# Estimating the Gains from Liberalizing Services Trade:
# The Case of Passenger Aviation[*]

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## Abstract:

Over a 22 year period the US signed 108 bilateral "Open Skies Agreements" that significantly liberalized international trade in passenger aviation services. We study how existing trade agreements distorted route structures, carrier entry and capacity, and how liberalization affected consumer welfare. We develop a novel two-stage game in which carriers first enter and decide on networks, then set capacity and a pricing schedule prior to the realization of uncertain demand. The model allows for three empirically relevant features of airline markets: carriers have unused capacity; prices vary across carriers due to quality; and prices for otherwise identical seats rise as planes near capacity and are sold only to highest valuation passengers. We further show that even complex network environments can be described in terms of average pricing functions that provide sufficient statistics for consumer welfare, and map closely into empirical objects. In this environment deregulation generates multiple gains for consumers: lowering costs, increasing flight quality, reallocating capacity, and increasing entry.

We evaluate the model using difference-in-difference regressions applied to a 16 year panel of detailed data on route structure, capacity, and ticket price, quantity, and quality. Liberalizing countries see expansions in route offerings and reallocations of carrier capacity, consistent with mechanisms highlighted in the model. Consumers enjoy lower prices, more direct flights, and large increases in passenger quantities conditional on prices and direct measures of quality. Consistent with the model, these effects are not uniform across cities. Quality adjusted prices fall by 8.7 percent on routes that were the least constrained prior to regulation, and 23 percent on the most constrained routes.

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## 1. Introduction

Services represent a large (20 percent) and growing share of world trade, but the exact reasons for that growth are not immediately clear. Growth in services trade may simply reflect the rising share of services in employment and output worldwide, or be due to trade facilitating improvements in information technology and telecommunications.[1] It may also be that a sustained focus on liberalizing services trade through the WTO General Agreement on Trade in Services (GATS) and through bilateral agreements have succeeded in eroding regulatory barriers to entry.[2]

While the literature features many papers on the effects of merchandise trade liberalization, careful empirical work on services trade liberalization is scarce.[3] The difference in research emphasis is likely due to the paucity of detailed data on international service transactions and to the difficulty in characterizing liberalization episodes. Feenstra et al. (2010) note that "value data for imports and exports of services are too aggregated and their valuation questionable, while price data are almost non-existent". Existing regulation of services trade often takes the form of restrictions on firm entry or complex rules governing the manner in which services are provided and so it can be challenging to describe precisely what liberalization accomplishes. This stands in stark contrast to manufacturing trade, where tariffs provide an exact measure of the price wedges imposed by policy intervention, and liberalization efforts correspond to well-defined reductions in these wedges.

This paper focuses on an internationally traded service sector, passenger aviation, where data limitations can be overcome and where it is possible to describe and carefully model the way in which regulations distort the provision of services. International passenger aviation is an important service, both in size ($190 billion of trade for the US and EU in 2010) and as an input into other international activities that require or may be facilitated by international movement of

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[1] See Freund and Weinhold (2002), Ariu and Mion (2011).

[2] See Hoekman et al. (2007) for a discussion on the state of services trade negotiations. Francois and Hoekman (2010) broadly survey the literature on services trade.

[3] An exception is Fink et al. (2003) who investigate the impact of telecommunication reforms on output and productivity in a panel of developing countries. Other papers, such as Arnold et al. (2011), examine services liberalization episodes but focus on the effects on downstream firms.

persons, including: FDI, international knowledge flows, exports of complex manufactures, and flows of other traded services.[4]

Critically, and unlike many other forms of services trade, the unit of output and its price is well defined. We draw on two datasets that contain carrier-specific data on the quantity of passengers and ticket prices for every city pair for international flights originating or terminating in the US from 1993-2008. Figure 1 displays passenger traffic and ticket prices in our data between 1993 and 2008. In this period we see a doubling of US international passenger traffic, and a 20-30 percent decline in ticket prices. What caused these changes?

One possibility is liberalization, which we discuss in greater depth in Section 2. Between 1993 and 2008, the US signed 87 bilateral "Open Skies Agreements" (OSA) that removed barriers to trade in passenger aviation. While OSA's altered aviation regulations in multiple ways, we focus on several aspects that appear particularly relevant. Existing Air Service Agreements restricted the set of "international gateway" cities into which carriers could fly, imposed additional constraints on the number and capacity of carriers operating on these routes, and prevented foreign competition entirely in other cities. OSAs eliminated these restrictions, setting the stage for potentially profound shifts in competition.[5]

In Section 3 we model these restrictions formally using a model of capacity constrained price competition with random demand shocks. Carriers decide whether to enter a market, then choose a capacity, and set prices before realizing the state of demand. We show the existence and uniqueness of a symmetric pure strategy equilibrium in which carriers ration tickets to set marginal revenue equal across demand states. The pricing function allows ticket prices to rise sharply as carriers near the capacity constraint of the plane with the last tickets purchased by the highest valuation consumers. Uncertain demand yields ex-post realizations that match two key properties of this market: as appendix Figure 1 shows, otherwise identical seats sell for different prices on different days, and capacity often goes unutilized.

We further show that the pricing functions of each carrier can be aggregated into an analytically tractable average price function for the market. This function describes average market prices prevailing in each period as a function of cost and demand parameters, the number of competitors, and the realization of the demand shock. Complex changes in the regulatory

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[4] See Cristea 2011, Poole, 2014 for effects on exports, Hovhannisyan and Keller 2011 for knowledge flows.

[5] OSAs also allowed for cooperative agreements including codeshares and alliances between domestic and foreign carriers, an issue highlighted by several previous authors, but one that we do not address here.

environment can be summarized through changes in the average price function because it is a sufficient statistic for consumer welfare (both ex-ante and ex-post), and because it provides a tight match to the empirical objects employed in our estimation.

We then embed this model in a stylized hub-and-spoke network game to capture the key features of the changing regulatory environment. In the Pre-OSA game, direct international service is only allowed between gateway cities, subject to a policy-imposed aggregate capacity constraint. Non-gateway "hub" cities can only be reached by indirect flights that first route through the gateway, and foreign carriers are excluded from these cities entirely.[6] Gateway restrictions impose three costs on consumers flying out of hubs: marginal cost are higher for indirect flights; consumers prefer direct flights and so indirect routing is equivalent to lowering service quality; and the restriction on foreign entry lowers competition. Consumers flying out of gateways suffer primarily from aggregate capacity restrictions that are worsened by forcing all passengers to route through gateways.

The model highlights several changes in market structure that result from liberalization. One, the number of cities with direct international connections increases and there is net entry of carriers on these routes, as foreign carriers can now fly directly to domestic hubs. Two, there is net exit of carriers flying through gateways, as domestic carriers opt to provide lower cost and higher quality direct service rather than providing indirect service through gateways. Three, relaxing aggregate capacity restrictions results in carriers increasing the aggregate capacity offered to the market, but lifting route restrictions reallocates that capacity away from pre-OSA gateways and toward other cities. These changes lead to unambiguous welfare gains as average prices drop for all consumers. However, the distribution of gains is uneven, as consumers outside of gateway cities enjoy quality gains from newly available direct flights as well as intensified competition on their routes.

The strength of the channels highlighted in the model and the magnitudes of the associated gains depend on the underlying parameters of the model. We turn next to empirics, describing our data in Section 4, and our econometric exercises in Section 5.

Because OSAs come into force discretely and sequentially, we can test for the effects of liberalization using difference-in-difference strategies. That is, we measure pre/post agreement

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[6] Cabotage rules, in force before and after OSAs, prevent foreign carriers from offering service between any two domestic cities. Pre-OSA, this excludes foreign carriers from reaching any gateway city. Post-OSA, foreign carriers can reach any city if they are willing to offer a direct flight.

changes in key variables (quantities, prices, capacity, route offerings) for a given country-pair or city-pair in comparison to pairs that have not yet liberalized. This allows us to control for changes in technology, input cost shocks, and exogenous changes in aviation demand to see whether liberalizing countries experience differential growth in variables. We can also look at the distribution of effects across city-pair markets to see if the core predictions of the model (different effects for gateway and non-gateway cities) can be found in the data.

We find evidence for significant changes in market structure after liberalization. Five or more years after the signing of an Open Skies Agreement, outbound air traffic is 17 percent higher in liberalized markets compared to still-regulated markets. The introduction of new non-stop routes to the liberalized foreign country explains 38 percent of this increase. Capacity rises 16 percent in liberalized markets relative to still-regulated markets, but the share of pre-OSA gateways in that capacity falls by 13 percent. All this is consistent with the view that pre-OSA gateway restrictions significantly reduced the desired route offerings of carriers, and both constrained and misallocated market capacity.

We turn next to estimation focused on isolating the mechanisms through which passenger traffic grew and in calculating consumer welfare changes associated with liberalization. Recall that the model can be described in terms of an average pricing function and equilibrium in a given period is given by the intersection of that average price curve with the (ex-post) demand curve. We can then characterize OSA-related changes in the environment into changes in average prices (moves along the demand curve), and changes in quality (shifts of the demand curve conditional on average prices). We can also identify and estimate an explicit measure of quality highlighted by the model, consumer's valuation of direct routing and changes in direct routing associated with OSAs.

We begin by estimating a series of partial derivatives, the direct effect of Open Skies Agreements on model variables. OSAs lead to a 2-4 percent drop in average air fares (controlling for trip characteristics). Prices are increasing in the number of segments, consistent with the model, and decreasing in (instrumented) passengers flown, consistent with economies of route density. The quantity of passengers flown grows 5 percent for pre-OSA gateways, 13 percent for small cities, and 17.5 percent for large hub cities capable of accepting international traffic. Consumers have a strong preference for direct flights, as doubling the number of flight segments has an equivalent demand effect of raising prices by 50 percent. Finally, OSAs generate a 4.5 percent reduction in the number of segments a passenger flies, but only on those cities where new direct connections occur. Passenger growth itself further reduces the number of segments flown.

To conclude the paper we combine these partial derivatives in a system of equations to get the total derivative of quantities and (quality-adjusted) prices with respect to OSAs. These show profound differences across cities depending on how much liberalization relaxed constraints facing the market. At the low end, liberalization increases quantities in pre-OSA gateways by 11.2 percent and lowers quality-adjusted prices by 8.7 percent. At the high end, liberalization increases quantities in cities with new direct connections by 30 percent and reduces quality-adjusted prices by 23 percent. A population weighted average across city types shows an aggregate decline in quality-adjusted prices of 14.4 percent.

## 2. Liberalization in International Air Transport Services and Related Literature.

Historically, the provision of international air services has been restricted by a complex web of regulations set on a bilateral basis.[7] A standard bilateral aviation agreement specifies a limited set of gateway points/airports that can be serviced by a restricted number of designated airlines (typically one or two carriers from each country). It also delineates the traffic rights granted to operating carriers, the capacity that can be supplied in each origin-destination city pair (with exact rules for sharing capacity), and the air fares to be charged on each route (with both countries' approval required before they can enter into effect). The prices agreed upon in the agreements frequently correspond to the fixed rates set by IATA during periodic air fare conferences (Doganis, 2006).[8]

As an example, the US-China Aviation Treaty (1980) restricts market access to two designated airlines per country, who can operate at most two round-trip flights per week each on routes connecting four U.S. points (New York, San Francisco, Los Angeles, Honolulu) to two Chinese cities (Shanghai, Beijing). Tokyo is the only third country location from where service

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[7] Efforts to set a multilateral regulatory framework go back to the Chicago Convention of 1944 when the International Civil Aviation Organization (ICAO) was established under the auspices of the UN. Apart from safety and technical rules, the Convention failed to reach common grounds. Bilateral agreements became the norm and passenger aviation remains outside the General Agreement on Trade in Services (GATS).

[8] IATA (International Air Transport Association) is the trade association of international airlines and one of its main tasks has been to fix prices on most international city-pair routes. Because IATA prices have to be agreed upon by all member airlines, they tend to be high enough to cover the costs of the least efficient carrier (Brueckner, 2003).

to either country's designated airports can be operated. Prices charged on all routes must be submitted to government authorities two months in advance for double approval. In addition, both countries can take ‘appropriate’ action to ensure that traffic is ‘reasonably balanced’ and mutually beneficial to all designated airlines.

In 1980, the United States passed the International Air Transportation Competition Act, which set the stage for opening international aviation markets. The liberalization efforts debuted with the renegotiation of many U.S. bilateral aviation agreements during the 1980s -- the “open markets” phase. The main focus of these treaty renewals was to relax market access and capacity restrictions by extending the number of designated airlines, the pre-defined points of service, and the flight frequencies. Some agreements also granted a partial relaxation of pricing provisions and beyond traffic rights (i.e., the right to fly passengers between two pre-approved foreign points on the way to/from a carrier's home country).

Between 1992 and 2013 the U.S. signed 108 bilateral Open Skies Agreements.[9] These agreements grant unlimited market access to any carrier for service between any two points in the signatory countries, full flexibility in setting prices, unconstrained capacity choice and flight frequencies, unlimited access to third country markets, and a commitment to approve inter-airline commercial agreements (e.g., code-share, strategic alliances). The timing and complete list of partner countries is reported in the Appendix Table A1. Apart from the completely liberalized intra-EU aviation market, US efforts to de-regulate international aviation in this period are atypical. While some air service agreements have been amended to relax regulatory provisions, overall the global aviation market remains fairly closed to trade.[10]

We next discuss the relevant theoretical and empirical literatures to which our paper contributes. Our model is closely related to work on hub-and-spoke network formation, and to models of Bertrand-Edgeworth price competition.

In the wake of US domestic airline de-regulation, many authors explored models of hub-and-spoke networks (e.g. Caves et al. (1984), Bailey et al (1985), Berry (1990), Brueckner and Spiller (1991), Brueckner et al. (1992), and Brueckner (2004).) These models usually focus on economies of route density and/or consumer preferences for direct flights and feature quantity

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[9] In this period, the US also signed a small number of partial liberalization agreements that served in several cases as a short transitory stage before signing a full OSA. We address these partial liberalization efforts in our empirical work. Of the 108 agreements, 87 occur within the time frame covered by our data..

[10] Piermartini and Rousova (2013) provide a comprehensive description of 2300 bilateral aviation treaties in force in 2005, concluding that 70 percent of bilateral agreements worldwide are still highly restrictive.

competition between firms who are free to choose network structure. Some authors, notably Hendricks et al. (1997, 1999) argue that price setting competition is a more appropriate environment for the airline industry, and focus on the difficulty of sustaining entry by multiple carriers when those carriers first establish networks and then compete in prices. Models such as Aquirregabiria and Ho (2010, 2012) feature differentiated products price-competition which allow multiple firms to compete in equilibrium because consumers differ in their taste for particular carriers.

Like several of these papers, our model features endogenous carrier entry and network formation, and allows carriers that are differentiated by type (direct, indirect flights) but are otherwise homogeneous within that type. Unlike the earlier work we sustain entry of multiple carriers of each type within a price setting game by assuming the existence of capacity constraints and uncertain demand. This has two additional merits. One, the model predicts empirically relevant facts: unused capacity and price dispersion both across firms and within a firm's own ticket offerings. Two, we can aggregate carrier ticket offerings into a tractable average price function that allows us to calculate welfare change after liberalization without estimating consumers' "brand loyalty" associated with entering/exiting carriers. This feature is especially important when considering the large number of routes we analyze, and the prevalence of multi-segment tickets offered by frequently changing combinations of multiple carriers.

Our modeling approach to capacity constrained price competition differs from standard Bertrand-Edgeworth competition (e.g. Kreps and Schienckman 1983, Osborne and Pitchik 1986, Allen and Helliwig 1986, Deneckere and Kovenock 1996) in several key ways. The Bertrand-Edgeworth model is typically formulated as a two-stage game in which firms first choose costly capacity, which is observable, and then firms compete via prices over known demand. Each firm has a constant per unit cost for production up to their respective capacity constraint, and each firm chooses a single price. Demand is efficiently rationed.[11] This can be thought of as a situation in which the consumers, each with unit demand for the good and heterogeneous reservation values, form an ordered queue that is decreasing with respect to the consumers' reservation values. Consumers buy from the lowest priced firm up to the point that the lowest price firm exhausts its capacity, then move on to the second lowest price firm and so on.

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[11] For an exception, see Davidson and Deneckere (1986) who use random rationing.

Our approach, which builds upon Prescott (1975), Eden (1990), Dana (1999), and Roberson, Cristea, and Hummels (2014), is a variation of the Bertrand-Edgeworth game. It features (i) intra-firm price dispersion, (ii) demand uncertainty, and (iii) random rationing, meaning that the consumer queue is random, not ordered. The first two distinctions, allowing each firm to sell tickets on a given route at multiple prices and uncertain demand, are clearly critical features of our airline industry application.[12]

Reynolds and Wilson (2000) and Lepore (2012)[13] also examine demand uncertainty in the Bertrand-Edgeworth model,[14] but the information structure there differs from our framework. Uncertain demand is modeled as a three-stage game: capacity choice, realization of the state of the demand, and then price competition. In our framework, demand is not realized until after the firms have chosen price-quantity schedules. Combining this information structure with intra-firm price dispersion and random rationing, we can summarize our game as follows. (i) carriers enter and set capacity; (ii) carriers simultaneously choose price-quantity schedules that specify the quantity of tickets to be sold at each price, (iii) heterogeneous consumers form a queue in which the order of reservation values is random and the length of the queue is random, (iv) consumers buy the lowest effective (quality-adjusted) price available tickets first, regardless of carriers. (v) ex-post, carriers have unsold tickets and face a capacity cost for holding them.

We also contribute to an empirical literature on airline deregulation. Liberalization of international aviation markets follows earlier de-regulation of US domestic markets. Studies of the U.S. domestic airline industry have shown that the inability of airlines to compete in prices caused them to invest in service enhancements (Borenstein and Rose, 1998). Limitations in route and capacity choices increased operating costs by restraining airlines' ability to optimize their network structure, size and traffic density (Baltagi et. al, 1995).

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[12] This is a simplification of the dynamic problem that carriers face in pricing tickets, but as shown by Escobari and Gan (2007) this simplification appears to fit well with the airline industry. For more on the airline’s dynamic pricing problem, see the surveys in McAfee and te Velde (2006) and Aviv et al. (2012). Recent examples of this dynamic pricing problem include Wright, et al. (2010), Deneckere and Peck (2012), Gallego and Hu (2014).

[13] Issues regarding demand uncertainty and production flexibility also feature prominently in the operations management literature. See for example Anupindi and Jiang (2008).

[14] Hu (2010) and Barla and Constantatos (2005) examine demand uncertainty in the context of hub-and-spoke network formation followed by quantity-setting competition. However, as in Reynolds and Wilson (2000) and Lepore (2012), the state of demand is realized prior to the final stage market competition subgame.

The liberalization of international passenger aviation services has been the focus of few recent studies.[15] Several studies employ the same datasets that we use, but very different sample cuts, to investigate the price effects of the inter-airline strategic alliances. (Brueckner and Whalen, 2000; Brueckner, 2003; Whalen, 2007; Bilotkach, 2007) These studies find that airline alliances reduce airfares, which is consistent with our price results as OSAs facilitate the formation of airline alliances.[16] We do not explicitly treat alliances but instead focus on features of agreements previously unexplored: route and capacity restrictions.

Piermartini and Rousova (2013) use a 2005 cross-section sample of worldwide country-pairs to estimate the impact of air services liberalization on the bilateral volume of air passenger flows. They estimate that OSAs increase traffic by 5 percent. Whalen (2007) uses similar data to ours but a substantially different sample. He finds that OSAs increase air fares and have no effect on passenger volumes once controlling for market competition and strategic alliances. Winston and Yan (2013) examine the impact of liberalization on fares and passengers for a subset of heavily trafficked international aviation routes, employing average fare data reported to IATA from 2005-2009. They employ a difference-in-difference at the country level for short run estimates, and employ cross-country variation for identification of long run estimates. They find very large (70 percent) reductions in average fares.

We differ from these earlier studies in three respects. One, we tie our estimates tightly to an explicit model of the mechanisms through which OSAs liberalize markets. We demonstrate the importance of these mechanisms in the data, and provide consumer welfare estimates that decompose the channels of response. Two, by using a comprehensive set of ticket data that includes connecting flights, we can demonstrate the differential impact of liberalization across different city types, as suggested by the model. This also allows us to explore a novel mechanism for liberalization: international connecting flights allow slow-to-sign countries to benefit from early liberalization of their neighbor's markets. Three, we have a longer panel which allows us to employ difference-in-difference estimates to identify within city-pair changes in price, quantity, and connection effects for a large number of agreements. This prevents heterogeneity across city-pairs from affecting our results. Related, the long panel allows us to address concerns about the endogeneity of liberalization. We restrict our samples to include only

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[15] Apart from passenger aviation, Micco and Serebrisky (2006) focus on air cargo, often carried in the holds of passenger aircraft. They estimate that from OSAs lowered air cargo freight rates in US imports by 9 percent.

[16] These results differ from ours substantially.

countries who sign OSAs so that we identify effects entirely from the timing of when an agreement is signed and not by comparing signers to non-signers.

## 3. Model

We study a three-stage model. In the first stage carriers enter and form international networks. In the second stage they set capacities and price-quantity schedules, after which uncertain demand is realized and tickets are purchased. We begin by describing the final stage price-capacity competition for an arbitrary international route $j$ with $n_D$ carriers providing direct service and $n_I$ carriers providing indirect service, where indirect service involves a single stop.[17] We then consider the network formation stage, and describe the equilibrium.

Our characterization of demand has three critical elements: a preference for directness, random rationing, and uncertain total demand. We assume that consumers prefer a direct flight to an indirect flight as long as $\alpha \in (0,1)$ times the price of the direct flight $p^D$ is less than or equal to the price of the indirect flight $p^I$, i.e. $\alpha p^D \leq p^I$. If $\alpha p^D > p^I$, then the indirect flight is preferred. It will be convenient to define the 'effective' price of a ticket, where for an indirect ticket with price $p^I$ the effective price is $\tilde{p} \equiv \frac{p^I}{\alpha}$ and for a direct ticket with price $p^D$ the effective price is $\tilde{p} \equiv p^D$.

