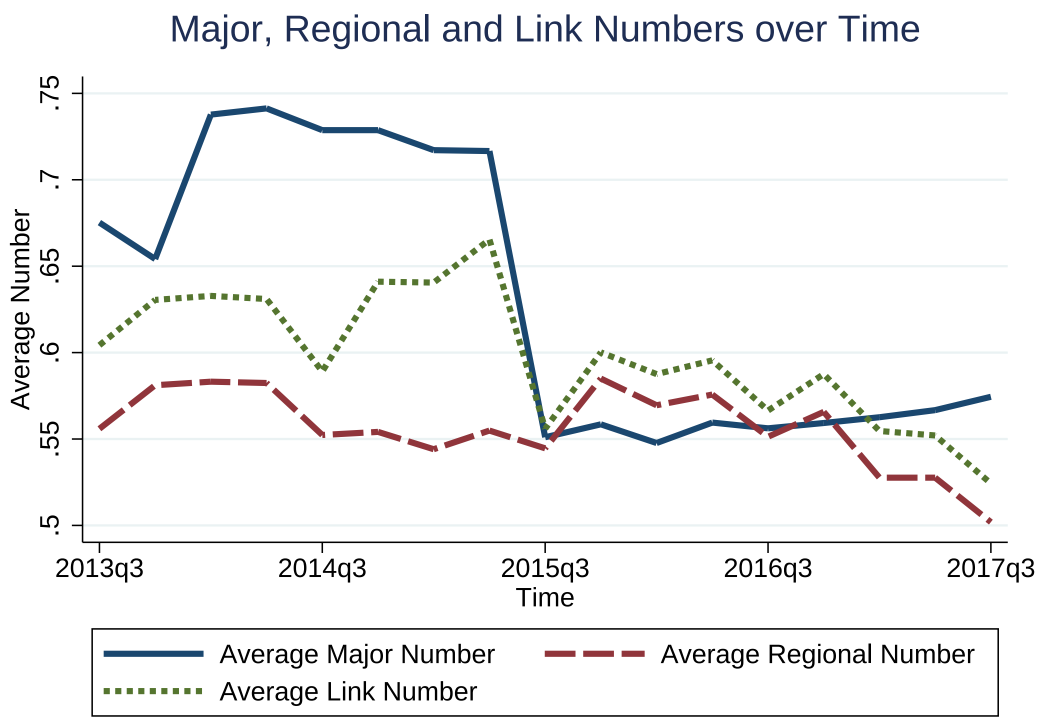


Figure 3: Major Carriers Subcontracting Route Numbers over Time

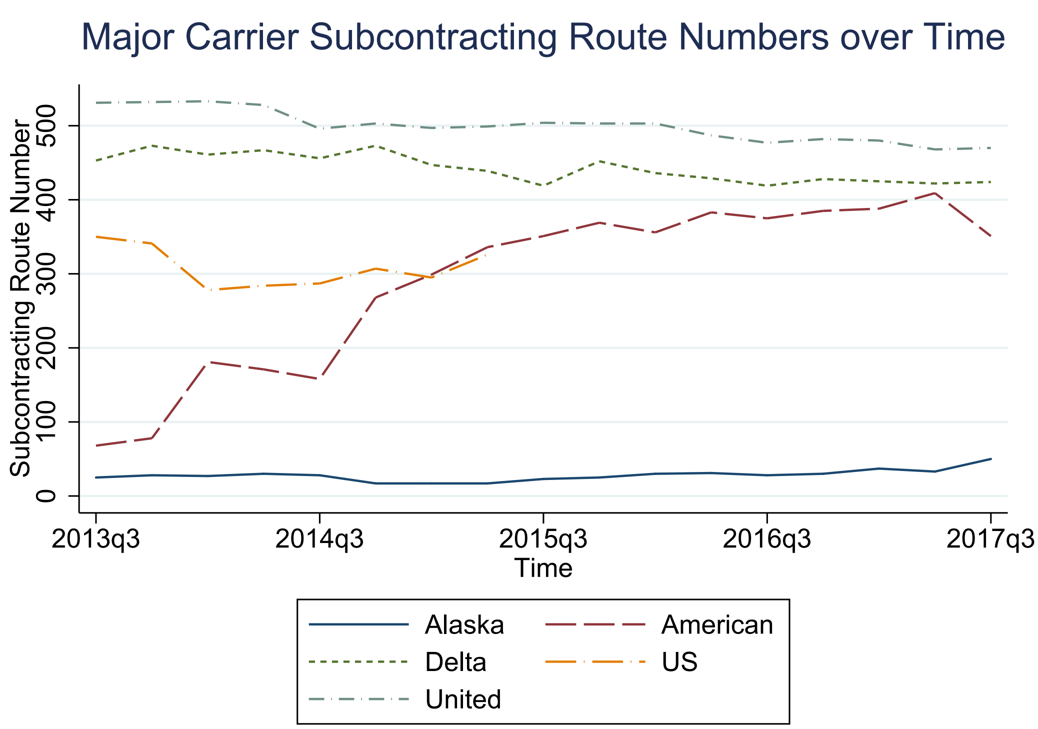


Figure 4: Selected Regional Carriers Subcontracting Route Numbers over Time

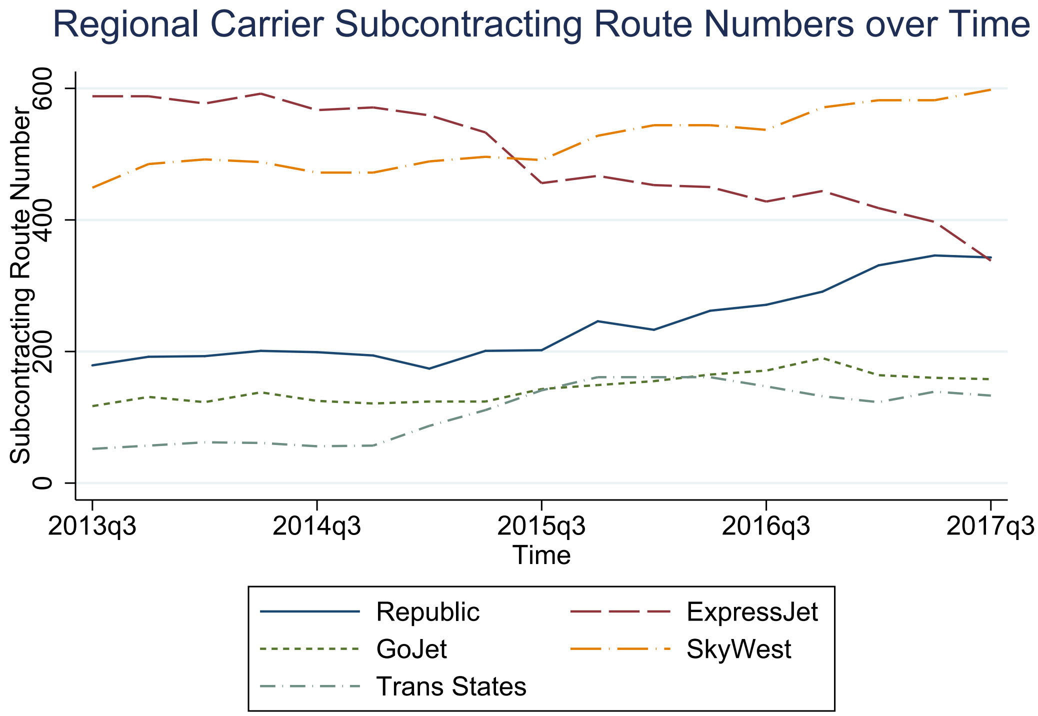
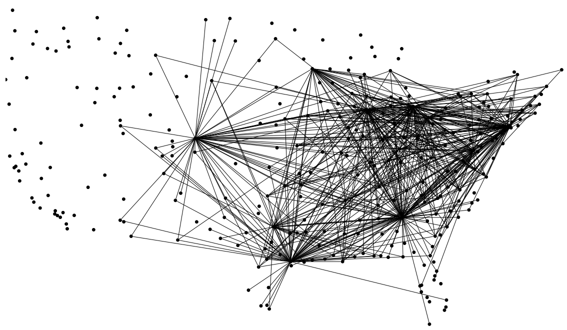
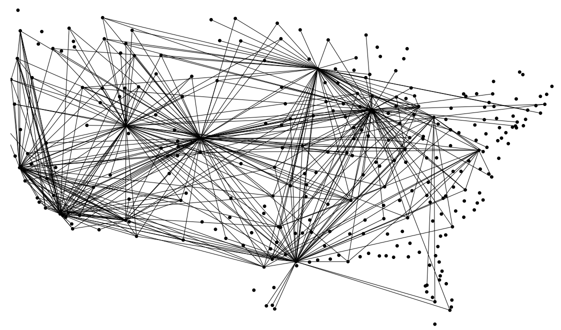


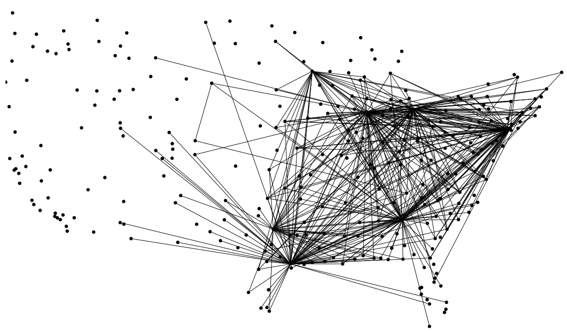
Figure 5: ExpressJet and SkyWest Route Networks over Time



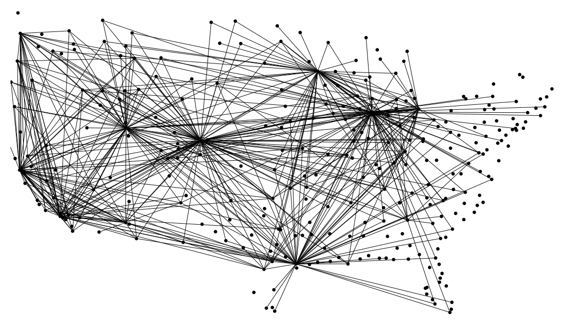
(a) ExpressJet Route Network in 2013q3



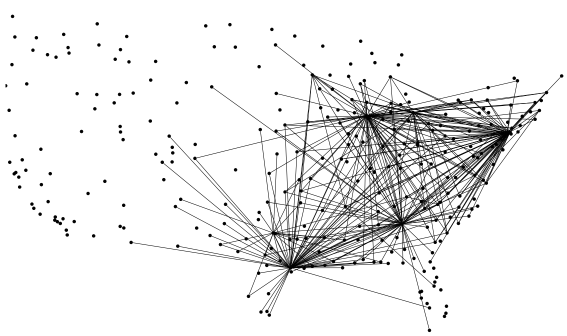
(b) SkyWest Route Network in 2013q3



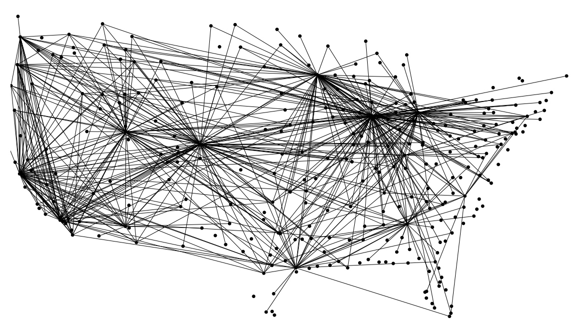
(c) ExpressJet Route Network in 2015q3



(d) SkyWest Route Network in 2015q3



(e) ExpressJet Route Network in 2017q3



(f) SkyWest Route Network in 2017q3

Table 1: Carriers List

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

Notes: The table lists the names of the carriers by commonly known types in our sample.

Table 2: Types of Relationships among Airline Carriers

Carrier Role in Flight Service		Same Operating/	Relationship	Agreement Type
Ticketing Carrier	Operating Carrier	Ticketing 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

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

Non-Subcontracting: Regional Carriers

	Self-Service	"Other-Type"
Regional 1	0	1
Regional 2	0	0
Regional 3	0	0

Non-Subcontracting: Major Carriers

	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 3 regional carriers on route m in the end of period t.