We assume random (also known as proportional) rationing. This is consistent with heterogeneous consumers, each having unit demand and differing reservation prices, randomly queuing and purchasing the lowest effective price tickets first, subject to availability. In addition to the random ordering of the heterogeneous consumers in the queue, there is uncertainty regarding the number of consumers/length of the queue, and this uncertainty is not resolved until after carriers make their price-capacity choices.

Formally, the demand uncertainty takes the form $eD(\tilde{p})$ where $e$ is the random state of demand that is distributed according to the distribution function $F(e)$ which is continuously differentiable with $F'(e) > 0$ and $F''(e) \leq 0$ for $e \in [0,1]$ and $F(0) = 0$. We assume that demand is twice continuously differentiable, with $D'(\tilde{p}) < 0$ and $D(\tilde{p}) + \tilde{p}D'(\tilde{p}) < 0$ for all $\tilde{p} \in [0, \overline{p}]$, and that there exists a finite price $\overline{p} = \inf\{\tilde{p} | D(\tilde{p}) = 0\}$.

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[17] We ignore directional flow issues, impose the restriction that prices must be the same in each direction, and focus on the total quantity of round-trip travel demanded on a given route at a given effective price.

In the final stage price-capacity competition, carriers choose both a total capacity and a ticket price for each unit of available capacity. Allocating capacity to a route is costly, and we assume that this takes the form of a constant per-unit cost of $\lambda_D$ for a direct international flight. In the case of indirect flights, there is only one stop and the capacity cost of this connecting flight is $\lambda_C$. Thus, the total capacity cost for an indirect flight is $\lambda_D + \lambda_C$. To simplify the expressions, we assume that up to the capacity constraint, the per-unit cost of utilizing existing capacity is zero. Although it is straightforward to relax this assumption,[18] many of the costs of providing service on a route, such as fuel burn, flight crew, etc., depend primarily on the capacity choice.

In order to ensure the existence of an equilibrium with strictly positive capacity choices, we assume that $\overline{p} > \frac{\lambda_D+\lambda_c}{\alpha}$, where $\overline{p} = \inf\{\tilde{p} | D(\tilde{p}) = 0\}$. For the case of constant elasticity demand, as is used in the empirical specification, this assumption regarding the choke price corresponds to $D(\tilde{p}) = A(\tilde{p})^{-\epsilon} > 0$ for all $\tilde{p} \leq \bar{p}$ and $D(\tilde{p}) = 0$ otherwise.

The model of oligopoly price-capacity competition that we have described to this point extends Dana (1999) and Roberson, Cristea, Hummels (2014) by allowing firms to be heterogeneous with respect to directness (which implies heterogeneous costs) and for consumers to have a preference for directness. As Dana (1999) shows, uncertain demand combined with capacity costs implies that equilibrium involves non-degenerate price-quantity schedules, i.e. price dispersion, in which ticket prices are increasing in quantities sold.

To understand why, consider the impact that demand uncertainty has on the probability of selling a marginal ticket. The minimum price is set to guarantee that at least one ticket sells even in the lowest state of demand. After this point, the probability of making a sale decreases as the cumulative market quantity of ticket sales increases. Then, because carriers require higher marginal revenue to hold inventories of seats that sell with lower probability (and have the same capacity costs), it follows that each carrier has a strict incentive to sell tickets at a range of prices rather than at a single price.

Formally, let $q_i(\tilde{p})$ denote carrier $i$'s marginal quantity schedule, where $Q_i(\tilde{p}) = \int_{\underline{p}}^{\tilde{p}} q_i(r)dr$ denotes the total number of tickets that carrier $i$ prices at or below $\tilde{p}$. Note that carrier $i$'s total capacity costs are $Q_i(\overline{p})\lambda_D$ if carrier $i$ is a direct carrier and $Q_i(\overline{p})(\lambda_D + \lambda_C)$ if carrier $i$ is an indirect carrier.

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[18] See Roberson, Cristea, and Hummels (2014) for details.

To calculate carrier $i$'s expected revenue, note that $\tilde{p}$ is the highest effective price at which a ticket has sold, $e$ is the state of demand, and the market marginal quantity schedule is given by $q(\tilde{p}) = \sum_i q_i(\tilde{p})$. Then under random rationing, the residual demand –is calculated as

$$eD(\tilde{p})\left(1 - \int_{\underline{p}}^{\tilde{p}} \frac{q(r)}{eD(r)} dr\right) \tag{1}$$

If $\tilde{p} < \overline{p}$ is the highest effective price at which a ticket sells when $e$ is the state of demand and $q(\cdot)$ is the market marginal quantity schedule, then we know that residual demand is equal to zero at effective price $\tilde{p}$, that is

$$eD(\tilde{p})\left(1 - \int_{\underline{p}}^{\tilde{p}} \frac{q(r)}{eD(r)} dr\right) = 0 \tag{2}$$

and we can define the 'market clearing' demand shock $e(\tilde{p}, q)$ as

$$e(\tilde{p}, q) = \int_{\underline{p}}^{\tilde{p}} \frac{q(r)}{D(r)} dr \tag{3}$$

Because the demand shock $e$ is distributed according to $F(\cdot)$, the probability that a ticket priced at $\tilde{p}$ sells is $1 - F\big(e(\tilde{p}, q)\big)$. Thus, the profit functional for a carrier $i$ offering a direct flight on the route is:

$$\pi_i^D(q_i, q_{-i}) = \int_{\underline{p}}^{\overline{p}} [\, \Big(1 - F\big(e(p, q)\big)\Big) p - \lambda_D] q_i(p) dp \tag{4}$$

Similarly, the profit functional for a carrier $i$ offering an indirect flight on a given route is given by:

$$\pi_i^I(q_i, q_{-i}) = \int_{\underline{p}}^{\overline{p}} [\, \Big(1 - F\big(e(\tilde{p}, q)\big)\Big) \alpha\tilde{p} - \lambda_D - \lambda_C] q_i(\tilde{p}) d\tilde{p} \tag{5}$$

To solve for the equilibrium price-quantity schedules, we utilize the approach developed in Roberson, Cristea, and Hummels (2014). They formulate each carrier's profit maximization problem as an optimal control problem. In this environment the Hamiltonian is not concave and so the (Pontryagin) Maximum Principle only provides a necessary condition for optimization.

However, by using the Extension Principle it is possible to solve for the final-stage local equilibrium price-quantity schedules[19] which are given in Theorem 1 in the next section.

Given the form of final stage price-capacity competition, we now move back to the first-stage international-hub formation game. There are two countries, a domestic country $A$ and a foreign country $B$, and two types of cities: (i) gateway cities that may serve as an international hub both pre- and post-OSA and (ii) non-gateway cities that are a domestic hub for one or more domestic carriers and are large enough that they may profitably serve as an international hub post-OSA. Country $A$ is a large country with an arbitrary (but strictly positive) number of gateway cities and an arbitrary (but strictly positive) number of non-gateway cities, and for simplicity, we will assume that country $B$ has a single gateway city and no non-gateway cities.

In the first stage of the game, we take the domestic network as given and each country $A$ carrier chooses whether to form an international hub at each of its (exogenously given) country $A$ domestic hubs. Each country $B$ carrier chooses whether or not to form an international hub at the country $B$ gateway city. For simplicity, we assume that any country $A$ domestic hub may offer direct service to each of the other country $A$ cities.

In the baseline model we assume that the cost of forming and maintaining an international hub is proportional to a carrier's international capacity choice, which is made in the second stage of the game. Note that this assumption makes the first-stage international-hub formation game trivial, and in equilibrium each carrier will form an international hub in each city where it has the ability to do so. However, it is straightforward to extend the baseline model to account for economies of scale and economies of traffic density issues by assuming a fixed cost of international hub formation, as in Hendricks et al. (1997, 1999) and similar to Aquirregabiria and Ho (2010, 2012).

In the equilibrium of the international hub-formation stage with fixed entry costs, the number of carriers forming international hubs decreases relative to the no fixed cost case. Each carrier only forms an international hub in a city if (a) the total traffic, direct and indirect, through the hub covers the fixed cost of forming the hub and (b) there are no alternative international hub

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[19] For more on this approach see Krotov (1996). This method involves mapping the original problem into a well-behaved equivalent extension, solving the extended version of the problem, and then mapping the solution back into the original problem.

configurations, in which indirect flights may be rerouted through alternative hubs, that are more profitable. In the following section, we examine an extension that accounts for these issues.

### 3.1 Equilibrium

We focus on subgame perfect equilibria that are symmetric in that the final-stage local equilibrium price-quantity schedules are symmetric within carrier type and where all equilibrium price-quantity schedules have the same price support for a given route. That is, all direct carriers offer the same price-quantity schedule, which differs from the indirect carriers, all of whom offer the same price-quantity schedule.

We begin in the final stage price-quantity schedule setting subgame and then move back through the game tree to the international network formation stage. Our setup simplifies the network stage intwo ways. One, the assumption that capacity costs are linear allows us to solve for the equilibrium price-quantity schedule on each route in isolation. Two, it is clearly suboptimal for a carrier with the ability to offer direct service to offer both direct and indirect service for the same city pair.[20] To economize on notation we will henceforth use $p$ instead of $\tilde{p}$ to denote the effective price.

**Theorem 1** *There exists a symmetric final-stage local equilibrium that is described as follows.*

1. *If* $n_I > 0$*, then let* $y^*(p)$ *be defined as*

$$y^*(p) = \frac{\lambda_D + \lambda_C}{\bar{p}\alpha}\left[\frac{\bar{p}D(\bar{p})}{pD(p)}\right]^{\frac{n}{n-1}} - \frac{1}{n-1}\frac{\int_p^{\bar{p}}\left(n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right)D'(r)\left(rD(r)\right)^{\frac{1}{n-1}}dr}{\left(pD(p)\right)^{\frac{n}{n-1}}}$$

*The lower bound of the support of the prices,* $\underline{p}$*, solves* $y^*(\underline{p}) = 1$*. Each direct carrier's equilibrium price-quantity schedule is, for* $p \in [\underline{p}, \bar{p})$

$$q^D(p) = \left(\frac{D(p)}{n}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))} - \frac{n_I D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}\left(\frac{\lambda_D+\lambda_C}{\alpha} - \lambda_D\right)\right)$$

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[20] Such a carrier could increase its profits by shifting all indirect flights to direct flights which would decrease costs and increase the prices that consumers are willing to pay.

*and each direct carrier places a mass point at* $\bar{p}$ *of size*

$$\Delta^D(\bar{p}) = \frac{1}{n_D}\left(F^{-1}\left(1-\frac{\lambda_D}{\bar{p}}\right) - F^{-1}\left(1-\frac{\lambda_D+\lambda_C}{\bar{p}\alpha}\right)\right)$$

*For indirect carriers, the equilibrium price-quantity schedule is*

$$q^I(p) = q^D(p) + \frac{D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}\left(\frac{\lambda_D+\lambda_C}{\alpha} - \lambda_D\right)$$

2. *If* $n_I = 0$, *then let* $y^*(p)$ *be defined as*

$$y^*(p) = \frac{\lambda_D}{\bar{p}}\left[\frac{\bar{p}D(\bar{p})}{pD(p)}\right]^{\frac{n}{n-1}} - \frac{n}{n-1}\frac{\int_p^{\bar{p}}\lambda_D D'(r)\left(rD(r)\right)^{\frac{1}{n-1}}dr}{\left(pD(p)\right)^{\frac{n}{n-1}}}$$

*The lower bound of the support of the prices,* $\underline{p}$, *solves* $y^*(\underline{p}) = 1$. *Each direct carrier'' equilibrium price-quantity pairs is, for* $p \in [\underline{p}, \bar{p}]$

$$q^D(p) = \left(\frac{D(p)}{n}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))}\right)$$

The proof of Theorem 1 is given in Appendix 1A. In solving for the equilibrium price-quantity schedules $\{q_i(p)\}_i$ , the carriers' optimization problems depend critically on the the probability that a ticket with effective price $p$ sells, which is given by $1 - F\big(e(p,q)\big)$. This probability depends on the total market price-quantity schedule, $q(p) = \sum_i q_i(p)$, via the 'market-clearing' shock $e(p,q)$.

The $y^*(p)$ expression in Theorem 1 provides the probability $1 - F\big(e(p,q)\big)$ at the equilibrium total market price-quantity schedule, $q(p)$. Then given the equilibrium probability of making a sale as a function of the price $y^*(p)$, the equilibrium price-quantity schedules for the direct and indirect carriers may be written in terms of $y^*(p)$, where $\dot{y}^*(p)$ denotes the equation of motion for $y^*(p)$ as the effective price $p$ varies over the price support. Because $q(p)$ is the market marginal quantity schedule, the cumulative market quantity of tickets that are sold at or below an effective price of $p$ is given by $Q(p) = \int_{\underline{p}}^{p} q(r)dr$ .

Thus, the model may be summarized as follows, a demand shock $e$ determines the length of the randomly ordered queue of customers with unit demand and heterogeneous unit demands, the customers in the queue buy the lowest effectively priced tickets first and then continue moving up the carriers' price-quantity schedules until either the demand for or the supply of tickets is exhausted. If $p$ is the highest effective price at which a ticket sells then the total quantity of tickets that are sold in the market is $Q(p)$.

Note that as tickets sell at multiple prices the cumulative market quantity of tickets sold is determined by the maximum price in the market. However, in matching the theory with the empirics, it will be convenient to write the market quantity as a function of the average price instead of the maximum price. Towards that end, let $\rho(e,q)$ denote the maximum price at which a ticket sells – which we henceforth make a slight abuse of terminology and refer to as the 'market-clearing' price. This price is a function of both the random length of the queue, (i.e. the demand shock $e$), and the market price-quantity schedule, $q$, where $\rho(e,q)$ is implicitly defined by $e(\rho(e,q),q) = e$.

For a given $q$ and $e$, the total quantity of tickets that are sold is $\tilde{Q}(e) \equiv Q(\rho(e,q))$. If the total quantity of tickets sold is Q, then the average market price as a function of $Q$, denoted $p^{avg}(Q)$, solves $\tilde{Q}^{-1}(Q)D(p^{avg}(Q)) = Q$ which implies that

$$p^{avg}(Q) = D^{-1}\left(\frac{Q}{\tilde{Q}^{-1}(Q)}\right) \tag{6}$$

To fix ideas, consider the special case of CES demand that will be used in the empirical section. We parameterize the demand for international travel on a city pair at the effective price $p$ as

$$D(p) = Ap^{-\epsilon} \tag{7}$$

where $A$ corresponds to the population of potential international travelers on the given route, and $\epsilon$ denotes the constant elasticity of demand. For the sake of this example, we will also assume that the demand shocks are uniformly distributed on $[0,1]$. From Theorem 1 we have that $y^*(p)$ is, for $p < \overline{p}$, given by

$$y^*(p) = \frac{\lambda_D + \lambda_C}{\overline{p}\alpha}\left[\frac{\overline{p}^{-\varepsilon+1}}{p^{-\varepsilon+1}}\right]^{\frac{n}{n-1}} + \frac{\left(n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right)\varepsilon}{1-n\varepsilon}\left(\frac{\overline{p}^{\frac{1-\varepsilon}{n-1}-\varepsilon}}{p^{\frac{(1-\varepsilon)n}{n-1}}} - \frac{1}{p}\right) \tag{8}$$

Then, the equilibrium market price-quantity schedule is, for $p < \overline{p},\ q(p) = D(p)(-\dot{y}^*(p))$ or equivalently,

$$\begin{aligned} q(p) = & -Ap^{-\varepsilon}\left(\frac{n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)}{n-1}\left(\frac{-\varepsilon}{p^2}\right)\right) \\ & -Ap^{-\varepsilon}\left(\frac{n(1-\varepsilon)}{(n-1)p}\left[\frac{\lambda_D + \lambda_C}{\overline{p}\alpha}\left[\frac{\overline{p}^{-\varepsilon+1}}{p^{-\varepsilon+1}}\right]^{\frac{n}{n-1}} + \frac{\left(n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right)\varepsilon}{1-n\varepsilon}\left(\frac{\overline{p}^{\frac{1-\varepsilon}{n-1}-\varepsilon}}{p^{\frac{(1-\varepsilon)n}{n-1}}} - \frac{1}{p}\right)\right]\right) \end{aligned} \tag{9}$$

Given $q(p)$, it is straightforward to construct $Q(p)$ and $p^{avg}(Q)$. These are complex expressions, and so we graph a particular parameterization in Figure 2. Figure 2 provides the cumulative market quantity of tickets sold as function of the maximum price. For a particular demand shock $e$, we have a market clearing price $\rho(e, q)$ which determines the market quantity $\tilde{Q}(e)$. The market quantity $\tilde{Q}(e)$ can be used to find the average price, which is simply the single price at which the quantity demanded is equal to the total quantity of tickets sold.

Note that the average price curve is essentially the market supply curve for which the market price is the average price. That is for each demand shock $e$, the average price curve identifies that point on the demand curve for which the quantity demanded is equal to the total quantity sold. As we vary the demand shock, the average price curve traces out those points on the various demand curves where supply is equal to demand.

### 3.2 Open Skies Agreements

We now examine the effects of OSAs on price-capacity competition and international network formation. Note that post-OSA, each gateway and non-gateway hub may see the number of carriers, $n$, increase (entry effect) and some of the indirect carriers may now offer direct connections (composition effect).

**Corollary 1** *The pre-OSA final-stage local equilibrium price-quantity schedules at the non-gateway hubs are given by part 1 of Theorem 1 with* $n_I = n$. *The post-OSA final-stage local price-quantity schedules at the non-gateway hubs are given by part 1 of Theorem 1 with* $n_I = n - n_D$. *At the gateway hubs, the pre- and post-OSA final-stage local price-quantity schedules are given by part 2 of Theorem 1.*

From part 1 of Theorem 1, it is clear that, at the non-gateway hubs, the final-stage local equilibrium quantities are, post-OSA, higher for carriers with direct connections, $q^D(p) > q^I(p)$. For each realization of the demand shock, carriers with a direct connection receive a higher price, $p > \alpha p$, pay lower costs, $\lambda_D < \lambda_D + \lambda_C$, and sell more tickets. Thus, each carrier that is able, in the network formation stage, to shift from an indirect non-gateway hub connection to a direct connection on that route has a strict incentive to do so, and the foreign carrier has incentive to enter each non-gateway hub.

**Corollary 2** *In the network formation stage of the pre-OSA game each carrier makes each of its feasible connections. In the network formation stage of the post-OSA game each domestic carrier chooses a direct connection over an indirect connection when possible and forms all remaining feasible indirect connections. And, the foreign carrier forms a direct connection with each of the non-gateway hubs in the network formation stage of the post-OSA game.*

As mentioned above, in moving from pre-OSA to post-OSA, we may have two effects at non-gateway hubs. First, some of the indirect carriers may now offer direct connections (composition effect). Additionally, the foreign carrier may enter (entry effect), which further increases the number of carriers offering direct flights, $n_D$. The following proposition summarizes the composition and entry effects on average ticket price and average consumer surplus at non-gateway hubs, where average consumer surplus is the expectation of the consumer surplus at the average price,

$$\int_0^1 \int_{p^{avg}(\tilde{Q}(e))}^{\bar{p}} eD(p)\, dp\, F'(e) de$$

**Proposition 1.** *At each non-gateway hub,* for *each price $p < \bar{p}$ both the composistion effect and the entry effect result in lower residual demand, and as a result both effects lower the average (effective) ticket price and increase the average consumer surplus. Furthermore, the magnitude of both the composition and entry effects is increasing in the additional cost of providing indirect service, $\lambda_C$, and the preference for direct service over indirect service, 1-$\alpha$.*

The proof of Proposition 1 is contained in Appendix 1B. Figure 3 shows the composition and entry effects in the context of the CES demand example. Beginning with the leftmost average price function $p^{avg}(Q)$, the first shift denotes composition effect from holding the number of carriers constant but allowing some of the domestic carriers to shift from indirect to direct service. As stated in Proposition 1, the size of this composition effect shift is increasing in the cost savings generated by the new direct service and in the magnitude of the preference for direct service over indirect service. The second shift of the average price curve is due to the entry of new direct carriers, and the size of this shift is, similarly, increasing the size of the cost savings generated by the new direct service and in the magnitude of the preference for direct service over indirect service.

### 3.3 Extensions (incomplete)

We now examine two extensions of the baseline model. The first extension examines pre-OSA capacity constraints on international travel between gateway cities. The second extension examines the issue of fixed entry costs in international hub formation. In these extensions, we make two assumptions that simplify the problem and allow for a clear focus on the new issues, but that are not necessary in order to solve the extensions. First, we assume that there is a single gateway city in country $\boldsymbol{A}$. Second, all country $\boldsymbol{A}$ carriers have a domestic hub at the country $\boldsymbol{A}$ gateway. In the capacity constraint extension, these assumptions are useful in that they imply a level of symmetry, among country $\boldsymbol{A}$ carriers, within the network, that simplifies the expressions for the equilibrium price-quantity schedules. In the entry cost extension, these assumptions have no effect on the equilibrium price-quantity schedules, but rather allow for a particularly simple entry condition in the first-stage international-hub formation stage.

### 3.3.1 Capacity Constraints

For the pre-OSA capacity constraint extension we assume that each country $\boldsymbol{A}$ carrier faces the same capacity constraint, $\boldsymbol{Q^A}$, on the total capacity of direct and indirect travel through the country $\boldsymbol{A}$ gateway. Let $\boldsymbol{Q^B}$ denote the total capacity constraint for the country $\boldsymbol{B}$ carrier. In equilibrium, it is clear that each country $\boldsymbol{A}$ carrier offers indirect flights from each of the non-gateway hubs and direct service from the gateway hub, and that the country $\boldsymbol{B}$ carrier offers direct service between the gateways. Thus, each country $\boldsymbol{A}$ carrier's problem is:

$$\mathbf{max}_{\boldsymbol{q^A_{i,D}, q^A_{i,I}}} \boldsymbol{\pi^D_i\left(q^A_{i,D}, q_{-i}\right) + n_{ng}\pi^I_i\left(q^A_{i,I}, q_{-i,I}\right)} \tag{10}$$

subject to the constraint that $\int_{\underline{p}_g}^{\overline{p}_g} q^A_{i,D}(r)dr + n_{ng} \int_{\underline{p}_{ng}}^{\overline{p}_{ng}} q^A_{i,I}(r)dr \leq Q^A$ and let $\lambda^{A*}_D$ denote the multiplier on this capacity constraint. The country B carrier's problem is :

$$\mathbf{max}_{\boldsymbol{q^B_{i,D}}} \boldsymbol{\pi^D_i\left(q^B_{i,D}, q_{-i}\right)} \tag{11}$$

subject to the constraint that $\int_{\underline{p}_g}^{\overline{p}_g} q^B_{i,D}(r)dr \leq Q^B$ where $\lambda^{B*}_D$ denotes the multiplier on the capacity constraint.

Appendix 1C provides the characterization of the symmetric equilibrium. With capacity constraints, the equilibrium multipliers $\boldsymbol{\lambda^{A*}_D}$ and $\lambda^{B*}_D$ take the smallest weakly positive values such that the capacity constraints are satisfied. As the average price function is decreasing in these capacity costs, a binding capacity constraint results in lower quantities and higher average prices.

### 3.3.2 Entry Costs

As our interest is primarily on post-OSA entry on the non-gateway hubs, we will assume that $FC^G = 0$ and $FC^{NG} > 0$, and will focus on asymmetric pure-strategy equilibria in the international-hub formation stage, where Theorem 1 provides the resulting final-stage price-quantity schedules. For any arbitrary non-gateway hub, let $\hat{n}_D$ denote the total number of carriers that have the ability to provide direct international service to that non-gateway city. The number of direct carriers at this non-gateway hub is either $n_D = \hat{n}_D$ and for each domestic carrier with the ability to form an international hub,

$$FC^{NG} < \pi^D(q|n_D) - \pi^I(q|n_D - 1) \tag{12}$$

or $n_D$ is the largest $n_D < \hat{n}_D$ such that

$$\pi^D(q|n_D + 1) - \pi^I(q|n_D) < FC^{NG} < \pi^D(q|n_D) - \pi^I(q|n_D - 1) \tag{13}$$

For the case of CES demand, where the expected profit functions are linear with respect the population $A$ the entry conditions can be characterized by $n_D = \hat{n}_D$ if for each domestic carrier with the ability to form an international hub, $\frac{FC^{NG}}{A} < \hat{\pi}^D(q|n_D) - \hat{\pi}^I(q|n_D - 1)$ or $n_D$ is the largest $n_D < \hat{n}_D$ such that $\hat{\pi}^D(q|n_D + 1) - \hat{\pi}^I(q|n_D) < \frac{FC^{NG}}{A} < \hat{\pi}^D(q|n_D) - \hat{\pi}^I(q|n_D - 1)$ where the expected profits where population $A$ is normalized to one. It follows directly that the number of direct carriers is proportional to the relevant population on the route.

## 4. Data Sources and Description

We draw on two rich datasets that cover international travel to and from the United States at quarterly frequencies over the period 1993-2008. The *Databank 1B (DB1B) Origin and Destination Passenger Survey* represents a 10 percent sample of airline tickets drawn from airport-pair routes with at least one end-point in the U.S. Each airline ticket purchase recorded in the data contains information on the complete trip itinerary including airports, air carriers marketing the ticket and operating each flight segment, the total air fare, distance traveled split by flight segments, ticket class type, as well as other segment level flight characteristics. We focus on U.S. outbound economy-class tickets, and restrict attention to foreign countries with at least one city-pair route serviced continuously over the time period.

One limitation of the DB1B data is that the foreign carriers not part of immunity alliances are not required to file ticket sales information to the U.S. Department of Transportation.[21] However, this is less of an issue for U.S. outbound tickets as compared to inbound ones. Tickets whose first segment originates in the U.S. are more likely to be sold by U.S. carriers and therefore appear in the data. We employ some additional filters to prepare the data sample, which are described in the Data Appendix. The resulting sample includes 40,376 origin-destination airport pairs, with an average of 13 observations per pair. The summary statistics for the variables of interest are provided in the Appendix Table A3.

We augment the empirical analysis with an alternative dataset that offers complete coverage of all U.S. international passenger traffic. The *T100 International Segment* database provides information on capacity and air traffic volumes on all U.S. non-stop international flight segments (defined at airport-pair level), distinguished by the direction of travel, and operated by both domestic and foreign carriers. The data is collected at monthly frequencies and reports for each carrier-route pair the number of departures scheduled and operated, seats supplied, onboard passengers, segment distance and airborne time.[22] The disadvantage to the T-100 data is two-fold. They do not include pricing information, and they do not provide details on complete origin-destination itineraries, but rather report only the flight segments that cross the US border.

Accordingly, the T100 data are best for describing changes in total passengers exiting the US, the number of distinct exit points out of the US, and the capacity allocated to those exit points. This makes it ideal for evaluating model mechanisms related to route restrictions and capacity reallocation. The DB1B data are best suited for describing prices and routing structures, especially for indirect tickets, for true origin-destination city pairs. This makes it ideally suited for evaluating changes in consumer welfare.

Table 1 summarizes regional growth in passenger traffic on non-stop segments, and regional growth in the share of traffic covered by OSAs, during the sample period 1993-2008. Figure 1 shows the annual time series aggregated over regions. By any measure of industry

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[21] Immunity alliances represent strategic alliances between domestic and foreign airlines with granted antitrust immunity from the U.S. Department of Transportation. Immunity grants allow carriers to behave as if they were merged, cooperating in setting prices and capacity on all joint international route to and from the U.S.

[22] However, the T100 Segment data does not easily match to the true Origin and Destination Passenger data, since passengers with very different start and end point itineraries get lumped together in a single observation in the T100 Segment dataset if their cross-border flight segment is the same. Unlike goods, which feature a one-to-one relation between a product and its producer, international air travel often involves the service of more than one airline. This is why firm- and product-level air travel datasets are imperfectly compatible.

performance - passenger volumes, number of non-stop international routes or annual departures performed (unreported) - international air traffic has grown rapidly during this period of deregulation. By 2007, 59 percent of the total U.S. international air passenger traffic passed through a foreign gateway airport located in an Open Skies country.

## 5. Econometric Analysis

We examine how international passenger aviation changes in the wake of trade liberalization efforts, focusing on change along three dimensions. First, we use a difference in difference methodology to compare growth in passenger traffic pre/post liberalization to growth in the same period for non-liberalization countries. Second, we decompose aggregate changes into growth in traffic along "new" and existing routes, and also evaluate reallocations of carrier capacity across routes. The decompositions provide insight into key model mechanisms and the role of route restrictions in pre-OSA regulation. Third, we estimate the partial effects of liberalization on the price, quantity and quality (directness) of passenger aviation, and examine whether these effects are asymmetric across gateway and non-gateway cities, as predicted by the theory. Finally, we combine these estimates to calculate the total change in (quality-adjusted) prices after OSAs in order to assess the consumer welfare gains from air services liberalization.

### 5.1 Growth of Passengers and Routes: T100 Data

We begin by examining traffic growth using the T-100 International segment data. We observe passenger traffic for every carrier and every city-pair route. Total air passenger traffic between the United States and destination country *d* at time *t* is the sum of traffic across all non-stop origin-destination routes and carriers offering service. We will also distinguish between growth along existing routes (i.e., intensive margin) versus newly introduced routes (i.e., extensive margin).

We use two ways to decompose the total U.S. outbound traffic to country d, $Q_{dt}$, into an intensive and extensive margin. The simplest approach is to count the number of direct connection city-pair aviation routes offered at a given point in time, $N_{dt}$, and then determine the average passenger volume per route:

$$Q_{dt} = \sum_r Q_{rdt} = N_{dt} * \overline{Q_{dt}} \tag{14}$$

A drawback of this ‘simple count’ approach is that it treats all air services as having equal value weights in the total consumption of international travel. Alternatively, we can weight the importance of existing routes using information on (lagged) passengers in a manner similar to the “new variety” literature following Feenstra (1994). In this second calculation, we define the intensive margin for destination country *d* as the volume of air traffic on aviation routes that are available in both the current and a three-year lag reference period. We also define the extensive margin as being the passenger-share weighted count of aviation routes that are “new” relative to the reference period. The details on the construction of the passenger-weighted decomposition is relegated to the Econometric Methodology Appendix 2A.

We normalize the level of each variable obtained from the decomposition by its value in the base year to get an expression for the cumulative air traffic growth during our sample:

$$\Delta Q_{dt}^{93} = \Delta IM_{dt}^{93} * \Delta EM_{dt}^{93} \qquad \text{where} \qquad \Delta Z_{dt}^{93} = \prod_{t=1994}^{93} \frac{Z_{dt}}{Z_{dt-1}} \tag{15}$$

with $Z \in \{Q, IM, EM\}$. We set $Z^{93}_{d,93}$ to one.

To estimate the impact of liberalization on air passenger transport, we rely on the time series dimension of the T100 International Segment data. Our identification strategy compares the change in passenger volumes within a country pair before and after the introduction of the Open Skies Agreements with the corresponding value calculated for countries that maintain restrictive aviation policies (control group). In using this difference-in-difference estimation method we consider the following regression model:

$$ln\Delta Z_{dqt}^{93} = \beta_1 OSA + \beta_2 ln\Delta(\tfrac{Y}{L})_{dqt}^{93} + \beta_3 ln\Delta L_{dqt}^{93} + X\beta + \alpha_{dq} + \alpha_t + \varepsilon_{dqt} \tag{16}$$

where $d$, $q$ and $t$ index the country, quarter and year respectively, and $Z \in \{Q_{dqt}, IM_{dqt}, EM_{dqt}\}$ takes in turn each variable, expressed as cumulative growth. The variable of interest $OSA_{dqt}$ is an indicator variable that equals 1 for all the years when an Open Skies Agreement exists between the U.S. and country $d$. We also control for per capita income $Y/L$ , and population $L$ of destination country $d$. $X$ denotes a vector of additional control variables, including *Partial Liberalization* (an indicator for non-OSA countries with more relaxed air transport agreements), a *9/11* control variable, and its interaction with a Visa Waiver Program (*VWP*) indicator to capture any differential response to the tightened security post 9/11 (Neiman and Swagel, 2009)[23]. We also include selected region and country trend variables, and country-season (e.g. travel to Mexico is greater in the 4th quarter than in the 2nd and both are higher than any quarter of travel to Ghana) and year fixed effects. Since all our data involve US bilateral flows, the year effects eliminate any time-varying changes that are common to all routes, including changes in input prices or technology, or secular change in aviation demand.

### ***Endogeneity of Open Skies Agreements***

One complication in policy evaluation comes from the potential endogeneity between the change in policy and the outcome variable(s) of interest. In our case, a primary concern is that some omitted variable affects the scale or expected future growth of aviation traffic with country *d* and this omitted variable is correlated with the likelihood and/or timing of an Open Skies Agreement. Countries differ substantially in size and income, the quality of aviation infrastructure, the dependence on aviation for trade, migration, or tourism, and the strength or political connections of their domestic airlines. The US may be more likely to sign agreements, or sign them earlier, when the benefits of signing are greater and the political opposition to signing is less.

This problem is likely to be most severe in the cross-section, as there are a host of difficult to control for reasons why Germany and Ghana differ in the structure of their aviation markets and the returns to agreements. Many studies of services liberalization are limited to cross-section data, but we are able to we exploit our 16 year panel and employ country fixed effects to exploit only within country time series variation pre/post signing. (In regressions using DB1B data we employ even more stringent city-pair fixed effects.) Taking a step further, countries that sign agreements at some point may be fundamentally different than countries that do not sign agreements at any point. Here, we can exploit our long time series and the fact that 108 countries have signed OSAs spread over the 1992-2013 period. In most of our regressions we restrict our samples to only those countries that sign agreements at some point and exploit only differences in the timing of when agreements are signed. Note that our T100 and DB1b

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[23] Very few countries change Visa Waiver Program Status during our sample period, so including the VWP variable independently in the regression has no effect on the estimates.

data samples end in 2008, so there are 21 eventual signers of OSAs included in our sample for whom the OSA "treatment" will be outside the sample.

This leaves the endogeneity of timing itself. As an initial look at this problem, we inspect the timing of agreements provided in appendix Table A1. What we see is that there is no clear pattern to the timing of the agreements. After The Netherlands signs the first agreement in 1992, 8 OECD European countries sign in 1995. But the rest of Europe is spread throughout the sample, with one each in 1996, 1998, 1999, 2001, and then a final group in 2007. Many Latin American countries sign in 1997, and other signings occur over the next 8 years. Similar partners are found for East Asia, South Asia, Central Europe, and Africa. Table 1 has the percentage of its region that signs at each of three points in time, and again there is no clear pattern. By the end of the period, all of OECD Europe is in, but other regions all have a mix of signers and non-signers.

Appendix Table A2 examines the timing of signing and its correlates, including levels and growth rates of population, GDP, GDP per capita, exports, distance, and tariffs. None are statistically significant (though if we enter a "high income" indicator with no other controls it is marginally significant). We also explored characteristics of air traffic routes prior to signing agreements including the country's number of departures worldwide, carrier concentration on routes, and the restrictiveness of existing agreements, including whether they included restrictions on routes, carriers, price setting, or capacity restrictions. Of these, only the existence of capacity restrictions is correlated with early signing, and so we include the degree of partial liberalization as a control in the regressions.[24]

A final possibility is that there are changes in growth rates that happen to coincide with signing OSAs. To rule this out we interact the OSA dummy with a vector of time dummies corresponding to t-4 through t+5, where t is the date of signing. This enables us to see whether aviation traffic was already growing prior to the OSA signing or whether changes in growth rates correspond to the date agreements were signed. We return to this point in the results discussion below.

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[24] We have explored similar regressions in which the dependent variable is binary (sign/don't sign), a source of variation that is taken out of the regression when we use samples of only signatories. Nevertheless even sign/don't sign shows similar lack of correlation, with the exception of a weak positive correlation with per capita income, driven by OECD Europe. It appears that there is no obvious pattern to which countries sign agreements.

### ***Estimation Results***

Panel A of Table 2 reports the regression model in equation (16) estimated using the cumulative growth decomposition in equation (15). In Column 1 we see that countries who liberalize their international aviation markets experience a 7.1 percent increase in passenger traffic. The increase in aggregate volumes is explained in part by the net expansion of international aviation routes. Countries that sign OSAs see 10.5 percent faster growth in the number of routes, as measured by a simple count (Column 2). When using weighted counts (Column 4) liberalization increases the extensive margin of passenger growth by 3.9 percent. The difference in the weighted and un-weighted estimates indicates that new routes, on average, are opened in smaller cities with fewer passengers.

Liberalization also affects the cumulative passenger growth along routes previously offered, though the intensive margin effect is imprecisely estimated in both specifications. Given the log-additive property of the components of the air traffic decomposition, the coefficients on OSA in the total traffic regression will be equal to the coefficients from the extensive and intensive margin regressions, respectively. We can then say that the extensive margin accounts for (3.9/7.1)=55 percent of overall growth in the weighted regression, and (10.5/7.1)=148 percent of overall growth in the simple count regressions.

The simple OSA indicator specification assumes that there is a one-time level change in growth rates after signing. But aviation markets may take time to adjust to new policies, as carriers experiment with new markets and route networks, and consumers learn of new opportunities. To account for this we interact the OSA indicator with a vector of time dummies corresponding to t-1 through t+5, where t is the date of signing. This enables us to see whether increases in traffic growth accumulate over time.

Panel B of Table 2 reports the regression results. Two points emerge from these estimates. First, for all three dependent variables, the impact of air services liberalization increases monotonically over time. Focusing on the long run effects, we find that the cumulative growth of air passenger travel after five or more years since an Open Skies Agreement is 17.2 percent. Using passenger weighted measures of the extensive margin, columns (4) and (5), new routes accounts for 38 percent of the growth while the remaining 62 percent is explained by passenger growth along previously offered routes.

This approach also allows us to address a final concern regarding endogeneity of OSAs, that some excluded variable induces a change in growth rates, and this change in growth rates induces the country to sign. We repeat the estimates, but interacting time dummies from (t-4) to (t+5) to explore whether the change in growth occurred prior to signing. We plot the coefficients in Figure 4. Each plot makes clear that in the years prior to signing of the Open Skies Agreements there are no statistically significant differences in the growth of air transport between signers and non-signers, but that growth after signing is significant. For this to be driven by some factor other than the OSA it would have to be the case that the omitted variable changed in the same year that the OSA was signed. Further, since we have 87 different signings over a 15-year period, this omitted variable would have to coincidentally change at the same time as the OSA signing in every market, but in a different year for every country. This seems unlikely.

### 5.2 Entry and Exit: Carriers and Capacity

Our model suggests that Open Skies Agreements lead to two distinct kinds of entry / exit patterns. Relaxing route and foreign carrier restrictions leads to an expansion of routes, as clearly shown in the last section, as well as an expansion of capacity and increased competition outside of gateways. Does this expansion represent entirely new activity or is it a reallocation of capacity and competition away from pre-OSA gateways to the new hub routes? In our model extension with fixed entry costs (section 3.3), expanding the set of routes leads to exit from gateways after signing. Domestic carriers who, pre-OSA, were forced to offer service through gateways to attract international passengers into their hub routes can, post-OSA, offer direct service and forego the fixed cost of establishing a gateway presence.

We examine these conjectures in the last two columns of Table 2 and in Figure 5. In Table 2 we measure capacity (total seats offered between the US and country *d*), and the share of pre-OSA gateways in total seats. (Multiplying these measures together gives the number of seats offered on pre-OSA gateways; adding the coefficients gives the change in those seats after OSAs). In panel A we see that the average effect is a 5.4 percent rise in total capacity post-OSA and a 6.4 percent reduction in the share of pre-OSA gateways. This implies that not only did capacity outside the gateways rise, but capacity on the gateways fell as it was no longer necessary to accommodate passengers transiting the gateway on the way to another destination within the US.

In Panel B we interact the OSA variable with a vector of time dummies to see transition and long run effects. Five years after signing, post-OSA capacity rises by 16 percent, and the share of pre-OSA gateways falls by 13 percent. If we compare the share of capacity on the gateways one year prior to the OSA to five years after, we see a decline on of 19 percent (relative to the country and time fixed effects). Relaxing restrictions both increases aggregate capacity and shifts it significantly away from the gateways.

In Figure 5 we examine whether this route reallocation also changed the number of competitors on different routes. We begin by counting the number of carriers competing on each origin-destination route at a point in time, and organizing these into 4 equal size bins from fewest competitors (at left) to most competitors. We then examine the change in the number of carriers over the subsequent two years. This is represented by the vertical bars in Figure 5, and distinguish between routes that experience a change in the aviation policy during the two year span (i.e., a switch in the OSA indicator from 0 to 1), versus routes that do not experience such a change.

Routes with the fewest carriers see the most entry, and routes with the most carriers see exits. More importantly for our purposes, these patterns of entry and exit are more accentuated on routes that experience liberalization of air services. For the routes with the fewest carriers, the average rate of entry is 22 percent higher for markets going through a liberalization process, while for the routes with the largest number of carriers, the average rate of exit is 25 percent higher. This is consistent with the view from the model that existing regulations force an "excess" of entry into a few gateway cities. These gateways enjoy intense competition, while remaining routes have few competitors. Post-OSA, not only is there entry on the off-gateway routes, but the ability to offer direct service causes exit on the gateways. The unregulated market results in a different, and less concentrated, distribution of both capacity and competition.

### 5.3 Price, Quantity and Quality Effects of Open Skies Agreements

Our model suggests several ways in which OSAs could affect prices, quantities and qualities. On non-gateway hubs, flying more direct routes reduces the marginal cost of providing service, lowers markups via carrier entry, and provides quality gains for consumers who value directness. On gateways, relaxed capacity constraints could lower average prices though this effect competes with the reallocation of capacity and carriers toward newly unrestricted routes.

While the signs of these changes are clear in the model, the magnitudes of these channels depend on the empirical counterparts of model parameters. For example, how much do forced indirect routings raise costs and how much do consumers value directness? We employ linear capacity costs in the model, but as an empirical matter increased traffic could raise costs (via competition for scarce resources such as gate space) or lower costs (if economies of route density are significant).[25] Finally, passenger aviation may be quality differentiated along multiple dimensions (flight frequency and connectivity, quality of aircraft and crew) with quality choices responsive to liberalization in ways we have not modeled.

***Model Specifications***

We represent a city-pair aviation market using the following system of equations:

$$lnP_{odt} = \alpha_{od} + \alpha_t + \beta_1 lnQ_{odt} + \beta_2 lnSeg_{odt} + \beta_3 OSA_{dt} + \beta_4 lnZ^P_{odt} + \beta_5 lnX_{odt} + \varepsilon_{odt} \quad (17)$$

$$lnQ_{odt} = \alpha_{od} + \alpha_t + \gamma_1 lnP_{odt} + \gamma_2 lnSeg_{odt} + \gamma_3 OSA_{dt} + \gamma_4 lnZ^Q_{odt} + \gamma_5 lnV_{odt} + \varepsilon_{odt} \quad (18)$$

$$lnSeg_{odt} = \alpha_{od} + \alpha_t + \delta_1 lnQ_{odt} + \delta_2 OSA_{dt} + \delta_3 \ln W_{odt} + \varepsilon_{odt} \quad (19)$$

where $P_{odt}$, $Q_{odt}$ and $Seg_{odt}$ denote the average airfare, the aggregate quantity and the average number of flight segments, respectively, that are observed for travel between a U.S. origin city $o$ and a foreign destination city $d$ at time $t$; and $\alpha_{od}$ and $\alpha_t$ represent origin-destination pair, respectively year fixed effects. The vectors of variables $Z^P{}_{odt}$ and $Z^Q{}_{odt}$ are exogenous determinants of, respectively, prices and quantities in a city-pair aviation market and are used as excluded instruments when estimating the model. The remaining vectors of variables $X_{odt}$, $V_{odt}$, and $W_{odt}$, consist of other control variables that improve the identification and fit of the model but may not qualify for instruments.

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[25] Similarly, alliances could either allow carriers to specialize on "comparative advantage" segments, or allow cooperating carriers to collude in setting prices or market shares.