Table 4: Subcontracting Partnerships among Airline Carriers in the Third Quarter of 2014 from RAA annual reports

Major Carrier	Regional Carrier
Alaska	**Horizon**
	SkyWest
American	**Envoy**
	Chautauqua
	ExpressJet
	Republic
	SkyWest
Delta	Chautauqua
	Compass
	Endeavor
	ExpressJet
	GoJet
	Shuttle America
	SkyWest

Major Carrier	Regional Carrier
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 5: Summary Statistics

	Ob	Mean	SD	Min	Max
$RouteDistance_m$	3889	848.983	471.400	30.000	1999.000
$Precipitation_m$ (in inch)	3889	43.500	12.706	4.830	70.970
$SnowFall_m$ (in inch)	3889	31.398	27.409	0.000	207.700
$CarrierNmbr_{mt}$	66113	1.117	1.063	0.000	9.000
$TopCarrierMktSh_{mt}$	66113	0.660	0.433	0.000	1.000
LCC_{mt}	66113	0.411	0.492	0.000	1.000
$LargerPop_{mt}$ (in million)	66113	5.949	5.110	0.030	20.321
$SmallerPop_{mt}$ (in million)	66113	1.248	1.421	0.024	9.561
$Disparity_{mt}$	66113	15.720	40.671	1.000	849.553
$LargerInc_{mt}$ (in thousand dollar)	66113	55.620	12.284	30.331	169.296
$SmallerInc_{mt}$ (in thousand dollar)	66113	44.746	6.330	23.564	91.459
$Larger(Emp/Pop)_{mt}$	66113	0.656	0.066	0.456	1.523
$Smaller(Emp/Pop)_{mt}$	66113	0.585	0.057	0.385	1.046
$MajorNmbr_{mt}$	66113	0.632	0.846	0.000	5.000
$RegionalNmbr_{mt}$	66113	0.556	1.039	0.000	8.000
$LinkNmbr_{mt}$	66113	0.598	1.156	0.000	13.000
$SelfServiceMajorNmbr_{mt}$	66113	0.417	0.675	0.000	5.000
$SubsidiaryMajorNmbr_{mt}$	66113	0.181	0.416	0.000	3.000
$CodeSharingMajorNmbr_{mt}$	66113	0.051	0.250	0.000	3.000
$OtherRelationMajorNmbr_{mt}$	66113	0.042	0.221	0.000	3.000
$SelfServiceRegionalNmbr_{mt}$	66113	0.005	0.071	0.000	2.000
$OtherRelationRegionalNmbr_{mt}$	66113	0.015	0.134	0.000	3.000

Notes: The table presents the summary statistics of variables at various levels. $SelfServiceMajorNmbr_{mt}$, $SubsidiaryMajorNmbr_{mt}$, $CodeSharingMajorNmbr_{mt}$, and $OtherRelationMajorNmbr_{mt}$ are the numbers of major carriers which operate their own flights, which use wholly-owned subsidiaries, which codeshare with other carriers, and which have "other-type" of relationships on route m in period t. $SelfServiceRegionalNmbr_{mt}$ and $OtherRelationRegionalNmbr_{mt}$ are the numbers of regional carriers which sell their own flight tickets, and which have "other-type" relationships on route m in period t.

Table 5: Summary Statistics (Continued)

	Ob	Mean	SD	Min	Max
$CommonRtNmbr_{ijt}$	1234	45.662	68.021	0.000	347.000
$MetricDistance_{ijt}$	1234	0.271	0.279	0.056	1.011
$SameLinkNmbr_{ijt}$	1234	32.016	64.465	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
$HubCentrality_{it}$	76	0.224	0.191	0.011	0.530
$RouteNmbr_{jt}$	275	133.742	162.812	0.000	598.000
$PassengerNmbr_{jt}$(in million)	275	0.133	0.187	0.000	0.804
$AuthCentrality_{jt}$	275	0.062	0.085	0.000	0.324
$PassengerNmbr_{imt}$ (in thousand)	295564	0.528	2.327	0.000	47.203
$MarketShare_{imt}$	295564	0.101	0.287	0.000	1.000
$HubCentrality_{imt}$	295564	0.069	0.244	0.000	1.000
$PassengerNmbr_{jmt}$ (in thousand)	1069475	0.034	0.279	0.000	13.948
$MarketShare_{jmt}$	1069475	0.019	0.124	0.000	1.000
$AuthCentrality_{jmt}$	1069475	0.019	0.117	0.000	1.000

Notes: The table presents the summary statistics of variables at various levels.

Table 6: Estimation Results

		All Major Carriers		Route-Serving Major Carriers	
		Major	Regional	Major	Regional
$TempLinkVar_t$	$RivalLink_{imt}$	0.1715^{***}		0.2854^{***}	
		(0.000)		(0.000)	
	$RivalLink_{jmt}$		-0.1485^{***}		-0.0689^{***}
			(0.000)		(0.000)
	$OtherLink^{i}_{ijmt}$	0.4921^{***}		-0.4838^{***}	
		(0.000)		(0.000)	
	$OtherLink^{j}_{ijmt}$		1.1150^{***}		0.5715^{***}
			(0.000)		(0.000)
	$SelfService_{imt}$	0.9483^{***}		0.1801^{***}	
		(0.000)		(0.000)	
	$SelfService_{jmt}$		2.8657^{***}		2.6086^{***}
			(0.000)		(0.000)
	$Subsidiary_{imt}$	0.9181^{***}		0.8883^{***}	
		(0.000)		(0.000)	
	$CodeSharing_{imt}$	0.9646^{***}		-0.8283^{***}	
		(0.000)		(0.000)	
	$OtherType_{imt}$	2.0284^{***}		-1.6170^{***}	
		(0.000)		(0.000)	
	$OtherType_{jmt}$		2.0255^{***}		4.3853^{***}
			(0.000)		(0.000)

The probability that the parameter has the opposite sign of its mean is shown in parentheses.
$*p < 0.1, **p < 0.05, ***p < 0.01$