In each equation, the OSA variable captures the partial impact of liberalization on the relevant variable, conditioning on other model variables and additional controls and determinants of prices, quantities and quality. A key feature of this system is that liberalization can also impact variables indirectly. For example, if OSAs lower the number of segments on a route, this can also affect quantities (if passengers value directness), as well as prices (both because multiple segments directly impact costs, and through a quantity channel if costs are not linear in quantities). To properly estimate these effects we incorporate a set of additional controls that include the instruments necessary to trace out exogenous variation in each right hand side variable. These instruments are discussed in depth below.

We focus initially on mapping these equations into the model. In the pricing equation (17), the dependence of average prices on the number of segments corresponds to the assumption that, c.p., indirect routes increase costs. In the model we assume that capacity costs are linear, which would imply a coefficient of zero on quantities. Here we allow the more general case that (exogenous) changes in passenger quantities affect prices. Note that there is a critical difference between exogenous (and predictable) changes in passenger demand and the random demand shocks described in the model. The latter generate a strong positive correlation between average prices and quantities ex-post but this effect will be purged from the estimation by instrumenting for demand.

Other than direct v indirect routes, the model features no heterogeneity in the cost of operating planes. Here we allow for costs to differ across routes and time periods. Most of these differences are captured by origin-destination and time fixed effects. In addition, some inputs vary across time and geography in a way that is useful for identifying changes in costs. For example, takeoff/landing intensively uses fuel, so fuel represents a larger percentage of costs on short haul flights. Changes in fuel costs over time will then represent a larger percentage change for short versus medium length flights. Accordingly, we use interactions of fuel costs with flight distance (direct distance, its square, and excess distance traveled) to construct the exogenous vector of instruments $Z^{P}_{odt.}$. Additional control variables included in the vector $X_{odt}$ in equation (19) are: aircraft insurance costs (which changed markedly in this period) interacted with indicators for main world geographic regions, and per capita incomes for origin and destination cities to account differences in consumers' willingness to pay for flights.

In the demand equation (18), the dependence of quantities on (exogenous) changes in average prices captures the slope of the demand curve. The effect of (exogenous) changes in the number of segments represents an outward shift of the demand curve and reflects consumer's valuation of more direct flights. These two variables account for the channels explicitly developed in the model while the OSA variable captures additional changes in quantity demanded conditional on price and number of segments. As such it captures changes in implicit quality of flights after OSA signing. The vector $Z^{Q}_{odt}$ controls for demand determinants that influence the number of passengers traveling in an *o-d* market. It consists of the city population and per-capita income at origin and destination.

Finally, the average number of segments, equation (19), depends on (exogenous) changes in passenger traffic and the OSA variable. As we show in the model extension with fixed costs of entry (3.3) carriers only establish hubs with direct flights in sufficiently large cities. Here, the OSA variable captures the relaxation of gateway restrictions. Apart from these effects, the number of segments is largely a function of geography (o-d fixed effect), but the cost of employing multiple takeoff/landings varies over time as a function of fuel prices. Like the average price regression we employ fuel prices interacted with direct and excess distances traveled on multiple segment routes. The vector $W_{odt}$ of control variables for the average number of flight segments (equation 19) accounts for the purchasing power of consumers at both origin and destination. Conditional on the volume of air traffic within the city pair market, higher levels of their per-capita income increase the directness of the air services provided.

### *Policy Variable*

The main variable of interest is $OSA_{dt}$. In its simplest form, it is defined as a dummy variable equal to one for all the years since the signing of an Open Skies Agreement by the country to which destination city *d* belongs. However, the networked nature of international passenger aviation means that a passenger in a non-signatory country can still benefit from OSAs signed by neighboring countries. Similarly, signing an agreement may have a smaller effect on market outcomes if neighbors have already signed. Ignoring these indirect OSA effects may bias the estimates by 'contaminating' the reference group of fully regulated air travel flows, thus making it difficult to identify the actual effect of air services liberalization.

To account for this issue, we construct an OSA variable that takes into account the extent to which passengers route through other OSA hubs in the periods prior to liberalization. We first calculate the passenger share within an origin-destination market that transit through third country OSA hubs on the way to their final destination.

$$OSA\ Pax\ Connect_{dt} = \sum_i \frac{Q_{oidt}}{Q_{odt}} * I(OSA_{it} = 1) \tag{20}$$

where *i* denotes a city hub located in a country different from the final destination country when travelers connect flights when traveling from origin *o* to destination *d*; and *I(.)* is an indicator function.

We define another similar OSA Connect variable that also takes into account the fraction of the trip distance traveled along flight segments covered by Open Skies Agreements:

$$OSA\ Dist\ Connect_{dt} = \sum_i \frac{Q_{oidt}}{Q_{odt}} * \frac{Dist_{oit}}{Dist_{odt}} * I(OSA_{it} = 1) \tag{21}$$

The regression variable used in the main estimation exercises combines information about the OSA signing by the final destination country with the previously defined OSA Connect variables, as follows:

$$OSA\ Combine_{dt} = \begin{cases} 1 & if \quad OSA_{dt} = 1 \\ 1 & if \quad OSA_{dt} = 0 \ \ and \ \ OSA\ Connect_{dt} > k \\ 0 & otherwise \end{cases} \tag{22}$$

where *k* is a threshold value such as the median or the 25th percentile, and *OSA Connect* is measured either as a passenger share, or as a distance share.

### *Model Identification*

The regression equations (17), (18) and (19) represent our main estimation models. Given the use of time and market-specific fixed effects, the identification of each model relies entirely on time variation within each origin-destination city pair. The main empirical challenge comes from the interrelation between the three dependent variables, giving rise to endogeneity concerns. To address this endogeneity problem, we estimate each of the three equations using the instrumental variables method and relay on exogenous instruments suggested either by the other regression equations, or by mechanisms external to the model.

For example, in the model the (ex-post) average price and aggregate quantity are simultaneously determined as a function of demand shocks. In the pricing equation we instrument for quantity using population size at origin and destination, and add two external instruments: the volume of U.S. state level exports to the final destination country, as well as an indicator for participation in the Visa Waiver Program. These latter excluded variables are also used to instrument for quantity in the flight segment regression.[26]

In the quantity regression we instrument for both the price level and for the number of segments. The natural candidates are input costs, particularly distance-related cost variables, since they are correlated both with prices but also the route structure through landing/take-off expenses. Therefore, we propose three exogenous instrument: 1) the non-stop distance between the origin and destination cities interacted with fuel prices; 2) the excess travel distance calculated in the base year as the ratio of the average ticket distance (determined by connections) to the non-stop distance, which again we interact with fuel prices; and 3) the excess distance squared interacted with fuel prices. One important thing to notice about the proposed instruments is that neither of them is based on time varying passenger-weighted average variables, thus removing any possible source of correlation between the residual demand and the excluded instruments.

Finally, we rely on model structure and assume that the relation between flight segments and prices is unidirectional. In the model, pricing functions are determined once the route structure and capacity allocation have already been decided, and average (ex-post) prices reflect idiosyncratic realizations of demand shocks. However, we assume there are no feedback effects from ex-post realizations of average prices into route structures.

### *Estimation Results*

To address the pricing, quality and directness effects of liberalization, we turn to the airline ticket database, Databank 1B (DB1B). As described in the data section, the DB1B data includes detailed information on prices, service characteristics and full itinerary captured at airport detail. Knowing the complete itinerary of travelers provides several advantages. First, we can account for the true origin and destination of the traveler, rather than relying only on the

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[26] We do not include population at origin and destination as instruments for quantity in the flight segment regression for lack of certainty about their excludability from the regression model. However, adding them to the list of exogenous instruments does not change the estimation results. Results are available upon request.

cross-border segment that is captured in the T-100 data. This allows us to properly account for demand shifters specific to each location. Second, knowing the identity of the transit locations allows us to factor in third country effects implied by bilateral policy changes. Lastly, by observing the complete itinerary, we can see whether OSAs lead to changes in flight characteristics such as the number of connections, that affect consumer valuation.

Table 3 contains the results of price regressions. In the first column we employ a simple 1,0 dummy variable for the signing of OSAs. This variable shows a small positive effect of signing OSAs on prices. The challenge is that this variable fails to account for the complex route structures passengers may employ. In the remaining columns we use the variable OSA connect which combines the liberalization effect of passengers transiting through liberalized neighbor countries with the change from own country signing. Here we see prices decline by 2 percent after signing, and this effect is robust to varying sample cuts such as focusing only on large or small cities, or using only countries with direct routes to the US. When we drop the EU countries from the sample we find a price decline of 3 percent. We also break US cities into three groups and interact these with the OSA variable. Small cities (the excluded group) see a price decline of 1.8 percent, large hubs 2.9 percent and pre-OSA gateways 3.9 percent.

There are several additional notable features of these results. First, partial liberalization (countries that, within sample, liberalize their markets with agreements that are less comprehensive than OSAs) experience price declines that are comparable in magnitude to OSAs. This suggests that the direct (partial) effect of OSAs on prices is not very different from more modest liberalizations. Second, an increase in the average number of segments on flight raises prices, consistent with model assumptions. Third, city-pairs that see exogenous changes in passenger growth (instrumented by population growth and other variables that affect passenger growth) see prices decline, with an elasticity of -0.1. This is consistent with economies of route density lowering costs, a finding that is common in the literature.

Finally it should be emphasized that the price effect reported in the table is only a partial effect conditional on other variables. If OSAs also affect the number of segments and number of passengers the total effect on prices will include the direct effect (2-4 percent declines) with additional effects operating through growth in passengers and reduction in the number of segments.

At the bottom of Table 3, we report the first stage coefficients for the excluded instruments as well as key instrumental variables statistics reflecting the joint predictive power and the exogeneity of the proposed instruments. Overall, the instruments perform well in that they have the expected sign and produce a large F-stat.[27]

Table 4 reports quantity regressions. As with prices, the 1,0 OSA dummy has a modest effect on passenger quantities, but the combined OSA variable that incorporates routing through early liberalizers shows large quantity effects. OSAs increase passenger traffic by around 14 percent in most specifications. Here, the interaction between OSAs and city types reveals particularly interesting results. Small cities see gains of 14 percent, large hubs 17.9 percent and pre-OSA gateways only 5.1 percent.

To understand these results, it is important to recognize the difference between these regressions and the quantity regressions in Table 2 that employed the T100 sample. First, the T100 sample excludes information on connecting flights: a passenger who originates in Indianapolis and connects through New York on the way to London is indistinguishable from a passenger who originates in New York. The DB1B data allows us to distinguish these passengers and identify differential growth in traffic across city pairs more cleanly. Here we see that large hubs, the types of cities that are the focus of our model, experience much larger growth than the gateways.

Second, unlike Table 2, these regressions condition on flight characteristics including prices and quality (number of segments.) Exogenous increases in prices decrease passenger quantities with an elasticity of -1.26, while exogenous increases in the number of segments decrease passenger quantities with an elasticity of -0.65. This means that going from 1 to 2 segments has the same effect on demand as increasing prices by 52%. Clearly, route restrictions that prevent direct flights can have profound effects on consumer welfare.

Since the regressions condition on prices and an explicit measure of quality, the additional shift outward in quantity demanded represents an implicit increase in flight quality. We can calculate the price equivalent of that implicit quality increase by dividing the coefficient on OSAs by the price elasticity. For large hubs it is equivalent to a (0.133+0.42)/-1.267 = 13.8

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[27] However, the test of overidentifying restriction is rejected at standard confidence levels. While from an economic point of view, our instruments should only affect prices through their impact on air traffic, it is possible that their time variation correlates in an unexpected way with the price residual.

percent decline in quality adjusted prices. For gateways it is only a (0.133-0.82)/-1.267 = 4 percent decline in quality adjust prices.

What are these implicit quality shifts capturing? One possibility is that carriers that were previously protected by restrictions on entry and capacity respond to increased competition by improving service offerings (better planes, food, and flight crews). Alternatively, it may be that an increase in flight frequency and directness may be valuable to consumers.

To illustrate this point, we investigate the impact of air liberalization on the diversity of U.S. exit points used within an origin-destination city pair. Table 5 reports the results. The estimates reveal some interesting patterns. First, the average effect reported in column 1 shows that liberalization increases the number of exit gateways used in reaching a particular destination. Second, these effects differ by city type. While small origin and non-gateway hub cities diversify their points of exit in reaching a foreign destination, gateway cities that offered international service pre-OSA consolidate most of the traffic on a reduced number of exit points.[28]

Overall, while it is difficult to pin down the precise sources of these implicit quality changes with our data, the pattern of effects across cities is instructive. The least constrained cities, experience the smallest implicit quality change while the most constrained cities experience the greatest implicit quality change.

In Table 6 we report the effect of OSAs on explicit measures of quality: the average number of segments on an origin-destination route. Column 1, which uses the 1,0 OSA variable shows a modest decrease in the number of segments, whereas columns that use the OSA connect variable generally show a small increase in the number of segments. The exception is column 4, which redefines the “Large Hub” indicator using the T100 data to include only those cities where direct flights were introduced after signing OSAs. For these cities, the number of segments drops by 3 percent after an OSA.

What’s going on here? The first thing to recognize is that there are 30 cities designated as large hubs by the FAA and 108 destinations in our data. When we introduce fixed costs of establishing an international hub (or equivalently, impose a constraint on the minimum capacity for a trans-oceanic passenger jet), relatively few of these hubs will have sufficient scale to

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[28] One possible explanation for the latter outcome is that once passengers from in-land U.S. are not forced any longer to route through the pre-determined (“pre-OSA”) gateways in reaching their final destination, capacity gets freed up in flying out of such cities, thus reducing the use of alternative exit points. We see a similar effect in those large cities that gain international hubs after liberalization.

support frequent direct flights to all 108 destinations even after pre-OSA route restrictions are lifted. For those passengers fortunate enough to live in a city where a new international hub is established, flight directness increases significantly.

For the remaining passengers we actually see a slight increase in number of connections. A key here is that relaxed routing restrictions may increase the number of segments for price-conscious consumers. For example, suppose we have 100 pre-OSA passengers flying out of a small city, all of whom take two flight segments (origin to gateway, gateway to destination) trips. If 2 of these passengers add a third segment to take advantage of a newly added international hub with lower fares that would generate the elasticity reported in Table 6. Related, the difference between columns 1 and 2 is key. Much of the increase in number of segments comes from routing traffic through third countries that have already signed an OSA.

### 5.4 Consumer Welfare Calculations

To summarize all our empirical findings in one statistic on consumer welfare, we combine the price, quality and connectivity effects into an overall price equivalent measure of air services liberalization. Our aim is to quantify the impact of such a policy change in the same way we evaluate the liberalization of goods by a fall in the price wedge between exporters and importers.

The strategy is to start from the set of estimated equations (10), (22) and (23) and perform comparative statics with respect to a change in the OSA variable in order to derive the total effect of air services liberalization on the average price, aggregate quantity and average number of flight segments per origin-destination market. Such a calculation needs to take into account and aggregate up all the direct and indirect channels (operating through the other endogenous variables) in which the policy shock affects each endogenous variable. For example, in deriving the total price effect of a switch in OSA from complete regulation to full liberalization, we need to include both the direct effect from equation (16) and the indirect effects operating through liberalization-induced changes in quantity and number of segments..

Once the comparative static calculations are derived, the next step is to convert the convert the quality effect of OSA into a price equivalent by dividing through the price elasticity of demand. This way we can aggregate all the gains from the air services liberalization into a comprehensive tariff equivalent measure. Appendix 2B describes in details the comparative statics and tariff equivalent calculations.

Table 7 reports the results. The first row reports the total effect on prices of a change in OSA. The price effect is calculated based on the average sample regression estimates (column 1), as well as based on the city-specific regression estimates (columns 2-5). Overall, the price effect ranges between a 5 percent and 6.9 percent drop in airfares, with the non-gateways large hub airports witnessing the largest decrease. Liberalization has a direct effect on prices via reductions in costs and/or price mark-ups (row 2), and it has an indirect effect on prices operating through changes in the volume of air traffic (row 3) and changes the average number of flight segments (row 4). The first two effects explain most of the price response to air services liberalization.

The subsequent rows report the effect of a change in OSA on the number of travelers within an origin destination market. The increase in passenger traffic ranges from 11.2 percent (for pre-OSA gateways) to 29.9 percent (for non-gateway large hubs). This pattern is consistent with theoretical predictions.

We further decompose the total demand effect into: a direct effect of OSA on air traffic operating via changes in service quality (row 6); an indirect effect operating through price changes (row 7), and an indirect effect operating through changes in the number of flight segments (row 8). The direct effects account for a large part of the total demand effect, with the flight connectivity effects making a significant difference only in the case of non-gateway hubs that benefit from non-stop service after signing OSA. By adding the direct effect and the indirect effect via changes in the number of segments, we can measure the shift in demand generated by an OSA conditional on prices. We interpret this as a quality effect of OSA described by equation (22), and convert it into a price equivalent by dividing though the price elasticity of demand (row 9).

Finally, combining the total price effect with the price equivalent measure of quality effects, we obtain the cumulative tariff equivalent of air services liberalization. It ranges between a 8.7 percent and a 23 percent drop in average prices, with the pre-OSA gateways benefiting the least from liberalization as compared to non-gateway hubs who gains the most. Using the distribution of the U.S. population across small cities, large hubs and pre-OSA gateway or the distribution of passengers across these cities we can generate a more representative measure of the average tariff equivalent of OSAs. These calculations are reported at the bottom of table 9, suggesting a 14.3 percent price drop enjoyed by the average U.S. consumer.

## 6 Conclusions

Services are large and growing fast, but we know relatively little about the importance of policy barriers to services trade, or the kinds of effects that are likely to result from liberalization. Recent US efforts to liberalize passenger aviation via Open Skies Agreements led to sweeping changes in the regulatory structure facing domestic and foreign carriers. But as we show in the accompanying model, the net effect of these changes on entry, pricing, and welfare is not obvious.

We draw on services data at the level of individual transactions (passenger tickets) combined with differences in the timing of liberalization across partner countries to identify the effect of Open Skies Agreements. We find that, compared to non-signatory countries, OSA signatories experienced 18 percent higher growth in traffic five years after signing. More than a third of this growth is accounted for by growth in new routes. This is channel is especially relevant since existing Air Services Agreements explicitly restricted the number of entry routes, and signatories see much more rapid growth in new routes than non-signatories.

Removing route restrictions also leads to changes in the equilibrium patterns of entry and exit by carriers. On non-gateway "hub" routes, foreign carriers cannot enter prior to OSAs because direct flights are prohibited, as is "cabotage", in which the foreign carriers transits a US gateway and continues onto the non-gateway city. Relaxing these restrictions led to carrier entry on these routes, but it also led to exit from gateways. Domestic carriers are no longer forced to offer service through gateways to attract international passengers into their hub routes, and these carriers exit. The unregulated market reallocates capacity across routes leading to a greater uniformity of competition.

Exploiting ticket-level data for thousands of true origin-destination aviation markets we find that Opens Skies Agreements are associated with a decrease in average airfares, and conditional on prices, an increase in the demand for international air traffic at route level. However, price effects are not uniform, as gateways routes with exiting carriers see prices increase. The rise in quantity conditional on prices suggests that OSAs lead to air service quality improvements such as more frequent departures and greater flexibility in scheduling, or more direct connections, all of which consumers value highly. Additionally, the estimated price and quality gains associated with the liberalization are enjoyed not only by consumers traveling to a liberalized market, but also by transit passengers connecting through gateway airports located in Open Skies Agreement countries. This suggests an important but unusual policy spillover: Open Skies Agreements are so powerful they benefit even countries unwilling to sign them.

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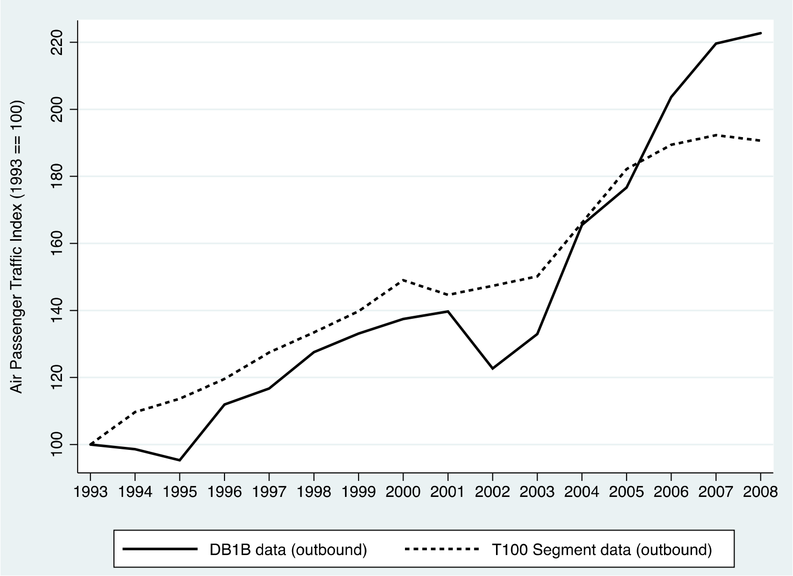
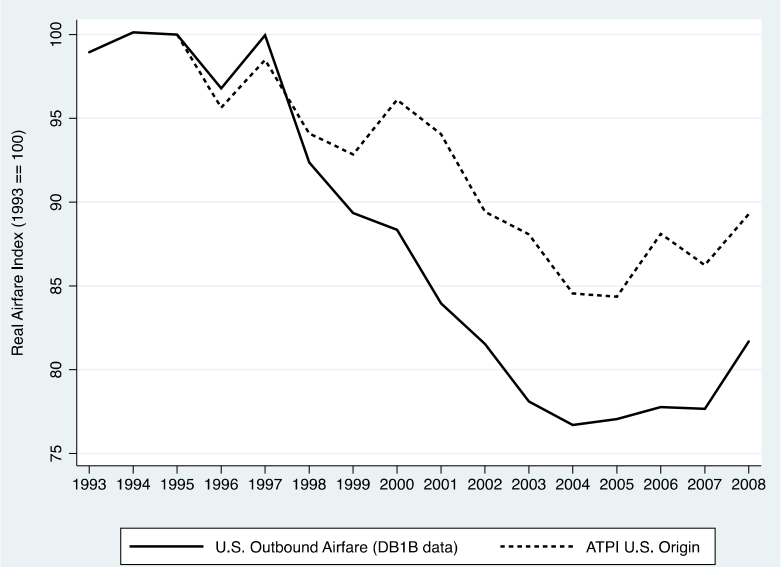
# Figure 1: The Evolution of Air Travel using True Origin-Destination Data (DB1B)

1A: Air Passenger Traffic Trend



1B: Average Inbound and Outbound Airfare Trend



*Notes:*

1. The series based on DB1B data represent the year intercepts from regressions with origin-destination city pair fixed effects. Economy class airfare values are expressed in real terms and represent averages over outbound tickets within a route.
2. The Air Travel Price Index (ATPI) is a price index series provided by the Bureau of Transport Statistics starting from 1995. It is constructed based on the Fisher formula, separately for inbound and outbound travel flows.

Figure 2: Cumulative Market Quantity and Average Price

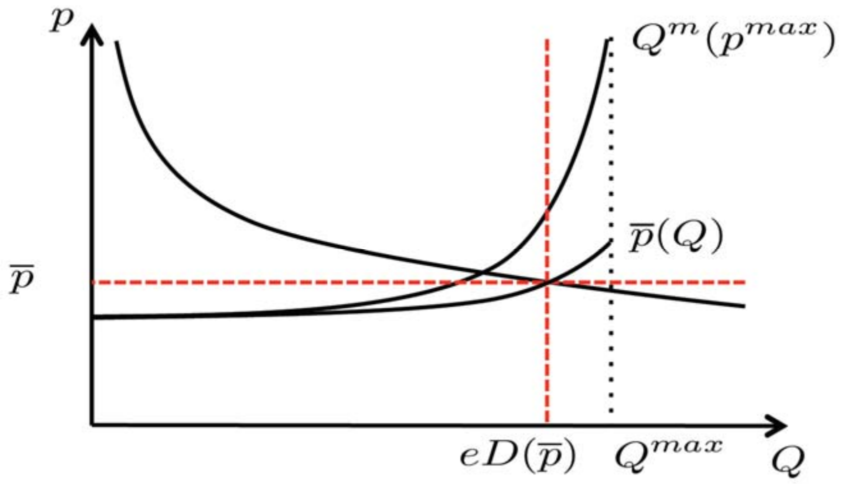
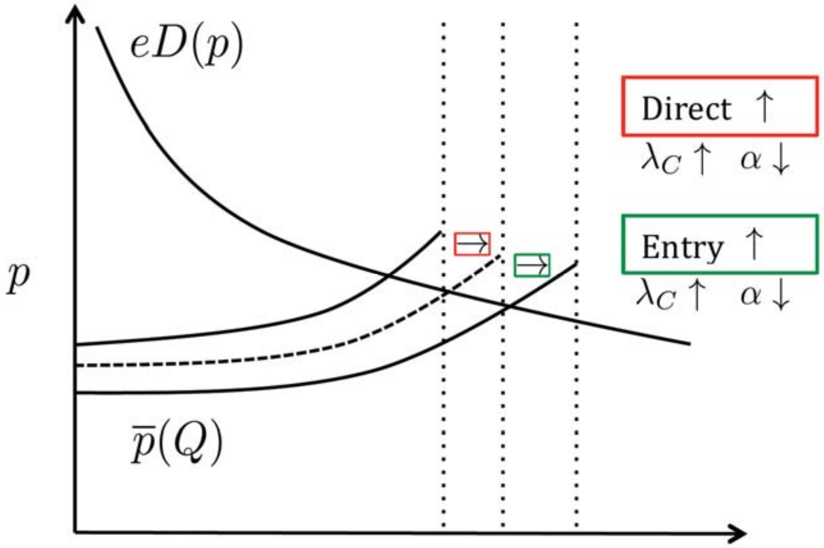
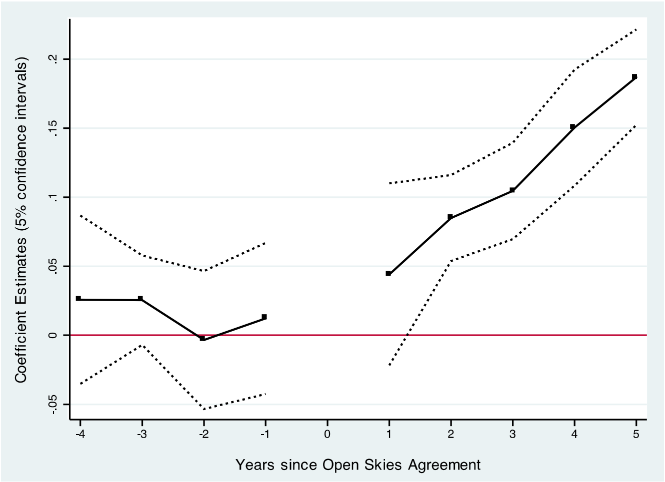


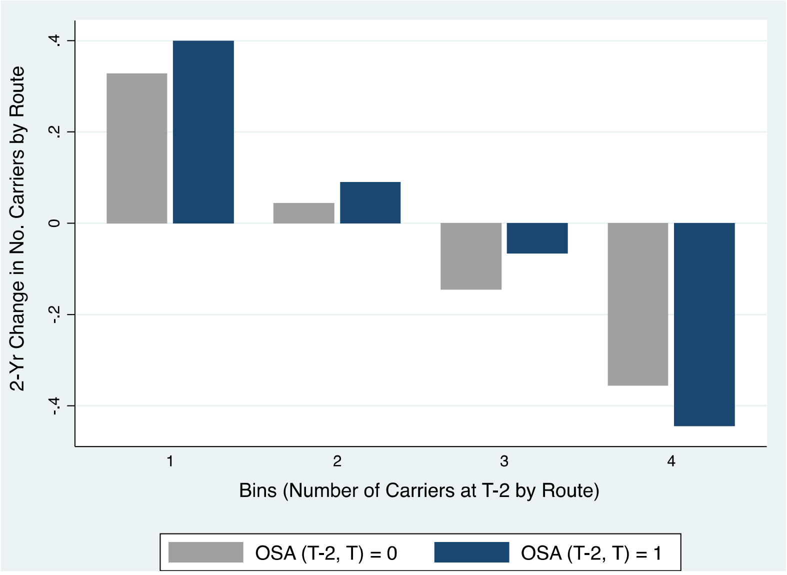
Figure 3: The Entry and Composition Effects of OSA



## Figure 4: Trends in Air Traffic Before and After the Policy Change



## Figure 5: Air Carrier Entry and Exit of Air Carriers across Routes



*Notes:* The number of carriers per cross-border flight segment is calculated based on simple count using T100 Data. Each origin-destination-time observation is assigned to one of the four an equal-sized bins based on the number of carriers in the market, with bin 1 including the least competitive routes. The vertical bars measure the change in carriers over a 2-year period for a given route, averaged across all routes in the respective bin. Within each bin, we distinguish between routes that went through liberalization.

## Table 1: Summary of U.S. International Air Passenger Transport

|  | 1993 | 2007 | Cumulative Percent Change 1993-2007 |
|---|---|---|---|
| **Total Passengers (thousands), T100 Data** |  |  |  |
| NAFTA | 10189 | 20553 | 101.7 |
| Latin America & Caribbean | 8824 | 16661 | 88.8 |
| OECD Europe | 14481 | 25212 | 74.1 |
| Europe & Central Asia | 271 | 871 | 221.5 |
| Southeast Asia & Pacific | 8954 | 13476 | 50.5 |
| Middle East & North Africa | 424 | 1371 | 223.2 |
| Sub-Saharan Africa | 79 | 323 | 308.2 |
| *TOTAL* | 43221 | 78467 | 81.5 |
| **Non-Stop Routes, T100 Data** |  |  |  |
| NAFTA | 265 | 570 | 115.1 |
| Latin America & Caribbean | 240 | 415 | 72.9 |
| OECD Europe | 234 | 235 | 0.4 |
| Europe & Central Asia | 16 | 18 | 12.5 |
| Southeast Asia & Pacific | 122 | 138 | 13.1 |
| Middle East & North Africa | 13 | 22 | 69.2 |
| Sub-Saharan Africa | 6 | 13 | 116.7 |
| *TOTAL* | 896 | 1411 | 57.5 |
| **True Origin-Destination Markets, DB1B Data** |  |  |  |
| NAFTA | 5353 | 7313 | 36.6 |
| Latin America & Caribbean | 4093 | 7003 | 71.1 |
| OECD Europe | 6653 | 9495 | 42.7 |
| Europe & Central Asia | 721 | 2266 | 214.3 |
| Southeast Asia & Pacific | 853 | 1303 | 52.8 |
| Middle East & North Africa | 4062 | 6248 | 53.8 |
| Sub-Saharan Africa | 368 | 902 | 145.1 |
| *TOTAL* | 22103 | 34530 | 56.2 |
| **Traffic Share Covered by OSA, T100 Data**[a] |  |  |  |
| NAFTA | 0.0 | 53.1 | 53.1 |
| Latin America & Caribbean | 0.0 | 40.4 | 40.4 |
| OECD Europe | 7.7 | 100.0 | 92.3 |
| Europe & Central Asia | 0.0 | 67.5 | 67.5 |
| Southeast Asia & Pacific | 0.0 | 28.2 | 28.2 |
| Middle East & North Africa | 0.0 | 43.1 | 43.1 |
| Sub-Saharan Africa | 0.0 | 73.9 | 73.9 |
| *TOTAL* | 2.6 | 61.3 | 58.7 |

[a] In the case of traffic share accounted for by OSA, the values reported in column 3 represent absolute percent differences rather than cumulative percentage changes.

*Notes:*

1. Data comes from the T100 Segment sample and includes only US outbound traffic.
2. All the reported values for total passengers, number of departures and non-stop routes are annual.
3. The number of non-stop routes represents a simple count of distinct origin-destination airport pairs within a year. So, if a route is serviced only in one quarter out of the full year, it counts the same as a route serviced in all four quarters.

## Table 2: Impact of Air Trade Liberalization on Country Level Passenger Transport

| | | **Cumulative Margins of Adjustment (log)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | Simple Route Count | | Common Routes defined relative to T-3 | | | |
| | **Total Air Traffic** | ***Extensive*** | ***Intensive*** | ***Extensive*** | ***Intensive*** | **Total Seats** | **Share Seats Pre-OSA Gateway** |
| **Panel A** | | | | | | | |
| OSA | 0.071** | 0.105*** | -0.034 | 0.038** | 0.034 | 0.054** | -0.064*** |
| | [0.030] | [0.031] | [0.033] | [0.015] | [0.028] | [0.026] | [0.020] |
| Observations | 4036 | 4036 | 4036 | 4036 | 4036 | 4,034 | 4,034 |
| R-squared | 0.512 | 0.305 | 0.234 | 0.304 | 0.341 | 0.370 | 0.433 |
| **Panel B** | | | | | | | |
| Year Prior OSA | 0.030 | 0.057** | -0.027 | -0.003 | 0.033 | 0.043* | 0.059*** |
| | [0.022] | [0.029] | [0.030] | [0.013] | [0.023] | [0.023] | [0.013] |
| Year OSA == 0 | 0.003 | 0.087** | -0.084** | -0.005 | 0.008 | -0.006 | 0.060*** |
| | [0.033] | [0.036] | [0.035] | [0.018] | [0.031] | [0.035] | [0.021] |
| Year OSA == 1 | 0.046 | 0.126*** | -0.080** | 0.018 | 0.028 | 0.054* | -0.001 |
| | [0.030] | [0.031] | [0.033] | [0.018] | [0.029] | [0.030] | [0.021] |
| Year OSA == 2 | 0.074** | 0.100** | -0.027 | 0.044** | 0.029 | 0.041 | -0.031 |
| | [0.035] | [0.043] | [0.042] | [0.020] | [0.033] | [0.032] | [0.021] |
| Year OSA == 3 | 0.091** | 0.093** | -0.002 | 0.045** | 0.046 | 0.047 | -0.045* |
| | [0.041] | [0.044] | [0.046] | [0.021] | [0.037] | [0.034] | [0.024] |
| Year OSA == 4 | 0.093* | 0.108** | -0.015 | 0.055** | 0.039 | 0.101*** | -0.087*** |
| | [0.052] | [0.044] | [0.058] | [0.022] | [0.051] | [0.037] | [0.028] |
| Year OSA == 5+ | 0.172*** | 0.202*** | -0.030 | 0.065*** | 0.107** | 0.160*** | -0.132*** |
| | [0.052] | [0.046] | [0.052] | [0.023] | [0.049] | [0.046] | [0.037] |
| Observations | 4036 | 4036 | 4036 | 4036 | 4036 | 4.529 | 4,034 |
| R-squared | 0.518 | 0.311 | 0.236 | 0.308 | 0.346 | [5.627] | 0.452 |

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in brackets.

*Notes*:

1. The table reports the estimates from the regression models described by equation (16) in the text using as dependent variables each component from the decomposition in equation (15). The estimation sample is constructed from the T100 dataset and includes only non-stop flight segments originating in the US (i.e., outbound traffic).
2. *Total Air Traffic* is the total number of US outbound travelers to a given country in a quarter and year. The *Intensive Margin* measures air traffic on routes that are operated in the same quarter of both the reference year (set to 3-year lag) and year *t*. The *Extensive Margin* represents the passenger share weighted count of routes that are new in quarter *q* and year *t* relative to the same quarter of the reference year (*t-3*). *OSA* is a country-year indicator equal to one for all years when a bilateral Open Skies Agreement is in effect. *Year OSA == i* is an indicator variable equal to one for the $i^{th}$ year since the introduction of an OSA.
3. All specifications include year and quarter-country fixed effects, as well as the following control variables: Ln Per Capita GDP (t/93), Ln Population (t/93), Sept 11 effect, Sept 11*Visa Waiver, Asia Crisis linear trend, Caribbean linear trend, and a partial liberalization dummy.

## Table 3: Price Regressions: True Origin-Destination Air Travel (DB1B Sample)

| | Dependent variable: Ln Airfare | | | | | | |
|---|---|---|---|---|---|---|---|
| | (1) Basic | (2) Basic | (3) By Gateways | (4) Large cities | (5) Small cities | (6) Direct Routes | (7) Drop EU |
| OSA | 0.005** | | | | | | |
| | [0.002] | | | | | | |
| OSA Combine | | -0.021*** | -0.018*** | -0.021*** | -0.022*** | -0.018*** | -0.031*** |
| | | [0.002] | [0.002] | [0.003] | [0.003] | [0.002] | [0.002] |
| OSA Combine*Pre-OSA Gateway | | | -0.021*** | | | | |
| | | | [0.006] | | | | |
| OSA Combine*Large Hub | | | -0.011*** | | | | |
| | | | [0.003] | | | | |
| Ln Pax | -0.105*** | -0.104*** | -0.104*** | -0.180*** | -0.061*** | -0.101*** | -0.079*** |
| | [0.008] | [0.008] | [0.008] | [0.014] | [0.010] | [0.008] | [0.007] |
| Ln Ticket Distance | 0.104*** | 0.106*** | 0.105*** | 0.081*** | 0.113*** | 0.104*** | 0.095*** |
| | [0.011] | [0.011] | [0.011] | [0.023] | [0.013] | [0.011] | [0.011] |
| Ln Flight Segments | 0.170*** | 0.173*** | 0.173*** | -0.002 | 0.258*** | 0.178*** | 0.220*** |
| | [0.009] | [0.009] | [0.009] | [0.020] | [0.011] | [0.009] | [0.010] |
| Ln MSA Income | 0.105*** | 0.105*** | 0.108*** | 0.035 | 0.107*** | 0.112*** | 0.131*** |
| | [0.015] | [0.015] | [0.015] | [0.027] | [0.018] | [0.015] | [0.017] |
| Ln PcGDP | -0.001 | -0.008 | -0.007 | 0.055*** | -0.047*** | -0.003 | 0.044*** |
| | [0.009] | [0.009] | [0.009] | [0.016] | [0.012] | [0.009] | [0.010] |
| Share One-way | 0.349*** | 0.349*** | 0.349*** | 0.336*** | 0.355*** | 0.350*** | 0.335*** |
| | [0.003] | [0.003] | [0.003] | [0.006] | [0.004] | [0.003] | [0.003] |
| Ln Fuel * NonStopDist | 0.335*** | 0.328*** | 0.331*** | 0.463*** | 0.255*** | 0.253*** | 0.017 |
| | [0.028] | [0.027] | [0.028] | [0.045] | [0.036] | [0.028] | [0.028] |
| Ln Fuel * NonStopDist^2 | -0.023*** | -0.022*** | -0.023*** | -0.030*** | -0.018*** | -0.017*** | -0.004** |
| | [0.002] | [0.002] | [0.002] | [0.003] | [0.002] | [0.002] | [0.002] |
| Partial Liberalization | -0.016*** | -0.029*** | -0.029*** | -0.016*** | -0.030*** | -0.027*** | -0.026*** |
| | [0.003] | [0.003] | [0.003] | [0.005] | [0.003] | [0.003] | [0.003] |
| Pre-OSA Gateway | | | 0.030*** | | | | |
| | | | [0.010] | | | | |
| Large Hub | | | 0.012*** | | | | |
| | | | [0.004] | | | | |
| OSA * Indirect Gateway | | | 0.010* | | | | |
| | | | [0.006] | | | | |
| Indirect Gateway | | | -0.002 | | | | |
| | | | [0.010] | | | | |
| Year FE | yes | yes | yes | yes | yes | yes | yes |
| Origin-Destination FE | yes | yes | yes | yes | yes | yes | yes |
| Additional Controls | World region * Insurance cost; Asia crisis linear trend; Caribbean linear trend; Annual quarters | | | | | | |
| Observations | 470,597 | 470,597 | 470,597 | 154,512 | 315,293 | 452,261 | 317,247 |
| R-squared | 0.184 | 0.185 | 0.185 | 0.158 | 0.186 | 0.183 | 0.226 |
| Hansen's j p-val | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Hansen's j stat | 562.3 | 544.3 | 547.4 | 189.9 | 332.0 | 533.9 | 200.4 |

(Table 3 Continued)

| | Dependent variable: Ln Airfare | | | | | | |
|---|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** |
| | **Basic** | **Basic** | **Gateways** | **Large cities** | **Small cities** | **Direct Routes** | **Drop EU** |
| <u>**1st Stage Dependent Var:**</u> | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* |
| Ln MSA Population | 1.002*** | 1.002*** | 0.977*** | 0.704*** | 1.117*** | 1.012*** | 1.133*** |
| | [0.021] | [0.021] | [0.021] | [0.038] | [0.027] | [0.021] | [0.027] |
| Ln Country Population | 1.256*** | 1.261*** | 1.238*** | 1.348*** | 1.216*** | 1.322*** | 1.880*** |
| | [0.035] | [0.035] | [0.035] | [0.064] | [0.043] | [0.037] | [0.047] |
| Ln State Exports | 0.017*** | 0.017*** | 0.018*** | 0.024*** | 0.016*** | 0.015*** | 0.014*** |
| | [0.002] | [0.002] | [0.002] | [0.003] | [0.002] | [0.002] | [0.002] |
| Visa Waiver Program Participation | -0.173*** | -0.178*** | -0.177*** | -0.178*** | -0.167*** | -0.176*** | -0.253*** |
| | [0.009] | [0.009] | [0.009] | [0.015] | [0.011] | [0.009] | [0.010] |
| Partial R-squared | 0.0106 | 0.0107 | 0.0102 | 0.00820 | 0.0112 | 0.0109 | 0.0156 |
| F-Test of IVs | 1023 | 1031 | 983.3 | 254.0 | 714.1 | 1017 | 1035 |

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in brackets.

*Notes:*

1. The table reports the estimates from the price regression described by equation (17) in the text. The estimation sample comes from the DB1B dataset and includes information on economy-class tickets for U.S. outbound travel. The unit of observation is a true origin-destination-year triplet.
2. The variable of interest is *OSA* (dummy), respectively *OSA Combine*. The latter is constructed as described in equation (22) in the text, using the distance share measure for *OSA Connect* defined in equation (21), and a threshold equal to the median value.
3. All specifications are estimated by 2SLS method using 4 instruments for the endogenous quantity variable: the population size at origin and destination, the state level bilateral volume of exports and an indicator for participation in the Visa Waiver Program. The first stage regression coefficients and main performance statistics are reported at the bottom of the table.
4. All specifications include year and city-pair fixed effects, as well as unreported controls for seasonality (i.e., annual quarters), as well as linear trends for the Asian crisis period and for Caribbean destinations.