Table 6: Estimation Results (Continued)

		All Major Carriers		Route-Serving Major Carriers	
		Major	Regional	Major	Regional
Homophily	$CommonRtNmbr_{ij,t-1}$	2.2838***	3.2724***	4.2310***	2.5675***
		(0.000)	(0.000)	(0.000)	(0.000)
	$MetricDistance_{ij,t-1}$	−4.0549***	−3.3231***	−2.5717***	−2.1117***
		(0.000)	(0.000)	(0.000)	(0.000)
$LinkVar_{t-1}$	$HubCentrality_{i,t-1}$	−0.1470	−3.1514***	−1.1153***	−0.1896*
		(0.302)	(0.000)	(0.000)	(0.060)
	$AuthCentrality_{j,t-1}$	−1.2224***	−3.4065***	−1.5977***	−1.4703***
		(0.000)	(0.000)	(0.000)	(0.000)
	$HubCentrality_{im,t-1}$	−0.7067***	1.7271***	0.1806***	0.4281***
		(0.000)	(0.000)	(0.000)	(0.000)
	$AuthCentrality_{jm,t-1}$	−0.8645***	−1.2463***	2.4365***	−2.1384***
		(0.000)	(0.000)	(0.000)	(0.000)
	$SameLinkNmbr_{ij,t-1}$	3.9662***	4.9195***	6.8258***	3.7593***
		(0.000)	(0.000)	(0.000)	(0.000)
	$Link_{ijm,t-1}$	3.7702***	4.8694***	7.1305***	3.0936***
		(0.000)	(0.000)	(0.000)	(0.000)
Carrier Fixed Effect		Yes	Yes	Yes	Yes
Time Fixed Effect		Yes	Yes	Yes	Yes
Carrier Characteristics		Yes	Yes	Yes	Yes
Route Characteristics		Yes	Yes	Yes	Yes

The probability that the parameter has the opposite sign of its mean is shown in parentheses. $*p < 0.1, **p < 0.05, ***p < 0.01$. Carrier characteristics and route characteristics are listed and explained as in Table A2. Estimates of these covariates are available upon request.

Table 7: Summary Statistics: Ticket Prices

	Observations	Mean	Standard Deviation	Minimum	Maximum
$Distance_m$	67056	831.7	463.1	54	1999
$Fare_{imt}$	67056	196.0	74.52	10	931.9
HHI_{mt}	67056	0.776	0.255	0.191	1
LCC_{mt}	67056	0.637	0.481	0	1
$Subcontracting_{mt}$	67056	0.474	0.499	0	1
IV_{mt}	67056	0.465	0.457	0.000797	1

Notes: The table shows the summary statistics in the sample of ticket price regressions.

Table 8: The Impact of Subcontracting on Ticket Prices

	(1)	(2)
	$log(fare)_{imt}$	$log(fare)_{imt}$
HHI_{mt}	0.160***	0.154***
	(0.0153)	(0.0155)
$Subcontracting_{mt}$	-0.00501	-0.0336**
	(0.00545)	(0.0140)
LCC_{mt}	-0.0357***	-0.0364***
	(0.00860)	(0.00861)
Observations	67056	66175
IV for Subcontracting	No	Yes
IV test Passed		Yes
# of Clusters	3830	3566

Standard errors in parentheses

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

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

Appendix

A An Example of a Potential Event Order with 3 Major and 3 Regional Airlines

Table A1 presents an example of a potential event order in the case of 3 major and 3 regional carriers at period t. Event 1 to 9 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 and decide whether to maintain or establish subcontracting relationships and if so on which routes. In Event 10 to 21, major carriers decide whether to form non-subcontracting relationships and if so on which routes.[30] Similarly, Event 22 to 27 provide the opportunities for each independent regional carrier to make their non-subcontracting decisions. The last event, Event 28, allows low-cost carriers to make their route entry decisions.

B Estimating Parameters

In this section, we elaborate on the estimation of β and event order. We use the Markov-Chain-Monte-Carlo (MCMC) method to update the estimates of the parameters and get a converged posterior distribution after a large number of iterations. We assume β contains N parameters and follows a prior normal distribution $N(0, I_N)$, where I_N is the identity matrix, and $\beta_0 = 0$. Letting q denote the iteration number and n index the element in β, 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

$$r = min\{1, \frac{\mathcal{L}(\beta^n | EO^q, Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N) p(\beta^n)}{\mathcal{L}(\beta_q^n | EO^q, Link, \beta_{q+1}^1, ..., \beta_{q+1}^{n-1}, \beta_q^{n+1}, ..., \beta_q^N) p(\beta_q^n)}\}, \tag{9}$$

[30] In this paper, we focus on the formation of a subcontracting network instead of non-subcontracting, so we do not model what factors affect carriers' non-subcontracting relationships. For simplicity, we aggregate carriers' non-subcontracting decisions rather than allowing them to meet with each carrier separately.

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

$$\beta^n_{q+1} = \begin{cases} \beta^n & \text{with probability } r \\ \beta^n_q & \text{with probability } 1-r. \end{cases} \tag{10}$$

Besides updating β, we update EO from EO^q to EO^{q+1} using the same MCMC method to get a converged posterior distribution. We assume EO follows a uniform distribution over $EventOrder$, the set of all possible EOs. We first draw an EO^{temp} from the distribution, and calculate the likelihood ratio,

$$r = min\{1, \frac{\mathcal{L}(\beta_{q+1}|EO^{temp}, Link)}{\mathcal{L}(\beta_{q+1}|EO^q, Link)}\}. \tag{11}$$

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

$$EO^{q+1} = \begin{cases} EO^{temp} & \text{with probability } r \\ EO^q & \text{with probability } 1-r. \end{cases} \tag{12}$$

C Data Filtering and Variable Constructing

We first discuss how we identify the five types of relationships among airline carriers: Self-service, Subsidiary, Subcontracting, Code-sharing, and Other-Type. DB1B Coupon Data directly provides information about ticketing carrier and operating carrier so we can distinguish self-service, code-sharing and relationships between major carriers and regional carriers.[31] Next, we identify relationships between major carriers 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

[31]The same ticketing and operating carrier implies self-service. If the ticketing carrier and the operating carriers are different network carriers, the observation indicates a code-sharing relationship. If the ticketing carrier is a major carrier and the operating carrier is a regional carrier, it represents one of the relationships between major carriers and regional carriers.