## Table 4: Quantity Regressions: True Origin-Destination Air Travel (DB1B Sample)

| | **Dependent variable: Ln Pax** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **(1)<br>Basic** | **(2)<br>Basic** | **(3)<br>By Gateways** | **(4)<br>Large cities** | **(5)<br>Small cities** | **(6)<br>Direct Routes** | **(7)<br>Drop EU** |
| OSA | 0.022*** | | | | | | |
| | [0.005] | | | | | | |
| OSA Combine | | 0.139*** | 0.133*** | 0.098*** | 0.159*** | 0.140*** | 0.146*** |
| | | [0.006] | [0.006] | [0.012] | [0.008] | [0.006] | [0.006] |
| OSA Combine*Pre-OSA Gateway | | | -0.082*** | | | | |
| | | | [0.016] | | | | |
| OSA Combine*Large Hub | | | 0.042*** | | | | |
| | | | [0.008] | | | | |
| Ln Airfare | -1.302*** | -1.291*** | -1.267*** | -1.308*** | -1.246*** | -1.306*** | -0.912*** |
| | [0.057] | [0.057] | [0.057] | [0.177] | [0.062] | [0.064] | [0.046] |
| Ln Flight Segments | -0.616*** | -0.657*** | -0.650*** | 0.226 | -1.039*** | -0.820*** | -1.686*** |
| | [0.176] | [0.180] | [0.179] | [0.437] | [0.221] | [0.186] | [0.197] |
| Ln MSA Income | 0.509*** | 0.500*** | 0.495*** | 0.100 | 0.629*** | 0.542*** | 0.582*** |
| | [0.035] | [0.035] | [0.035] | [0.072] | [0.043] | [0.036] | [0.042] |
| Ln MSA Population | 1.028*** | 1.015*** | 0.998*** | 0.719*** | 1.153*** | 1.020*** | 1.071*** |
| | [0.025] | [0.025] | [0.025] | [0.045] | [0.034] | [0.026] | [0.029] |
| Ln State Exports | 0.024*** | 0.025*** | 0.025*** | 0.035*** | 0.022*** | 0.024*** | 0.018*** |
| | [0.002] | [0.002] | [0.002] | [0.004] | [0.003] | [0.002] | [0.003] |
| Ln PcGDP | 0.591*** | 0.594*** | 0.591*** | 0.672*** | 0.535*** | 0.585*** | 0.758*** |
| | [0.022] | [0.022] | [0.022] | [0.042] | [0.026] | [0.023] | [0.026] |
| Ln Country Population | 0.410*** | 0.379*** | 0.366*** | 0.462*** | 0.273*** | 0.394*** | 1.384*** |
| | [0.047] | [0.047] | [0.047] | [0.100] | [0.062] | [0.049] | [0.055] |
| Partial Liberalization | 0.017** | 0.047*** | 0.045*** | 0.106*** | 0.020*** | 0.044*** | 0.077*** |
| | [0.007] | [0.006] | [0.006] | [0.011] | [0.007] | [0.006] | [0.007] |
| Pre-OSA Gateway | | | -0.012 | | | | |
| | | | [0.031] | | | | |
| Large Hub | | | 0.028*** | | | | |
| | | | [0.010] | | | | |
| OSA * Indirect Gateway | | | 0.010 | | | | |
| | | | [0.018] | | | | |
| Indirect Gateway | | | 0.150*** | | | | |
| | | | [0.032] | | | | |
| Year FE | yes | yes | yes | yes | yes | yes | yes |
| Origin-Destination FE | yes | yes | yes | yes | yes | yes | yes |
| Additional Controls | Asia crisis linear trend; Caribbean linear trend; Annual quarters | | | | | | |
| Observations | 470,597 | 470,597 | 470,597 | 154,512 | 315,293 | 452,261 | 317,247 |
| R-squared | -0.077 | -0.069 | -0.057 | 0.016 | -0.139 | -0.076 | 0.126 |
| Hansen's j p-val | 0.240 | 0.241 | 0.241 | 0.0825 | 0.420 | 0.192 | 0.368 |
| Hansen's j stat | 1.380 | 1.373 | 1.377 | 3.015 | 0.651 | 1.702 | 0.811 |

(Table 4 Continued)

| | Dependent variable: Ln Pax | | | | | | |
|---|---|---|---|---|---|---|---|
| | **(1)** **Basic** | **(2)** **Basic** | **(3)** **By Gateways** | **(4)** **Large cities** | **(5)** **Small cities** | **(6)** **Direct Routes** | **(7)** **Drop EU** |
| **1st Stage Dependent Var:** | *Ln Airfare* | *Ln Airfare* | *Ln Airfare* | *Ln Airfare* | *Ln Airfare* | *Ln Airfare* | *Ln Airfare* |
| Ln Fuel * ExcessDistance | -0.032 | -0.033 | -0.316*** | 0.000 | -0.062** | -0.025 | -0.051** |
| | [0.023] | [0.023] | [0.022] | [0.047] | [0.026] | [0.023] | [0.023] |
| Ln Fuel * ExcessDistance^2 | 0.300*** | 0.299*** | 0.298*** | 0.329*** | 0.293*** | 0.304*** | 0.197*** |
| | [0.042] | [0.042] | [0.042] | [0.081] | [0.051] | [0.042] | [0.045] |
| Ln Fuel * NonStopDist | -0.071*** | -0.071*** | -0.071*** | -0.041*** | -0.082*** | -0.066*** | -0.085*** |
| | [0.002] | [0.002] | [0.002] | [0.003] | [0.002] | [0.002] | [0.002] |
| Partial R-squared | 0.00423 | 0.00430 | 0.00428 | 0.00210 | 0.00524 | 0.00382 | 0.00867 |
| F-Test of IVs | 668.7 | 679.5 | 676.7 | 108.1 | 537.3 | 577.3 | 849.2 |
| **1st Stage Dependent Var:** | *Ln Segm* | *Ln Segm* | *Ln Segm* | *Ln Segm* | *Ln Segm* | *Ln Segm* | *Ln Segm* |
| Ln Fuel * ExcessDistance | 0.021** | 0.020** | -0.241*** | 0.037 | 0.013 | 0.016* | 0.006 |
| | [0.010] | [0.010] | [0.009] | [0.023] | [0.010] | [0.010] | [0.010] |
| Ln Fuel * ExcessDistance^2 | 0.277*** | 0.275*** | 0.275*** | 0.250*** | 0.279*** | 0.274*** | 0.244*** |
| | [0.017] | [0.017] | [0.017] | [0.039] | [0.019] | [0.017] | [0.019] |
| Ln Fuel * NonStopDist | 0.000 | -0.001 | -0.001 | 0.003** | -0.005*** | -0.003*** | -0.001 |
| | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] |
| Partial R-squared | 0.00354 | 0.00347 | 0.00346 | 0.00209 | 0.00379 | 0.00352 | 0.00345 |
| F-Test of IVs | 448.6 | 438.5 | 437.4 | 82.27 | 322.1 | 425.3 | 299.9 |

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in brackets.

*Notes:*

1. The table reports the estimates from the quantity regression described by equation (18) in the text. The estimation sample comes from the DB1B dataset and includes information on economy-class tickets for U.S. outbound travel. The unit of observation is a true origin-destination-year triplet.
2. The variable of interest is *OSA* (dummy), respectively *OSA Combine*. The latter is constructed as described in equation (22) in the text, using the passenger share measure for *OSA Connect* defined in equation (20), and a threshold value equal to the 25th percentile.
3. All specifications are estimated by 2SLS method. The excluded instruments for the endogenous price and flight segments variables are: the non-stop distance between the origin and destination cities interacted with fuel prices, the excess travel distance in the base year calculated relative to the non-stop distance, and its squared value, both interacted with fuel prices. The first stage regression coefficients and main performance statistics are reported at the bottom of the table.
4. All specifications include year and city-pair fixed effects, as well as unreported controls for seasonality (i.e., annual quarters), as well as linear trends for the Asian crisis period and for Caribbean destinations.

## Table 5: Impact of Air Liberalization on the Number of U.S. Exit Points Used per Origin-Destination Route (DB1B Sample)

| | Dependent variable: Ln Number US Exit Points | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| OSA Combine | 0.027*** | 0.035*** | 0.034*** |
| | [0.002] | [0.003] | [0.002] |
| OSA Combine*Pre-OSA Gateway | | -0.062*** | -0.062*** |
| | | [0.008] | [0.008] |
| OSA Combine*Large Hub | | -0.005 | |
| | | [0.005] | |
| OSA Combine*Large Hub (T100) | | | -0.104*** |
| | | | [0.010] |
| Ln Pax | 0.483*** | 0.481*** | 0.484*** |
| | [0.022] | [0.022] | [0.022] |
| Ln MSA Income | -0.028 | -0.018 | -0.021 |
| | [0.018] | [0.018] | [0.019] |
| Ln PcGDP | -0.087*** | -0.086*** | -0.089*** |
| | [0.019] | [0.019] | [0.019] |
| Share One-way | -0.055*** | -0.055*** | -0.055*** |
| | [0.002] | [0.002] | [0.002] |
| Partial Liberalization | -0.032*** | -0.034*** | -0.035*** |
| | [0.003] | [0.003] | [0.003] |
| Pre-OSA Gateway | | -0.053*** | -0.052*** |
| | | [0.014] | [0.014] |
| Large Hub | | -0.023*** | -- |
| | | [0.005] | |
| OSA * Indirect Gateway | | -0.021*** | -0.021*** |
| | | [0.008] | [0.008] |
| Indirect Gateway | | -0.061*** | -0.063*** |
| | | [0.016] | [0.016] |
| Year FE | yes | yes | yes |
| Origin-Destination FE | yes | yes | yes |
| Observations | 470,597 | 470,597 | 470,597 |
| R-squared | 0.275 | 0.276 | 0.275 |
| Hansen's j p-val | 0.142 | 0.371 | 0.427 |
| Hansen's j stat | 2.152 | 0.800 | 0.632 |
| **First Stage Dependent Var:** | *Ln Pax* | *Ln Pax* | *Ln Pax* |
| Ln State Exports | 0.030*** | 0.031*** | 0.030*** |
| | [0.002] | [0.002] | [0.002] |
| Visa Waiver Program Participation | -0.185*** | -0.186*** | -0.185*** |
| | [0.009] | [0.009] | [0.009] |
| Partial R-squared | 0.00167 | 0.00172 | 0.00167 |
| F-Test of IVs | 365.5 | 375.4 | 365.5 |

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in brackets.

*Notes:*

1. The table reports the estimates from a regression specification similar to equation (19) in the text, except that the dependent variable in this case is the number of distinct U.S. exit points transited by passengers from an origin city *o* going to the final destination *d* at time *t*. The sample and estimation specification descriptions from Tables 3 and 4 apply here as well.
2. The variable of interest is *OSA Combine*, which is constructed as described in equation (22) in the text, using the distance share measure for *OSA Connect* defined in equation (21), and a threshold equal to the median value. All specifications are estimated by 2SLS method. The first stage regression coefficients and main performance statistics are reported at the bottom of the table.

# Table 6: Flight Segments Regressions: True Origin-Destination Air Travel (DB1B Sample)

| | **Dependent variable: Ln Flight Segments** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6)** | **(7)** | **(8)** |
| | **OSA** | **OSA** | **By Gateways** | **By Gateways** | **Large cities** | **Small cities** | **Direct Routes** | **Drop EU** |
| OSA | -0.004*** | | | | | | | |
| | [0.001] | | | | | | | |
| OSA Combine | | 0.012*** | 0.009*** | 0.012*** | 0.006*** | 0.014*** | 0.012*** | 0.006*** |
| | | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] | [0.001] |
| OSA Combine*Pre-OSA Gateway | | | 0.003 | -0.004 | | | | |
| | | | [0.003] | [0.003] | | | | |
| OSA Combine*Large Hub | | | 0.011*** | | | | | |
| | | | [0.002] | | | | | |
| OSA Combine*Large Hub (T100) | | | | -0.045*** | | | | |
| | | | | [0.003] | | | | |
| Ln Pax | -0.060*** | -0.065*** | -0.065*** | -0.065*** | -0.051*** | -0.069*** | -0.080*** | -0.078*** |
| | [0.007] | [0.007] | [0.007] | [0.007] | [0.010] | [0.010] | [0.008] | [0.006] |
| Ln MSA Income | 0.038*** | 0.040*** | 0.039*** | 0.041*** | -0.030*** | 0.065*** | 0.049*** | 0.079*** |
| | [0.006] | [0.006] | [0.006] | [0.006] | [0.011] | [0.007] | [0.006] | [0.007] |
| Ln PcGDP | -0.017*** | -0.011* | -0.011* | -0.011* | -0.025*** | -0.010 | -0.008 | -0.008 |
| | [0.006] | [0.006] | [0.006] | [0.006] | [0.009] | [0.008] | [0.007] | [0.007] |
| Share One-way | 0.022*** | 0.022*** | 0.022*** | 0.022*** | 0.028*** | 0.019*** | 0.022*** | 0.014*** |
| | [0.001] | [0.001] | [0.001] | [0.001] | [0.002] | [0.001] | [0.001] | [0.001] |
| Partial Liberalization | -0.011*** | -0.004*** | -0.004*** | -0.004*** | -0.000 | -0.005*** | -0.004*** | -0.001 |
| | [0.001] | [0.001] | [0.001] | [0.001] | [0.002] | [0.001] | [0.001] | [0.001] |
| Pre-OSA Gateway | | | -0.088*** | -0.085*** | | | | |
| | | | [0.005] | [0.005] | | | | |
| Large Hub | | | -0.012*** | | | | | |
| | | | [0.002] | | | | | |
| OSA * Indirect Gateway | | | 0.005* | 0.010*** | | | | |
| | | | [0.003] | [0.003] | | | | |
| Indirect Gateway | | | -0.033*** | -0.035*** | | | | |
| | | | [0.005] | [0.005] | | | | |
| Year FE | yes | yes | yes | yes | yes | yes | yes | yes |
| Origin-Destination FE | yes | yes | yes | yes | yes | yes | yes | yes |
| Additional Controls | Asia crisis linear trend; Caribbean linear trend; Annual quarters | | | | | | | |
| Observations | 470,597 | 470,597 | 470,597 | 470,597 | 154,512 | 315,293 | 452,261 | 317,247 |
| R-squared | 0.090 | 0.082 | 0.085 | 0.085 | 0.107 | 0.069 | 0.059 | 0.077 |
| Hansen's j p-val | 0.00235 | 0.00882 | 0.0129 | 0.00527 | 0.00419 | 0.375 | 4.29e-05 | 0.200 |
| Hansen's j stat | 9.252 | 6.858 | 6.187 | 7.784 | 8.199 | 0.787 | 16.74 | 1.641 |
| **1st Stage Dependent Var:** | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* | *Ln Pax* |
| Ln State Exports | 0.030*** | 0.029*** | 0.031*** | 0.030*** | 0.039*** | 0.030*** | 0.030*** | 0.037*** |
| | [0.002] | [0.002] | [0.002] | [0.002] | [0.003] | [0.002] | [0.002] | [0.002] |
| Visa Waiver Program Participation | -0.179*** | -0.159*** | -0.186*** | -0.185*** | -0.209*** | -0.185*** | -0.180*** | -0.272*** |
| | [0.009] | [0.011] | [0.009] | [0.009] | [0.015] | [0.009] | [0.009] | [0.010] |
| Partial R-squared | 0.00159 | 0.00167 | 0.00172 | 0.00167 | 0.00237 | 0.00138 | 0.00155 | 0.00300 |
| F-Test of IVs | 348.0 | 365.5 | 375.4 | 365.5 | 172.8 | 191.1 | 331.7 | 498.1 |

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in brackets.

*Notes:* The table reports the estimates from regression described by equation (19) in the text, using the number of flight segments per origin-destination market as the dependent variable. The sample and estimation specification descriptions from Tables 3 and 4 apply here as well. The variable of interest is *OSA Combine*, which is constructed as described in equation (22) in the text, using the distance share measure for *OSA Connect* defined in equation (21), and a threshold equal to the median value. All specifications are estimated by 2SLS method. The first stage regression coefficients and main performance statistics are reported at the bottom of the table.

## Table 7: Consumer Welfare Calculations

| | Consumer Welfare Effects of OSA | | | | |
|---|---|---|---|---|---|
| | Pooled Estimates | Pre-OSA Gateway | Large Hub | Large Hub T100 | Small City |
| *Total Price Effects:* | *-0.041* | *-0.050* | *-0.053* | *-0.069* | *-0.038* |
| Of which: | | | | | |
| Direct Effect: | -0.021 | -0.039 | -0.029 | -0.029 | -0.018 |
| Indirect Effect via Quantity: | -0.020 | -0.012 | -0.025 | -0.031 | -0.019 |
| Indirect Effect via Connectivity: | 0.000 | 0.001 | 0.001 | -0.009 | -0.001 |
| *Total Quantity (Demand)Effects:* | *0.192* | *0.112* | *0.241* | *0.299* | *0.183* |
| Of which: | | | | | |
| Direct Effect: | 0.139 | 0.051 | 0.175 | 0.175 | 0.133 |
| Indirect Effect via Prices: | 0.053 | 0.064 | 0.069 | 0.089 | 0.049 |
| Indirect Effect via Connectivity: | 0.000 | -0.003 | -0.003 | 0.034 | 0.002 |
| *Piece Equivalent Quality Effect:* | *-0.108* | *-0.037* | *-0.133* | *-0.162* | *-0.105* |
| ***Total tariff equivalent of OSA:*** | ***-0.149*** | ***-0.087*** | ***-0.187*** | ***-0.231*** | ***-0.142*** |
| **Average Price Effect at U.S. Level** | | | | | |
| *City Pop. Shares as Weights* | | | ***-0.144*** | | |
| *City Pax Shares as Weights* | | | ***-0.143*** | | |

*Notes:* The calculations reported in this table reflect a comparative statics exercise and correspond to the partial and total effects resulting from the signing of an Open Skies Agreement (i.e., change in OSA from 0 to 1). The Empirical Methodology Appendix 2B provides the analytical details behind the comparative statics calculation. The calculations are done using average sample estimates (pooled city sample), as well as estimates specific to each type of origin city. Rows 1 and 5 (in italics) report the total effect of a change in OSA on the average price and aggregate quantity of travel in an origin-destination market. Each of these total effects can be decomposed into partial effects consisting of a direct effect of a change in OSA, an indirect effect operating via a change in price or quantity, and an indirect effect operating via a change in directness (i.e., the average number of segments). These partial effects, which sum up to the total effect, are reported in rows 2-4 for prices, respectively 6-8 for quantities. The quantity effect net of price changes (i.e., rows 6 and 8) correspond to a broadly defined quality effect. To express it in price equivalent terms (row 9), the quality effect is divided by the price elasticity of demand. The total tariff equivalent of OSA corresponds to the aggregate price drop generated by the price and quality effects (row 1 + row 9). The last two rows of the table represent the weighted average of the tariff equivalents for each city type, where the weights reflect the U.S. population share or passenger share accounted by those city types.

# Appendix Tables

## Table A1: List of Countries and Years when Open Skies Agreements were signed

| Year OSA | Country | Region | Population 1993 | Pop. Growth 1993-2008 | Per-capita Income 1993 | Income Growth 1993-2008 |
|---|---|---|---:|---:|---:|---:|
| 1992 | Netherlands | OECD Europe | 16.54 | 4.68 | 9.88 | 4.95 |
| 1995 | Austria | OECD Europe | 15.89 | 4.66 | 9.89 | 4.92 |
| 1995 | Belgium | OECD Europe | 16.13 | 4.66 | 9.85 | 4.88 |
| 1995 | Denmark | OECD Europe | 15.46 | 4.66 | 10.11 | 4.88 |
| 1995 | Finland | OECD Europe | 15.44 | 4.65 | 9.78 | 5.10 |
| 1995 | Iceland | OECD Europe | 12.48 | 4.79 | 10.13 | 5.02 |
| 1995 | Norway | OECD Europe | 15.28 | 4.71 | 10.30 | 4.96 |
| 1995 | Sweden | OECD Europe | 15.98 | 4.66 | 10.00 | 4.98 |
| 1995 | Switzerland | OECD Europe | 15.75 | 4.70 | 10.37 | 4.78 |
| 1995 | Czech Republic | Europe & Central Asia | 16.15 | 4.61 | 8.46 | 5.09 |
| 1996 | Germany | OECD Europe | 18.21 | 4.62 | 9.91 | 4.84 |
| 1996 | Jordan | Middle East & North Africa | 15.18 | 5.02 | 7.41 | 5.01 |
| 1997 | Chile | Latin America & Caribbean | 16.45 | 4.79 | 8.23 | 5.11 |
| 1997 | Costa Rica | Latin America & Caribbean | 15.01 | 4.92 | 8.15 | 5.01 |
| 1997 | El Salvador | Latin America & Caribbean | 15.53 | 4.70 | 7.49 | 5.00 |
| 1997 | Guatemala | Latin America & Caribbean | 16.07 | 4.97 | 7.33 | 4.83 |
| 1997 | Honduras | Latin America & Caribbean | 15.49 | 4.92 | 7.02 | 4.85 |
| 1997 | Malaysia | East Asia & Pacific | 16.79 | 4.93 | 8.06 | 5.09 |
| 1997 | New Zealand | East Asia & Pacific | 15.09 | 4.78 | 9.34 | 4.90 |
| 1997 | Nicaragua | Latin America & Caribbean | 15.31 | 4.85 | 6.45 | 4.96 |
| 1997 | Panama | Latin America & Caribbean | 14.76 | 4.89 | 8.15 | 5.11 |
| 1997 | Singapore | East Asia & Pacific | 15.01 | 4.98 | 9.74 | 5.17 |
| 1998 | Italy | OECD Europe | 17.86 | 4.66 | 9.73 | 4.76 |
| 1998 | Korea | East Asia & Pacific | 17.60 | 4.70 | 9.02 | 5.23 |
| 1998 | Peru | Latin America & Caribbean | 16.95 | 4.83 | 7.42 | 5.17 |
| 1998 | Romania | Europe & Central Asia | 16.94 | 4.55 | 7.35 | 5.21 |
| 1999 | Bahrain | Middle East & North Africa | 13.21 | 4.96 | 9.34 | 5.00 |
| 1999 | Pakistan | South Asia | 18.57 | 4.96 | 6.21 | 4.87 |
| 1999 | Portugal | OECD Europe | 16.12 | 4.67 | 9.08 | 4.88 |
| 1999 | Tanzania | Sub-Saharan Africa | 17.15 | 5.02 | 5.53 | 4.97 |
| 1999 | UAE* | Middle East & North Africa | 14.60 | 9.99 | 9.99 | 4.78 |
| 2000 | Ghana | Sub-Saharan Africa | 16.61 | 4.97 | 5.44 | 4.96 |
| 2000 | Malta and Gozo* | Europe & Central Asia | 12.82 | 8.92 | 8.92 | 4.95 |
| 2000 | Morocco | Middle East & North Africa | 17.08 | 4.80 | 7.04 | 5.03 |
| 2000 | Nigeria | Sub-Saharan Africa | 18.47 | 4.97 | 5.90 | 4.90 |
| 2000 | Senegal | Sub-Saharan Africa | 15.92 | 5.00 | 6.10 | 4.79 |
| 2000 | The Gambia* | Sub-Saharan Africa | 13.82 | 5.81 | 5.81 | 4.69 |
| 2000 | Turkey | Europe & Central Asia | 17.90 | 4.83 | 8.19 | 4.95 |
| 2001 | France | OECD Europe | 17.87 | 4.69 | 9.87 | 4.83 |
| 2001 | Oman* | Middle East & North Africa | 14.53 | 8.93 | 8.93 | 4.86 |
| 2001 | Poland | Europe & Central Asia | 17.47 | 4.60 | 8.02 | 5.32 |
| 2001 | Sri Lanka | South Asia | 16.69 | 4.74 | 6.47 | 5.22 |
| 2002 | Jamaica | Latin America & Caribbean | 14.71 | 4.70 | 8.19 | 4.65 |
| 2002 | Uganda | Sub-Saharan Africa | 16.79 | 5.08 | 5.27 | 5.18 |
| 2003 | Albania | Europe & Central Asia | 14.98 | 4.58 | 6.57 | 5.53 |
| 2004 | Indonesia | East Asia & Pacific | 19.04 | 4.80 | 6.60 | 5.00 |
| 2004 | Uruguay | Latin America & Caribbean | 14.97 | 4.66 | 8.72 | 4.96 |
| 2005 | India | South Asia | 20.62 | 4.84 | 5.82 | 5.36 |
| 2005 | Mali | Sub-Saharan Africa | 16.03 | 4.93 | 5.25 | 5.05 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2005 | Paraguay | Latin America & Caribbean | 15.34 | 4.91 | 7.26 | 4.67 |
| 2005 | Thailand | East Asia & Pacific | 17.89 | 4.74 | 7.45 | 5.04 |
| 2006 | Cameroon | Sub-Saharan Africa | 16.41 | 4.97 | 6.39 | 4.77 |
| 2007 | Bulgaria | Europe & Central Asia | 15.95 | 4.50 | 7.30 | 5.16 |
| 2007 | Canada | NAFTA | 17.18 | 4.75 | 9.85 | 4.94 |
| 2007 | Cyprus | Europe & Central Asia | 13.47 | 4.80 | 9.18 | 4.99 |
| 2007 | Greece | OECD Europe | 16.16 | 4.67 | 9.18 | 5.05 |
| 2007 | Hungary | Europe & Central Asia | 16.15 | 4.57 | 8.19 | 5.15 |
| 2007 | Ireland | OECD Europe | 15.09 | 4.82 | 9.60 | 5.34 |
| 2007 | Liberia | Sub-Saharan Africa | 14.48 | 5.27 | 4.42 | 5.18 |
| 2007 | Spain | OECD Europe | 17.48 | 4.76 | 9.35 | 4.95 |
| 2007 | United Kingdom | OECD Europe | 17.87 | 4.67 | 9.91 | 4.97 |
| 2008 | Australia | East Asia & Pacific | 16.69 | 4.80 | 9.78 | 4.96 |
| 2008 | Kenya | Sub-Saharan Africa | 17.07 | 5.01 | 6.02 | 4.70 |
| 2008 | Laos | East Asia & Pacific | 15.33 | 4.91 | 5.49 | 5.27 |

* Growth rates are for the period 1993-2007.