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.[32]

Following the literature, we only keep the largest 300 airports in terms of passenger numbers in the lower 48 U.S. states[33]. 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. After aggregate the data into route-quarter-ticketing carrier-operating carrier level, we drop the observation if it has less than 20 passengers. Since we focus on the subcontracting relationships between major carriers and regional carriers, we do not consider directly the behaviors of 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 construct our variables according to Table A2. In order to construct some route level covariates, we also use information regarding population, income and employment in the metropolitan and micropolitan statistical areas provided by Bureau of Economic Analysis. In addition, National Oceanic and Atmospheric Administration provides the average level of precipitation and snowfall across years.

[32]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 formed 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 frequent changes within a short time, we consider this as a reasonable extrapolation.

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

Figure A1: Parameter Posterior Distributions: The Effect on the Probability of Major Carriers' Route Entry in Subcontracting Services with a Regional Carrier

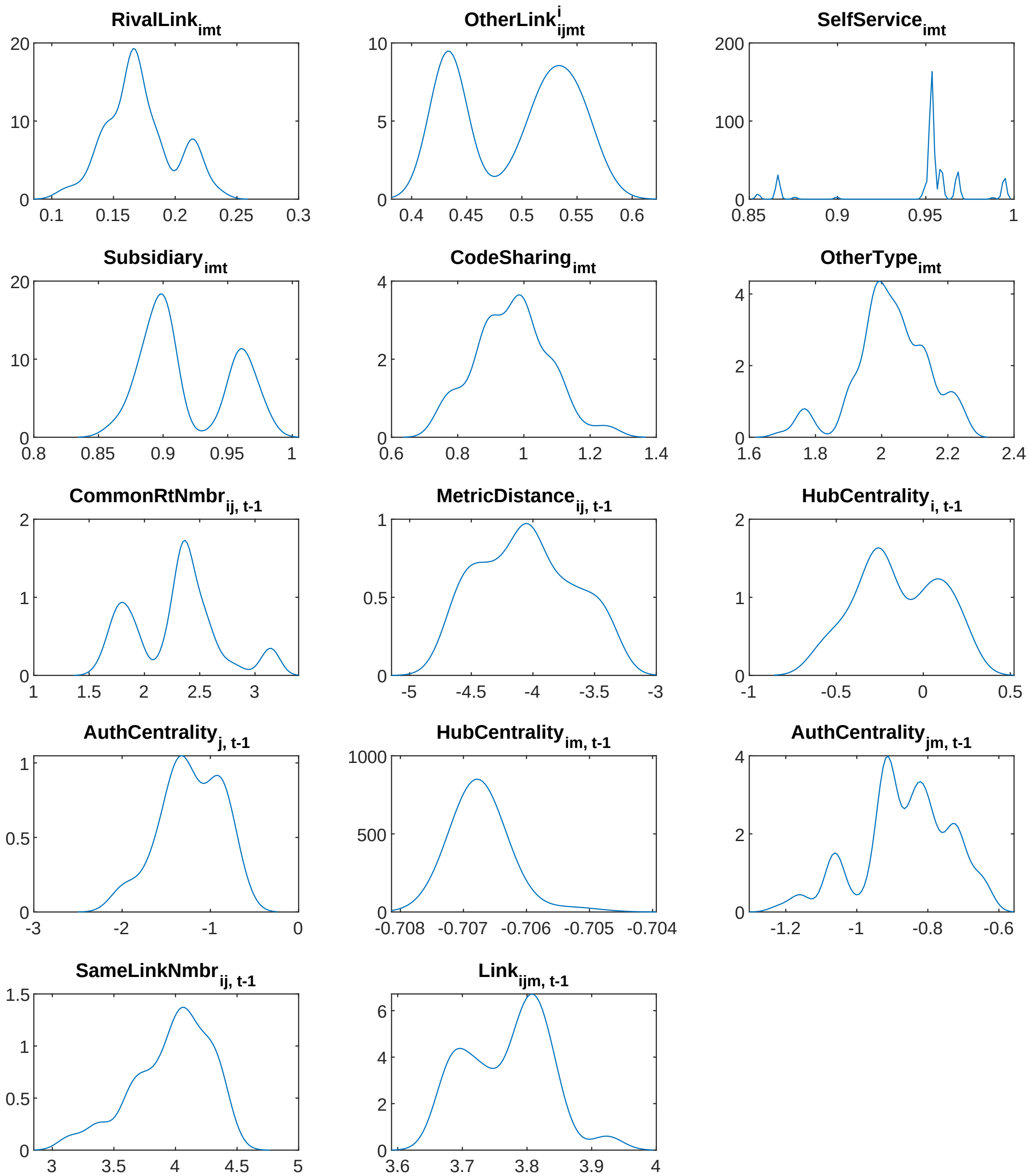


Figure A2: Parameter Posterior Distributions: The Effect on the Probability of Regional Carriers' Link Formation with All Potential Major Carriers

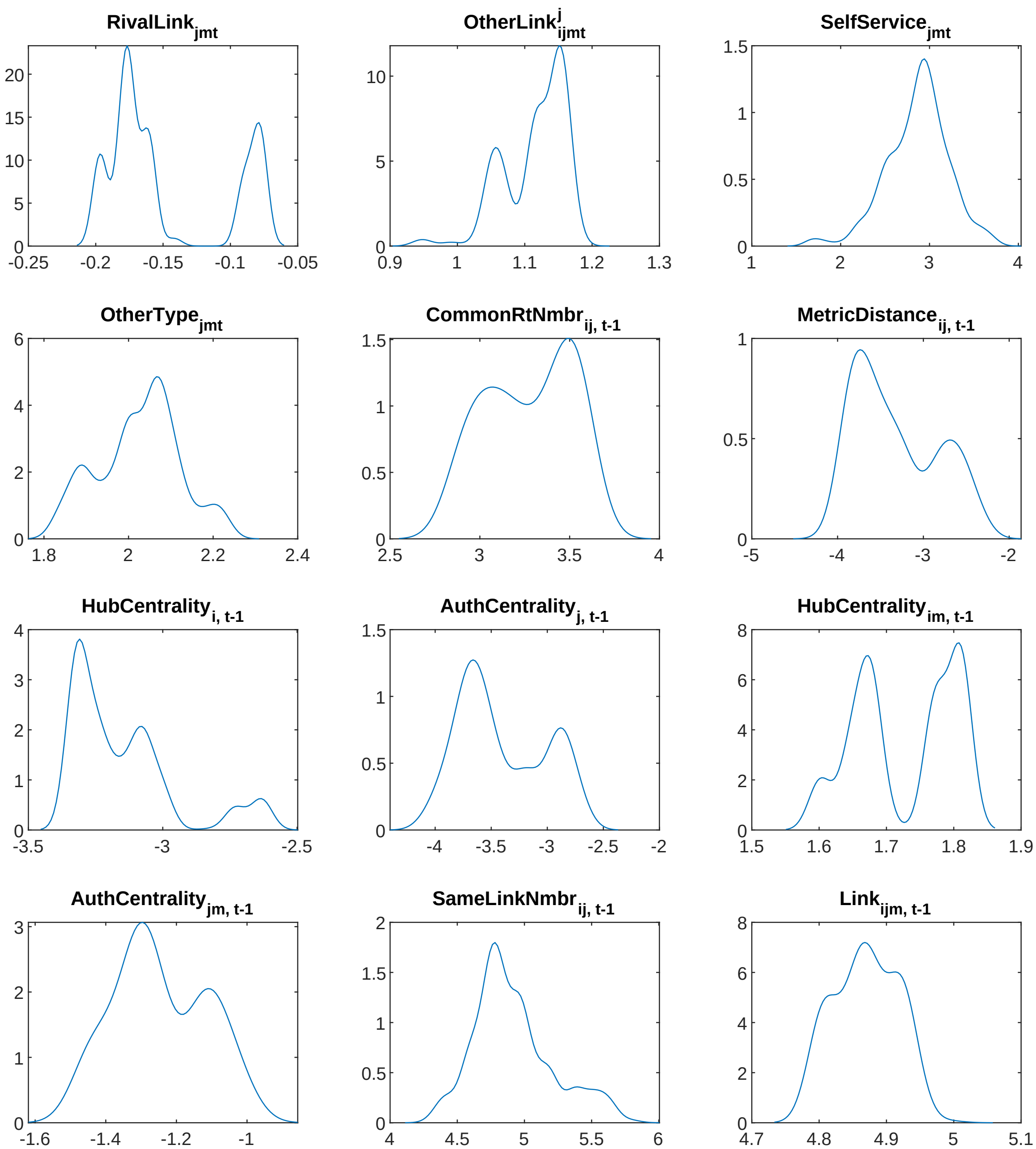


Figure A3: Parameter Posterior Distributions: The Effect on the Probability of Route-Serving Major Carriers' Link Formation