*Note*: The following 16 countries have signed an Open Skies Agreement with the U.S. but there is missing data on either population or income for the period of interest: Armenia (2008), Aruba (1997), Bosnia-Hercegovina (2007), Croatia (2008), Estonia (2007), Georgia (2007), Kuwait (2006), Latvia (2006), Lithuania (2007), Luxembourg (1995), Quatar (2001), Slovakia (2000), Slovenia (2007), Tonga (2003), Uzbekistan (1998), Western Samoa (2002).

## Table A2: Testing for Endogeneity in the Timing of Open Skies Agreements

| | **Dependent Variable: (Year OSA - 1992)** | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Log Population 1993 | 0.504 | | | | 0.180 | 0.501 |
| | [0.307] | | | | [0.412] | [0.513] |
| Log Population Growth ‘93-‘08 | 3.413 | | | | -1.041 | -7.399 |
| | [3.422] | | | | [4.363] | [5.509] |
| Log GDP 1993 | | -0.154 | | | | |
| | | [0.310] | | | | |
| Log GDP Growth ‘93-‘08 | | 3.635 | | | | |
| | | [2.506] | | | | |
| Log Per-Capita GDP 1993 | | | -0.501 | | -0.470 | -0.173 |
| | | | [0.513] | | [0.692] | [1.062] |
| Log Per Capita GDP Growth ‘93-‘08 | | | 3.292 | | 2.452 | -2.564 |
| | | | [2.758] | | [3.561] | [3.892] |
| Log Exports 1993 | | | | -0.279 | | |
| | | | | [0.214] | | |
| Log Export Growth ‘93-‘08 | | | | -0.838 | -0.420 | -0.175 |
| | | | | [0.688] | [0.615] | [1.062] |
| Log Distance | | | | | 1.499 | |
| | | | | | [1.697] | |
| Log Average Tariffs (year 2001) | | | | | | 0.683 |
| | | | | | | [0.858] |
| High & Upper Middle Income Dummy | | | -1.299 | -1.868 | -1.568 | -2.124 |
| | | | [1.611] | [1.205] | [1.661] | [1.849] |
| Constant | -16.101 | -6.729 | -3.277 | 19.862*** | -8.113 | 51.420 |
| | [18.107] | [17.785] | [15.610] | [6.570] | [34.723] | [47.141] |
| Observations | 64 | 64 | 64 | 64 | 64 | 41 |
| R-squared | 0.039 | 0.048 | 0.124 | 0.105 | 0.160 | 0.171 |

*** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in brackets.

## Table A3: Summary Statistics

| Variable | Obs. | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|---|
| **Policy Variables:** | | | | | |
| OSA | 470606 | 0.386 | 0.487 | 0.000 | 1.000 |
| OSA Combine (Dist) | 470606 | 0.450 | 0.473 | 0.000 | 1.000 |
| OSA Combine (Pax) | 470606 | 0.531 | 0.499 | 0.000 | 1.000 |
| Partial Liberalization | 470606 | 0.215 | 0.411 | 0.000 | 1.000 |
| Pre-OSA Gateway | 470606 | 0.060 | 0.238 | 0.000 | 1.000 |
| Large Hub | 470606 | 0.266 | 0.442 | 0.000 | 1.000 |
| Indirect Gateway | 470606 | 0.054 | 0.225 | 0.000 | 1.000 |
| **Route Characteristics:** | | | | | |
| Ln Pax (coach class) | 470606 | 1.797 | 1.630 | 0.000 | 10.373 |
| Ln Airfare | 470606 | 1.623 | 0.544 | -0.895 | 4.367 |
| Ln Ticket Distance | 470606 | 4820 | 2743 | 96 | 15998 |
| (Pax) Share Direct Flight | 470606 | 0.012 | 0.096 | 0.000 | 1.000 |
| Ln Flight Segments | 470606 | 0.961 | 0.221 | 0.000 | 1.386 |
| (Pax) Share One-way | 470606 | 0.148 | 0.249 | 0.000 | 1.000 |
| Number US Exit Points | 470606 | 2.933 | 2.650 | 1.000 | 36.000 |
| Ln Number US Exit Points | 470606 | 0.780 | 0.734 | 0.000 | 3.584 |
| Ln Excess Distance (base year) | 470606 | 0.120 | 0.114 | -1.190 | 0.975 |
| **Demand and Cost Shifters:** | | | | | |
| Ln MSA Population | 470606 | 13.906 | 1.239 | 10.911 | 16.743 |
| Ln MSA Income | 470606 | 10.318 | 0.251 | 9.262 | 11.112 |
| Ln Country Population | 470606 | 17.126 | 1.803 | 10.600 | 21.001 |
| Ln PcGDP | 470606 | 8.960 | 1.267 | 4.817 | 11.189 |
| Ln State Exports | 470606 | 14.083 | 2.660 | 3.084 | 19.980 |
| Insurance Cost Index | 470606 | 162.544 | 76.414 | 79.288 | 320.907 |
| Fuel Cost Index | 470606 | 131.897 | 67.390 | 69.096 | 290.210 |
| Visa Waiver Program Participation | 470606 | 0.333 | 0.471 | 0.000 | 1.000 |
| EU dummy | 470606 | 0.326 | 0.469 | 0.000 | 1.000 |
| NAFTA dummy | 470606 | 0.215 | 0.411 | 0.000 | 1.000 |
| Carribbean dummy | 470606 | 0.182 | 0.386 | 0.000 | 1.000 |
| Ln Fuel * ExcessDistance | 470606 | 0.575 | 0.550 | -5.554 | 5.530 |
| Ln Fuel * ExcessDistance^2 | 470606 | 0.131 | 0.282 | 0.000 | 6.608 |
| (Pax) Share Quarter 1 | 470606 | 0.219 | 0.267 | 0.000 | 1.000 |
| (Pax) Share Quarter 2 | 470606 | 0.276 | 0.282 | 0.000 | 1.000 |
| (Pax) Share Quarter 3 | 470606 | 0.262 | 0.281 | 0.000 | 1.000 |
| (Pax) Share Quarter 4 | 470606 | 0.244 | 0.274 | 0.000 | 1.000 |

*Note:* The reported summary statistics correspond to the estimation sample used in generating the price, quantity and directness effects reported in Tables 3-6.

## I. Theory Appendix

### Appendix 1A:

Recall that the profit functional for a direct flight is:

$$\pi_i^D(q_i, q_{-i}) = \int_{\underline{p}}^{\overline{p}} [\left(1 - F\left(e(p,q)\right)\right) p - \lambda_D] q_i(p) dp \tag{3}$$

the profit functional for an indirect flight is given by:

$$\pi_i^I(q_i, q_{-i}) = \int_{\underline{p}}^{\overline{p}} [\left(1 - F\left(e(p,q)\right)\right) \alpha p - \lambda_D - \lambda_C] q_i(p) dp \tag{4}$$

and that under proportional rationing

$$e(p,q) = \int_p^p \frac{q(r)}{D(r)} dr$$

We formulate the direct carriers' profit maximization problem as an optimal control problem as follows. Let $\dot{Q}_i(p) = q_i(p) \equiv u(p)$ be the control. There is a monotonicity constraint on the control variable, $u(p) \geq 0$. Let $Q_i(p) \equiv x_1(p)$ be a state variable, where $\dot{x}_1(p) = u(p)$. Let $e(p,q) \equiv x_2(p)$ be a second state variable and note that $\dot{x}_2(p) = \frac{q_{-i}(p)+u(p)}{D(p)}$. If indirect carriers are offering service on the route, then the second state variable satisfies the boundary condition $1 - F(x_2(\overline{p})) = \frac{\lambda_D+\lambda_C}{\overline{p}\alpha}$.[29] If only direct service is offered on the route, then the boundary condition on the second state variable is $1 - F(x_2(\overline{p})) = \frac{\lambda_D}{\overline{p}}$. The corresponding problem for the indirect carriers follows directly.

As the Hamiltonian is not concave with respect to $(u, x_1, x_2)$ we cannot appeal directly to the (Pontryagin) Maximum Principle as a sufficient condition for maximization. However, as this is a one-dimensional problem that is linear with respect to the control, we can use the Extension Principle to solve for the global maximizer.

As the first state variable $x_1$ does not appear in the objective function, we will economize on notation by redefining $x_2(p)$ as just $x(p)$. We focus on the case that the market has indirect carriers and may have direct carriers ($n_I > 0$, $n_D \geq 0$), and that equilibrium is symmetric in the

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[29] In the case that both direct and indirect carriers are offering service, this boundary condition only applies to the left-hand limit of $x_2(p)$.

sense defined above. The problem for the direct carriers is described as follows. Define the function $\phi^D(p,x)$ as:

$$\phi^D(p,x) = -\int_0^x [(1-F(z))p - \lambda_D]D(p)dz$$

Next, define the function $R^D(p,x)$ as follows:

$$R^D(p,x) = -\left[\left(1 - F(x)\right)p - \lambda_D\right]q^D_{-i}(p) + \phi^D_p \tag{5}$$

The function $R^D(p,x)$ is continuous and under Assumption 1, there exists an $x^*(p)$ such that $R^D(p,x^*(p)) = \max_x R^D(p,x)$ for all $p \in [\underline{p}, \overline{p}]$ and $x^*(\overline{p}) = 1$. By the Extension Principle the original problem of maximizing $\pi_i(q_i, q_{-i})$ with respect to $q_i$ is reduced to the problem of finding the global maximum $x^*(p)$ of $R^D(p,x(p))$, in which the control $u$ is excluded from the problem. Moving on to the indirect carriers, define the function $\phi^I(p,x)$ as:

$$\phi^I(p,x) = -\int_0^x [(1-F(z))\alpha p - \lambda_D - \lambda_C]D(p)dz$$

and the function $R^I(p,x)$ as:

$$R^I(p,x) = -[\left(1 - F(x)\right)\alpha p - \lambda_D - \lambda_C]q^I_{-i}(p) + \phi^I_p \tag{6}$$

As before, there exists an $x^*(p)$ such that $R^I(p,x^*(p)) = \max_x R^I(p,x)$ for all $p \in [\underline{p}, \overline{p}]$ and $x^*(\overline{p}) = 1$. Furthermore, $x^*(p)$ must be the same for the direct and indirect carriers.

We now solve for $x^*(p)$. Setting $R^D_x = 0$, we have:

$$F'(x)pq^D_{-i}(p) - (1-F(x))D(p) - [(1-F(x))p - \lambda_D]D'(p) = 0 \tag{7}$$

Note that due to Assumption 1, $R^D(p,x)$ is strictly concave in $x$, and so by the Maximum Theorem there exists a continuous function $x^*(p)$ that solves (7). Similarly, setting $R^I_x = 0$,

$$F'(x)\alpha pq^I_{-i}(p) - (1-F(x))\alpha D(p) - [(1-F(x))\alpha p - \lambda_D - \lambda_C]D'(p) = 0 \tag{8}$$

As before, $R^I(p,x)$ is strictly concave in $x$, and there exists a continuous function $x^*(p)$ that solves (8).

From (7) and (8), we see that $q^D_{-i}(p)$ must be the same for each carrier $i$ with a direct connection and that $q^I_{-i}(p)$ must be the same for each carrier $i$ with an indirect connection.

Thus, the equilibrium price-quantity schedules, $q_i(p)$, must necessarily be symmetric[30] within carrier type (direct or indirect) and we have that:

$$q_{-i}^D(p) = (n_D - 1)q^D(p) + n_I q^I(p) \tag{9}$$

and

$$q_{-i}^I(p) = n_D q^D(p) + (n_I - 1)q^I(p). \tag{10}$$

Combining this with (7) and (8) it follows that

$$q_{-i}^I(p) - q_{-i}^D(p) = q^D(p) - q^I(p) = -\frac{D'(p)}{F'(x)p}\left(\frac{\lambda_D + \lambda_C}{\alpha} - \lambda_D\right) \tag{11}$$

and so

$$q^I(p) = q^D(p) + \frac{D'(p)}{F'(x)p}\left(\frac{\lambda_D + \lambda_C}{\alpha} - \lambda_D\right) \tag{12}$$

and

$$q(p) = nq^D(p) + \frac{n_I D'(p)}{F'(x)p}\left(\frac{\lambda_D + \lambda_C}{\alpha} - \lambda_D\right) \tag{13}$$

At this point it is useful to define $y(p) = 1 - F(x(p))$, with $\dot{y}(p) = -F'(x(p))\dot{x}(p)$, and note that $u(p) = q^D(p)$ and so $\dot{x}(p) = \frac{nq^D(p)}{D(p)} + \frac{n_I D'(p)}{F'(x)pD(p)}\left(\frac{\lambda_D + \lambda_C}{\alpha} - \lambda_D\right)$. Inserting this into (7), we have

$$\dot{y}(p) + \frac{y(p)n[D(p) + pD'(p)]}{pD(p)(n-1)} = \frac{\left(n_D\lambda_D + n_I\left(\frac{\lambda_D + \lambda_C}{\alpha}\right)\right)D'(p)}{pD(p)(n-1)} \tag{14}$$

which is a first-order linear differential equation.

As indirect carriers are offering service on the route, the boundary condition is given by $y(\bar{p}) = 1 - F(x(\bar{p})) = \frac{\lambda_D + \lambda_C}{\bar{p}\alpha}$. Thus, the unique solution of this differential equation is given by:

$$y^*(p) = \frac{\lambda_D + \lambda_C}{\bar{p}\alpha}\left[\frac{\bar{p}D(\bar{p})}{pD(p)}\right]^{\frac{n}{n-1}} - \frac{1}{n-1}\frac{\int_p^{\bar{p}}\left(n_D\lambda_D + n_I\left(\frac{\lambda_D + \lambda_C}{\alpha}\right)\right)D'(r)\left(rD(r)\right)^{\frac{1}{n-1}}dr}{\left(pD(p)\right)^{\frac{n}{n-1}}} \tag{15}$$

The lower bound of the support of the prices $\underline{p}$ solves $y^*(\underline{p}) = 1$.

---

[30] Except for possibly at a mass point at the upper boundary of the price support.

Recall that $x^*(p) = F^{-1}(1 - y^*(p))$ and so $\dot{x}^*(p) = \frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))}$, but $\dot{x}^*(p) = \frac{nq^D(p)}{D(p)} + \frac{n_I D'(p)}{F'(x)pD(p)}\left(\frac{\lambda_D+\lambda_C}{\alpha} - \lambda_D\right)$ and so for $p \in [\underline{p}, \overline{p})$

$$q^D(p) = \left(\frac{D(p)}{n}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))} - \frac{n_I D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}\left(\frac{\lambda_D+\lambda_C}{\alpha} - \lambda_D\right)\right)$$

and each direct carrier places a mass point at $\overline{p}$ of size

$$\Delta(\overline{p}) = \frac{1}{n_D}\left(F^{-1}\left(1 - \frac{\lambda_D}{\overline{p}}\right) - F^{-1}\left(1 - \frac{\lambda_D + \lambda_C}{\overline{p}\alpha}\right)\right)$$

Note that for $p \in [\underline{p}, \overline{p})$, $q^I(p)$ is given by equation (12). For the case that $n_D = n$, the preceding arguments apply given that the boundary condition is now given by $y(\overline{p}) = \frac{\lambda_D}{\overline{p}}$.

The arguments above establish that $(q^D(\cdot), q^I(\cdot))$ is the unique symmetric equilibrium under the restriction that each carrier's marginal quantity schedule, $q^D(\cdot)$ or $q^I(\cdot)$, is continuous on the interior of the price support, i.e. there are no mass points in the carriers' cumulative quantity schedules except for possibly on the boundaries of the price support. To complete the proof that $(q^D(\cdot), q^I(\cdot))$ is the unique symmetric equilibrium we can argue along the lines of Roberson, Cristea, and Hummels (2014) that in any equilibrium each player uses a marginal quantity schedule that is continuous on the interior of the price support and no player places strictly positive mass at the lower bound of the price support.

## Appendix 1B:

To be completed.

## Appendix 1C:

This appendix provides the final-stage local price-quantity schedules for the capacity constraint extension.

**Theorem 2** *With capacity constraints, there exists a symmetric final-stage local equilibrium that is described as follows.*

1. *On the non-gateway hubs,* $n_I = n_A$ *and* $n_D = 0$*, then let* $y^*(p)$ *be defined as*

$$y^*(p) = \frac{\lambda_D^* + \lambda_C}{\overline{p}\,\alpha}\left[\frac{\overline{p}D(\overline{p})}{pD(p)}\right]^{\frac{n_A}{n_A-1}} - \frac{1}{n_A-1}\frac{\int_p^{\overline{p}} n_A\left(\frac{\lambda_D^{A*}+\lambda_C}{\alpha}\right)D'(r)\big(rD(r)\big)^{\frac{1}{n_A-1}}dr}{\big(pD(p)\big)^{\frac{n_A}{n_A-1}}}$$

*The lower bound of the support of the prices,* $\underline{p}$*, solves* $y^*(\underline{p}) = 1$. *The indirect carrier equilibrium price-quantity schedule is, for* $p \in [\underline{p}, \overline{p})$

$$q^I(p) = \left(\frac{D(p)}{n}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))}\right)$$

2. *On the gateway hub* $n_D = n_A + 1$ *and* $n_I = 0$*, then let* $y^*(p)$ *be defined as*

$$y^*(p) = \frac{\lambda_D^*}{\overline{p}}\left[\frac{\overline{p}D(\overline{p})}{pD(p)}\right]^{\frac{n_A+1}{n_A}} - \frac{1}{n_A}\frac{\int_p^{\overline{p}}\big(\lambda_D^{B*} + n_A(\lambda_D^{A*})\big)D'(r)\big(rD(r)\big)^{\frac{1}{n_A}}dr}{\big(pD(p)\big)^{\frac{n_A+1}{n_A}}}$$

*The lower bound of the support of the prices,* $\underline{p}$*, solves* $y^*(\underline{p}) = 1$.

*If* $\lambda_D^{B*} \le \lambda_D^{A*}$ *then the country B carrier equilibrium price-quantity schedule is, for* $p \in [\underline{p}, \overline{p})$

$$q^B(p) = \left(\frac{D(p)}{n_A+1}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))} - \frac{n_A D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}\left(\lambda_D^{A*} - \lambda_D^{B*}\right)\right)$$

*and places a mass point at* $\overline{p}$ *of size*

$$\Delta^B(\overline{p}) = \left(F^{-1}\left(1 - \frac{\lambda_D^{B*}}{\overline{p}}\right) - F^{-1}\left(1 - \frac{\lambda_D^{A*}}{\overline{p}}\right)\right)$$

*For the country A carriers, the equilibrium price-quantity schedule is*

$$q^A(p) = q^B(p) + \frac{D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}(\lambda_D^{A*} - \lambda_D^{B*})$$

*If $\lambda_D^{A*} \leq \lambda_D^{B*}$ then for the country A carriers the equilibrium price-quantity schedule is, for $p \in [\underline{p}, \overline{p})$*

$$q^A(p) = \left(\frac{D(p)}{n_A+1}\right)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1-y^*(p)))} - \frac{D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}(\lambda_D^{B*} - \lambda_D^{A*})\right)$$

*and places a mass point at $\overline{p}$ of size*

$$\Delta^A(\overline{p}) = \frac{1}{n_A}\left(F^{-1}\left(1 - \frac{\lambda_D^{A*}}{\overline{p}}\right) - F^{-1}\left(1 - \frac{\lambda_D^{B*}}{\overline{p}}\right)\right)$$

*For the country B carrier, the equilibrium price-quantity schedule is*

$$q^B(p) = q^A(p) + \frac{D'(p)}{F'(F^{-1}(1-y^*(p)))pD(p)}(\lambda_D^{B*} - \lambda_D^{A*})$$

*where $\lambda_D^{A*}$ and $\lambda_D^{B*}$ take the smallest values, $\lambda_D^A \geq 0$ and $\lambda_D^B \geq 0$ respectively, such that the capacity constraints are satisfied for the carriers from both countries.*

The proof of Theorem 2 follows along the same lines as the proof for Theorem 1 and is thus omitted.[31]

## II. Empirical Methodology Appendix

### Appendix 2A: Air Traffic Decomposition

To motivate our analysis, we examine traffic growth patterns using the T-100 International segment data. Total air passenger traffic between the United States and destination country d at time t is defined as the sum of traffic across all routes r and carriers c.