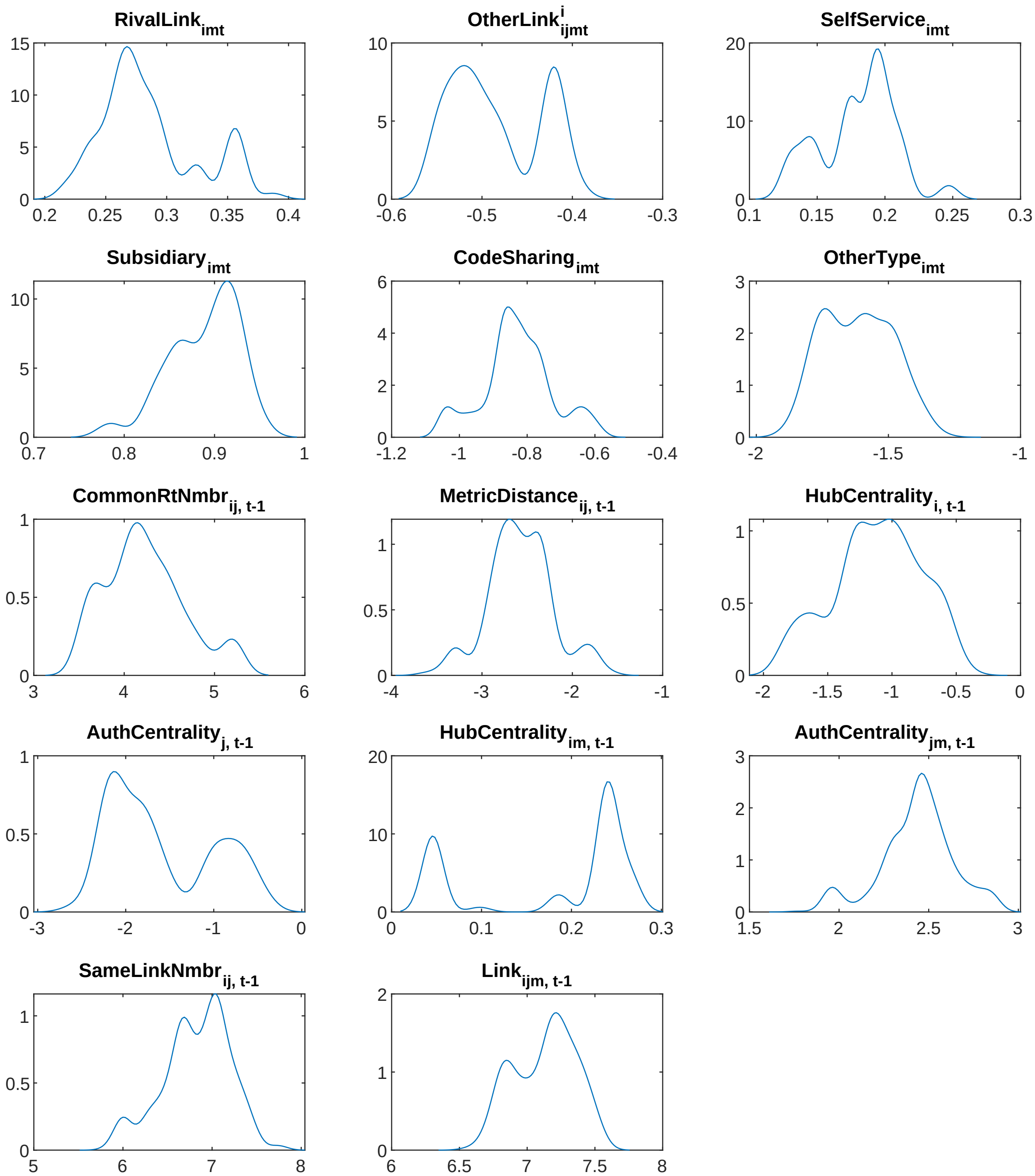


Figure A4: Parameter Posterior Distributions: The Effect on the Probability of Regional Carriers' Link Formation with Route-Serving Major Carriers

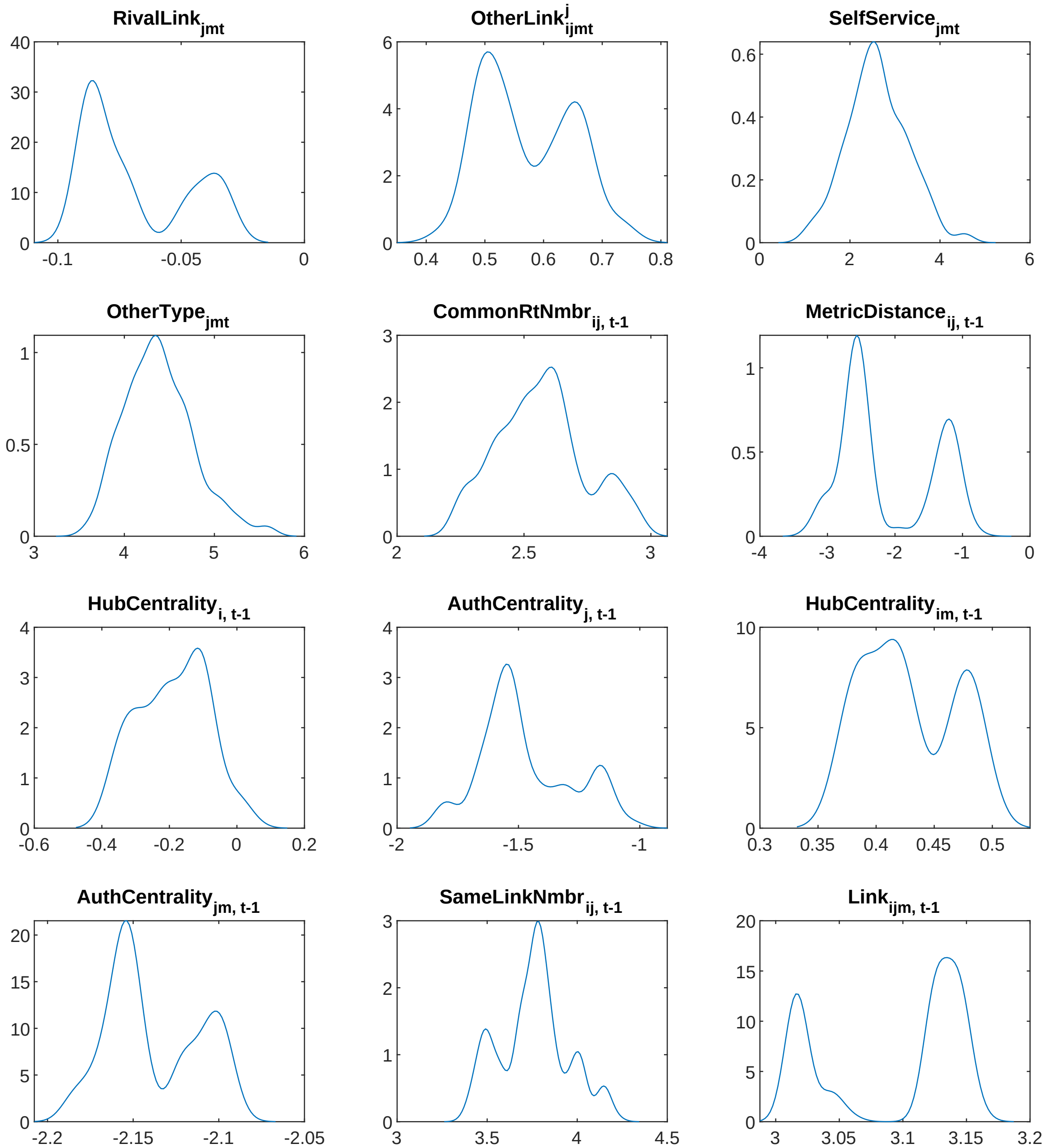


Table A1: A Possible Event Order at Period t

Event 1	Major 1 sub. Regional 1	Event 15	Major 2: Subsidiary
Event 2	Major 1 sub. Regional 2	Event 16	Major 2: Code-Sharing
Event 3	Major 1 sub. Regional 3	Event 17	Major 2: Other-Type
Event 4	Major 2 sub. Regional 1	Event 18	Major 3: Self-Service
Event 5	Major 2 sub. Regional 2	Event 19	Major 3: Subsidiary
Event 6	Major 2 sub. Regional 3	Event 20	Major 3: Code-Sharing
Event 7	Major 3 sub. Regional 1	Event 21	Major 3: Other-Type
Event 8	Major 3 sub. Regional 2	Event 22	Regional 1: Self-Service
Event 9	Major 3 sub. Regional 3	Event 23	Regional 1: Other-Type
Event 10	Major 1: Self-Service	Event 24	Regional 2: Self-Service
Event 11	Major 1: Subsidiary	Event 25	Regional 2: Other-Type
Event 12	Major 1: Code-Sharing	Event 26	Regional 3: Self-Service
Event 13	Major 1: Other-Type	Event 27	Regional 3: Other-Type
Event 14	Major 2: Self-Service	Event 28	Low-Cost Carriers: Entry

Notes: The table shows a possible event order in the case of 3 major and 3 regional carriers in period t. In each event, carriers make their corresponding decisions for all their possible routes.

Table A2: Variables

Variable	Explanation
$TempLinkVar_t$, variables generated from transition networks	
$RivalLink_{imt}$/ $RivalLink_{jmt}$	A dummy variable indicating whether the rivals of Major Carrier i/ Regional Carrier j has subcontracting relationships (links) with other carriers on route m at period t when the carrier is making subcontracting decision.
$OtherLink^i_{ijmt}$/ $OtherLink^j_{ijmt}$	A dumy variable indicating whether Major Carrier i/ Regional Carrier j has subcontracting relationships with other carriers rather than Regional Carrier j/ Major Carrier i on route m at period t when i and j are making the subcontracting decisions.
$SelfService_{imt}$	A dummy variable indicating whether Major Carrier i flies its own flights (serves itself) on route m at period t when it is making the subcontracting decisions.
$SelfService_{jmt}$	A dummy variable indicating whether Regional Carrier j schedules its own flights and sells its own tickets (serves itself) on route m at period t when it is making the subcontracting decisions.
$Subsidiary_{imt}$	A dummy variable indicating whether Major Carrier i uses its wholly owned subsidiaries on route m at period t when it is making the subcontracting decisions.
$CodeSharing_{imt}$	A dummy variable indicating whether Major carrier i codeshares with other carriers on route m at period t when it is making the subcontracting decisions.
$OtherType_{imt}$/ $OtherType_{jmt}$	A dummy variable indicating whether Major Carrier i/ Regional Carrier j has "other-type" of relationships on route m at period t when it is making the subcontracting decisions.

Notes: The table explains the variables included in the estimations.

Table A2: Variables (Continued)

Variable	Explanation
	$LinkVar_{t-1}$, variables generated from networks in the last period
$HubCentrality_{i,t-1}$/ $HubCentrality_{im,t-1}$	Hub Centrality: a centrality measurement in $[0,1]$, capturing the relative importance of Major Carrier i compared to other major carriers. It not only captures how many carriers Major Carrier i connects to, but also considers the importance of those carriers being connected to. It is calcualted at both carrier and route-carrier level.
$AuthCentrality_{j,t-1}$/ $AuthCentrality_{jm,t-1}$	Authority Centrality: a centrality measurement in $[0,1]$, capturing the relative importance of Regional Carrier j compared to other regional carriers. It not only captures how many carriers Regional Carrier j connects to, but also considers the importance of those carriers being connected to. It is calcualted at both carrier and route-carrier level.
$SameLinkNmbr_{ij,t-1}$	The number of the same links Major Carrier i and Regional Carrier j form at period $t-1$.
$Link_{ijm,t-1}$	A dummy indicating whether Major Carrier i and Regional Carrier j forms a link on route m at period $t-1$.

Notes: The table explains the variables included in the estimations.

Table A2: Variables (Continued)

Variable	Explanation
Homophily, the similarity between two carriers	
$CommonRtNmbr_{ij,t-1}$	The number of common routes on which Major Carrier i and Regional Carrier j serve at period $t-1$.
$MetricDistance_{ij,t-1}$	The metric distance between the two vectors of Major Carrier i's and Regional Carrier j's passenger shares across routes at period $t-1$. The smaller it is, the more similar these two carriers are. $MetricDistance_{ij,t-1} = \sqrt{\sum_{m\in\{1,\ldots,M\}}(\frac{passenger_{im,t-1}}{passenger_{i,t-1}} - \frac{passenger_{jm,t-1}}{passenger_{j,t-1}})^2}$
CarrierChar, carrier characteristics	
$RouteNmbr_{i,t-1}$/ $RouteNmbr_{j,t-1}$	The number of routes on which Major Carrier i/ Regional Carrier j serves at period $t-1$.
$PassengerNmbr_{i,t-1}$/ $PassengerNmbr_{j,t-1}$	The number of passengers Major Carrier i/ Regional Carrier j serves at period $t-1$.
$PassengerNmbr_{im,t-1}$/ $PassengerNmbr_{jm,t-1}$	The number of passengers Major Carrier i/ Regional Carrier j serves on route m at period $t-1$.
$MarketShare_{im,t-1}$	The percentage of tickets sold by Major Carrier i out of all tickets on route m at period $t-1$.
$MarketShare_{jm,t-1}$	The percentage of passengers delivered by Regional Carrier j out of all passengers on route m at period $t-1$.

Notes: The table explains the variables included in the estimations.

Table A2: Variables (Continued)

Variable	Explanation
	$RouteChar$, route characteristics
$RouteDistance_m$	Route distance.
$Precipitation_m$	The maximum of the average annual precipitation between 1981 and 2010 at the two airports of route m.
$SnowFall_m$	The maximum of the average annual snow fall between 1981 and 2010 at the two airports of route m.
$CarrierNmbr_{m,t-1}$	The number of ticketing carriers on route m at period $t-1$.
$TopCarrierMktSh_{m,t-1}$	The percentage of the tickets sold by the largest ticketing carrier out of all tickets sold on route m at period $t-1$.
LCC_{mt}	A dummy variable indicating whether there is a low-cost ticketing carrier on route m at period t.
$log(gmean(pop))_{mt}$	The logarithm of the geometric mean of the populations around the two airports of route m at period t.
$Disparity_{mt}$	The ratio of the larger population and the smaller population around the two airports of route m at period t. It captures the relative size of the two airports' populations
$log(gemean(inc))_{mt}$	The logarithm of the geometric mean of the income per capita around the two airports of route m at period t.
$log(gemean(emp/pop))_{mt}$	The logarithm of the geometric mean of the employment population ratio around the two airports of route m at period t.

Notes: The table explains the variables included in the estimations.
We use $CarrierNmbr_{m,t-1}$ and $TopCarrierMktSh_{m,t-1}$ rather than Herfindahl-Hirschman Index to measure market competition levels because HHI cannot be defined on a route during a period when no carriers operate there.