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[31] In particular, note that given a value for $\lambda_D^{A*}$ part 1 of Theorem 2 follows directly from part 1 of Theorem 1, and that given values for $\lambda_D^{A*}$ and $\lambda_D^{B*}$ part 2 of Theorem 2 is isomorphic to part 2 of Theorem 1, where $\alpha = 1$, $\lambda_D = \min\{\lambda_D^{A*}, \lambda_D^{B*}\}$, $\frac{\lambda_D+\lambda_C}{\alpha} = \max\{\lambda_D^{A*}, \lambda_D^{B*}\}$, $n = n_A + 1$, if $\lambda_D^{B*} < \lambda_D^{A*}$ then $n_D = 1$ and $n_I = n_A$, if $\lambda_D^{A*} < \lambda_D^{B*}$ then $n_D = n_A$ and $n_I = 1$, and if $\lambda_D^{A*} = \lambda_D^{B*}$ then $n_D = n_A + 1$ and $n_I = 0$.

$$Q_{dt} = \sum_r Q_{r\in dt} = \sum_r \sum_c Q_{c,r\in dt}$$

We are interested in aggregate traffic growth with country d, as well as a decomposition of that growth into new routes and old routes. For this decomposition, we treat each city-pair route within country d as a distinct traded 'variety', but aggregate over carriers. That is, we count Chicago-Paris as distinct from Atlanta-Paris, but do not distinguish whether that service was operated by United Airlines or Air France.[32]

One simple decomposition of $Q_{dt}$ is to count the number of routes offered $N_{dt}$ and the average passenger volume per route at a given point in time:

$$Q_{dt} = \sum_r Q_{rdt} = N_{dt} * \overline{Q_{dt}}$$

A drawback of this approach is that it treats all air services as having equal value weights in the total consumption of international travel. Alternatively, we can assess the importance of each aviation route using its share of passenger shares for country d. Similar to the extensive margin calculation in Feenstra (1994) and the decomposition method in Hummels and Klenow (2005), we denote by $I_{dt}$ the set of all routes offered between the US and country d in period $t$, and by $I_d$ the subset of routes operated between the US and country d in both the reference period $t_0$ and current period $t$, i.e., $I_d \subseteq \left(I_{dt} \cap I_{dt_0}\right)$.[33] Then the total bilateral volume of air passengers can be decomposed as follows:

$$Q_{dt} = \left(\sum_{r\in I_d} Q_{rdt}\right)(\lambda_{dt})^{-1} \qquad \text{where} \quad \lambda_{dt} = \frac{\sum_{r\in I_d} Q_{rdt}}{\sum_{r\in I_{dt}} Q_{rdt}}$$

The first term of the decomposition -- the intensive margin -- measures the volume of air traffic accounted by aviation routes that are available in both the current and reference periods. The lambda term represents the (passenger-share) weighted count of aviation routes to country d

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[32] Retaining carrier specific traffic information is difficult as carriers frequently enter/exit particular routes, change names, merge, and go out of business. In instances where it is possible to track longer time series for multiple carriers on the same route, we can estimate elasticities of substitution between carriers. We find elasticities of substitution between carriers on a given route almost an order of magnitude larger than elasticities across routes.

[33] In the empirical exercises, we will define the common variety set $I_j$ to include those varieties that are have been available in the current year as well as there years before. This ensures that experimental or temporary aviation routes are excluded from $I_j$. We also experiment with a common variety set including routes offered both currently and in the previous year.

available in both time periods. Alternatively, the lambda term can be viewed as one minus the passenger-share weighted count of aviation routes that are "new" relative to the reference period.[34]

It is useful to express total air traffic in terms of annual growth rates as follows:

$$\frac{Q_{dt}}{Q_{dt-1}} = \left(\frac{\sum_{r \in I_d} Q_{rdt}}{\sum_{r \in I_d} Q_{rdt-1}}\right)\left(\frac{\lambda_{dt}}{\lambda_{dt-1}}\right)^{-1}$$

In this formulation, the first bracketed term captures the growth in air passenger traffic on "common" service varieties (routes), while the second bracketed term measures the *net* change in route offerings between two consecutive years. A lambda-ratio greater (less) than one implies a gain (loss) in service varieties. The benefit of expressing the extensive margin as a net measure is that in this way it accounts not only for new route additions, but also for any disappearing routes since the reference period. However, if adding or withdrawing city-pair routes are discrete, less frequent events, then cumulative (rather than annual) growth rates are a better way to decompose growth. Summing the annual growth rates over time periods until the current year, we get an expression for the cumulative air traffic growth relative to the first sample year 1993:

$$\Delta Q_{dt}^{93} = \Delta IM_{dt}^{93} * \Delta EM_{dt}^{93} \qquad \text{where} \qquad \Delta Z_{dt}^{93} = \prod_{t=1994}^{93} \frac{Z_{dt}}{Z_{dt-1}}$$

and $Z \in \{Q, IM, EM\}$, with each element defined as in equation (9). We normalize $Z^{93}_{d,93}$ to one.

## Appendix 2B: Consumer Welfare Calculation

Estimated regressions:
$$\begin{cases} lnP = \beta_1 lnQ + \beta_2 lnSeg + \beta_3 OSA + \beta_4 lnZ \\ lnQ = \gamma_1 lnP + \gamma_2 lnSeg + \gamma_3 OSA + \gamma_4 lnZ \\ lnSeg = \delta_1 lnQ + \delta_2 OSA + \delta_3 lnZ \end{cases}$$

where Z is a vector of variables that is independent of the OSA aviation policy.

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[34] If all routes carried the same traffic volume (i.e., they have equal weights), then the lambda term would correspond to the fraction of routes from the total number currently offered, that were already available in the reference period. If traffic on new routes is non-negligible, then the inverse of lambda - the extensive margin - is large, having an important contribution towards the total bilateral air traffic flow.

The resulting system of simultaneous equation can be written as:

$$\begin{cases} F^1(lnP, lnQ, lnSeg; OSA) = -lnP + \beta_1 lnQ + \beta_2 lnSeg + \beta_3 OSA + \beta_4 lnZ = 0 \\ F^2(lnP, lnQ, lnSeg; OSA) = \gamma_1 lnP - lnQ + \gamma_2 lnSeg + \gamma_3 OSA + \gamma_4 lnZ = 0 \\ F^3(lnP, lnQ, lnSeg; OSA) = \delta_1 lnQ - lnSeg + \delta_2 OSA + \delta_3 lnZ = 0 \end{cases}$$

Taking the partial derivatives with respect to the policy variable OSA leads to the following:

$$-\frac{\partial lnP}{\partial OSA} + \beta_1 \frac{\partial lnQ}{\partial OSA} + \beta_2 \frac{\partial lnSeg}{\partial OSA} = -\beta_3$$

$$\gamma_1 \frac{\partial lnP}{\partial OSA} - \frac{\partial lnQ}{\partial OSA} + \gamma_2 \frac{\partial lnSeg}{\partial OSA} = -\gamma_3$$

$$\delta_1 \frac{\partial lnQ}{\partial OSA} - \frac{\partial lnSeg}{\partial OSA} = -\delta_2$$

This can be written in matrix form as:

$$\begin{bmatrix} -1 & \beta_1 & \beta_2 \\ \gamma_1 & -1 & \gamma_2 \\ 0 & \delta_1 & -1 \end{bmatrix} \begin{bmatrix} \frac{\partial lnP}{\partial OSA} \\ \frac{\partial lnQ}{\partial OSA} \\ \frac{\partial lnSeg}{\partial OSA} \end{bmatrix} = \begin{bmatrix} -\beta_3 \\ -\gamma_3 \\ -\delta_2 \end{bmatrix}$$

with the relevant Jacobian determinant equal to:

$$|J| = \begin{vmatrix} -1 & \beta_1 & \beta_2 \\ \gamma_1 & -1 & \gamma_2 \\ 0 & \delta_1 & -1 \end{vmatrix} = -1 + \beta_2\gamma_1\delta_1 + \beta_1\gamma_1 + \delta_1\gamma_2$$

By Cramer's rule, the solution comparative statics derivatives are given by:

$$\frac{\partial lnP}{\partial OSA} = \frac{|J_1|}{|J|} = \frac{-\beta_1 (\gamma_3 + \gamma_2\delta_2) - \beta_2(\gamma_3\delta_1 + \delta_2) + \beta_3 (-1 + \delta_1\gamma_2)}{-1 + \beta_2\gamma_1\delta_1 + \beta_1\gamma_1 + \delta_1\gamma_2}$$

$$\frac{\partial lnQ}{\partial OSA} = \frac{|J_2|}{|J|} = \frac{-\gamma_3 - \beta_2\gamma_1\delta_2 - \gamma_1\beta_3 - \delta_2\gamma_2}{-1 + \beta_2\gamma_1\delta_1 + \beta_1\gamma_1 + \delta_1\gamma_2}$$

$$\frac{\partial lnSeg}{\partial OSA} = \frac{|J_3|}{|J|} = \frac{-\delta_2 - \gamma_1\delta_1\beta_3 + \beta_1\gamma_1\delta_2 - \delta_1\gamma_3}{-1 + \beta_2\gamma_1\delta_1 + \beta_1\gamma_1 + \delta_1\gamma_2}$$

Once the total derivatives are calculated, we can use the equations in (2) to decompose the effect of the policy change on each variable of interest into direct and indirect effects (via the other endogenous variables), as follows:

$$\frac{\partial lnP}{\partial OSA} = \beta_3 + \beta_1 \frac{\partial lnQ}{\partial OSA} + \beta_2 \frac{\partial lnSeg}{\partial OSA}$$
$$\frac{\partial lnQ}{\partial OSA} = \gamma_3 + \gamma_1 \frac{\partial lnP}{\partial OSA} + \gamma_2 \frac{\partial lnSeg}{\partial OSA}$$

To calculate the price equivalent of air liberalization, we first convert the indirect effects of OSA on air traffic (Q) into price equivalents, and then add them to the total price effect:

$$Price\ equivalent\ of\ OSA = \frac{1}{\gamma_1}\left(\gamma_3 + \gamma_2 \frac{\partial lnSeg}{\partial OSA}\right) + \frac{\partial lnP}{\partial OSA}$$

## III. Data Appendix

### *T100 International Segment Data*

The original data contains international non-stop segment information reported by both U.S. and foreign air carriers, including the origin and destination airport, transported passengers, available capacity, departures scheduled and performed, when at least one point of service is in the United States. The data is reported at monthly frequencies, with origin-destination-carrier observations distinguished by the direction of air travel.

We perform minor changes to the original dataset to get our estimation sample.
First, we drop entries that correspond to freight or mail air services, and also entries registering positive transported passengers but zero departures operated. Then we create an indicator for outbound air travel equal to 1 if the origin of the flight segment is in the U.S. To avoid the double counting for the (majority) case of round-trip passengers we keep only U.S. outbound observations. Finally, we remove the monthly frequency of the data by aggregating all the origin-destination-carrier observations within each quarter. The resulting sample becomes the main estimation sample for T100 Segment data analyses.

For the calculation of the intensive and extensive margins, we trim the estimation sample further to ensure there are sufficient ‘common variety’ observations. The reason for doing this is because our estimation exercises rely on within group time variation, and so not having a common variety offered for several periods affects the calculation of the intensive and extensive margins and makes our identification problematic. Therefore, we trim the data as follows:

- When a traded service is defines as a distinct route within a country-pair, we keep all quarter-country pairs with at least one segment that is sampled more than 6 times (irrespective of which air carrier operates on that route), i.e., more than half the number of years in the sample.

The choice of cutoff values is made to ensure sufficiently many observations within a cross-section group to be able to rely exclusively on time variation for model identification. However, for narrowly defined cross-sections – e.g., route level – the threshold had to be lowered to maintain sample coverage. Overall, these data trimmings no not remove more than 4 percent of all passenger flows.

### *Databank 1B (DB1B) Origin and Destination Passenger Survey*

The *Databank 1B (DB1B) Origin and Destination Passenger Survey* represents a 10 percent sample of airline tickets drawn from airport-pair routes with at least one end-point in the U.S. Each airline ticket purchase recorded in the data contains information on the complete trip itinerary at airport level of detail, the air carriers marketing the ticket and operating each flight segment, the total air fare, distance traveled split by flight segments, ticket class type, as well as other segment level flight characteristics. Even though more than one air carrier may operate the travel itinerary, the responsibility to report the complete flight information to the DOT falls on the marketing carrier, which is also the one setting the air fare.

We apply several filters to the original DB1B dataset before using it for the empirical analysis. First, we keep only international airline tickets, dropping all domestic itineraries and all international trips transiting only the U.S. Second, we remove circuitous itineraries and keep only tickets that have a single trip break point used in identifying the final destination of the traveler. Third, to limit heterogeneity and coding errors in ticket prices, we further drop the following observations: a). business and first class tickets; b). tickets flagged by the Department of Transportation during data assembly as having unreasonably high fares; c). tickets with fares below \$100 or above \$9,999; d). tickets with more than four flight connections per direction of travel; e). tickets that involve land segments longer than 35 miles (i.e., transfers between two airports of the same city would not be dropped). Using the resulting sample, we construct a few additional ticket-level variables such as indicators for one-way trip, for direct service, and for the U.S. outbound itinerary. For round trip tickets we replace the fare level and ticket distance with half their values, to be directly comparable with one-way tickets. All observations for the same origin-destination pair are collapsed across all quarters within a given year using passenger-share weights to obtain route level annual aggregates. Finally, for reasons dictated by our traffic decomposition methods and described later on, we restrict attention to foreign countries with at least one city-pair route serviced continuously over we remove the very thin and infrequent aviation routes to be able to exploit in the empirics within city-pair variation.[35] The resulting restricted sample is going to be used for the estimation exercises. It includes about 50,000 origin-

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[35] To do this, we drop the bottom 10% city-pairs in terms of sample frequency across all quarters and years, the bottom 5% state-country pairs in terms of sample frequency across all quarters and years and with and we also drop the bottom 10% city-pairs in terms of number of sampled passengers across all time periods. While we end up dropping 27% of origin-destination-time observations, they represent only 2 percent of the observed international air passenger flows. Note that eliminating infrequent state-country pairs as opposed to infrequent foreign countries has the benefit of maintaining international routes between gateway airports, for example New York City to Dakar, Senegal, while removing barely sampled routes such as Indianapolis to Dakar.

destination airport pairs, with an average of 12 observations per pair. The summary statistics for the variables of interest are provided in the Appendix Table A3.

One limitation of the DB1B data is that foreign carriers that are not part of immunity alliances are not required to file ticket sales information to the U.S. Department of Transportation.[36] This implies that itineraries along routes with a U.S. gateway airport end-point (i.e., US gateway-to-foreign gateway and US gateway-to-beyond foreign gateway routes) are under-represented in the estimation sample. However, information about foreign operated flights does appear in the DB1B dataset provided at least one segment of the tickets is operated by a US carrier. In fact, since international air traffic on routes involving non-gateway U.S. airports always requires a U.S. air carrier to provide service on the domestic spoke, then these sampled itineraries are representative for the population. Appendix Table A4 summarizes the distribution of international air traffic by route categories. The most frequently sampled route category is the U.S. behind-to-gateway routes, which reflects the extensive coverage of the U.S. domestic network. However, when factoring in traffic densities, 70 percent of the observed international air passenger traffic represents gateway-to-gateway trips.[37] In fact, there is significant difference in average traffic densities across route categories. Therefore, the trade-off between representativity and relevance of the estimation sample is serious. If we were to consider a representative sample and only focus on behind-to-gateway and behind-to-beyond routes, we would essentially omit at least 77 percent of international traffic. So instead of doing that, we keep all sampled ticket itineraries in the sample and augment the empirical analysis with an alternative air travel dataset, which is more aggregated but offers complete coverage.

A second dataset we use in this paper is *T100 International Segment*. This is a firm level dataset that provides information on capacity and air traffic volumes on all U.S. non-stop international flight segments (defined at airport-pair level), distinguished by the direction of travel, and operated by both domestic and foreign carriers. The data is collected at monthly frequencies and reports for each carrier-route pair the number of departures scheduled and operated, seats supplied, onboard passengers, segment distance and airborne time. A more detailed description of the data and sample construction is included in the Data Appendix. One important advantage of the T100 Segment dataset is that it provides an exhaustive account of all U.S. cross-border air passenger traffic by operating carrier and airport-pair route.[38] Appendix Table A5 summarizes the aggregate market share of U.S. and foreign air carriers in total international air passenger transport, with the foreign airlines distinguished based on participation in antitrust immunity alliances. Two aspects are worth pointing out. First, the market share of US carriers has constantly dropped in the first half of the sample -- consistent with on-going efforts towards openness in air services trade -- although this downward trend reversed after 2001. Second, the fraction of international traffic operated by non-immunized

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[36] Immunity alliances represent strategic alliances between domestic and foreign airlines with granted antitrust immunity from the U.S. Department of Transportation. Immunity grants allow carriers to behave as if they were merged, cooperating in setting prices and capacity on all joint international route to and from the U.S.

[37] This is a lower estimate of the true value given the unobserved number of travelers flying on foreign carries.

[38] However, the T100 Segment data does not easily match to the true Origin and Destination Passenger data, since passengers with very different start and end point itineraries get lumped together in a single observation in the T100 Segment dataset if their cross-border flight segment is the same. Unlike goods, which feature a one-to-one relation between a product and its producer, international air travel often involves the service of more than one airline. This is why firm- and product-level air travel datasets are imperfectly compatible.

foreign carriers is on average 36 percent. A fraction of these passenger flows (those having *all* flight segments operated by foreign air carriers) are omitted from the DB1B ticket level dataset.[39]

To complete the data description, Table 1 provides a summary of the evolution of international traffic on non-stop segments during the sample period 1993-2008. By any measure of industry performance - passenger volumes, number of non-stop international routes or annual departures performed (unreported) - international air traffic has grown at remarkable rates.[40] This period of expansion in international air travel has overlapped with a time of "global deregulation" (DOT, 1999). In fact, by 2008, as much as 62 percent of total U.S. international air passenger traffic passed through a foreign gateway airport located in an Open Skies country. Table 1 reports for each world geographic region the passenger share accounted for by OSA countries. Variations in the extent of air services liberalization across the globe reflect not only differences in countries' participation in liberalization policies but also differences in the timing of these decisions.

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[39] Because only U.S. carriers can operate domestic routes, all international passengers that enter (exit) the U.S. on foreign carriers, yet fly an extra domestic leg to (from) their final (starting) point of their itinerary, have the same likelihood of being sampled in the DB1B dataset through reports prepared by the domestic carrier.

[40] The September 11 terrorist attracts, followed by other disrupting events like the Iraq war and SARS, have significantly affected the international aviation industry curbing its ascending trend. However these shocks were temporary, so traffic growth rates picked up again.

# Appendix 2

As we will break down the pre- to post-OSA changes into an entry effect and a composition effect, let $q^1(p)$ denote the pre-OSA equilibrium market price-quantity schedule for an arbitrary non gateway hub (i.e. $n_I = n$), and let $q^2(p)$ denote the post-OSA equilibrium market price-quantity schedule with $n_I + n_D = n$, i.e. prior to the entry of the foreign carrier. Let $y^1(p)$, $\dot{y}^1(p)$, $\underline{p}^1$ and $y^2(p)$, $\dot{y}^2(p)$, $\underline{p}^2$ be analogously defined for the pre- and post-OSA equilibrium functions $y^*(p)$ and $\dot{y}^*(p)$. To simplify the expressions, we are going to assume that post-OSA $0 < n_I < n$.

We wish to show that in moving from pre- to post-OSA the average ticket prices fall and average consumer welfare increases. Beginning with the average ticket prices, which are, for $j = 1, 2$, calculated as

$$\int_0^{\overline{e}} D^{-1}\left(\frac{Q^j(\rho(e, q^j))}{e}\right) F'(e)de$$

where $\rho(e, q^j)$ is the market-clearing price, or the highest price that a ticket is purchased given the demand shock $e$ and the market price-quantity schedule $q^j$, which is given implicitly by $\epsilon(\rho(e, q^j), q^j) = e$, and $Q^j(\rho(e, q^j))$ denotes the total quantity of tickets that are sold as a function of $\rho(e, q^j)$ and is calculated as

$$Q^j(\rho(e, q^j)) = \int_{\underline{p}^j}^{\rho(e, q^j)} q^j(p)dp = \int_0^e q^j(\rho(e', q^j))de'$$

The proof has two steps. First we show that $\rho(e, q^2|n_D+1) \leq \rho(e, q^1)$ where $\rho(e, q^2|n_D+1)$ denotes the post-OSA market clearing price given the entry of the foreign carrier, i.e. for any feasible demand shock $e$ the post-OSA market-clearing price is weakly lower than the pre-OSA market-clearing price. In step two, we show that $Q^2(\rho(e, q^2|n_D + 1)|n_D + 1) \geq Q^1(\rho(e, q^1))$ for all $e$ and thus

$$D^{-1}\left(\frac{Q^2(\rho(e, q^2|n_D + 1))}{e}\right) \leq D^{-1}\left(\frac{Q^1(\rho(e, q^1))}{e}\right)$$

and thus the average ticket price falls. For step one, note that

$$y^1(p) - y^2(p) = \left(\frac{\lambda_D + \lambda_C}{\alpha} - \lambda_D\right)\left(-\frac{n_D}{n-1}\frac{\int_p^{\overline{p}} D'(r)(rD(r))^{\frac{1}{n-1}}dr}{(pD(p))^{\frac{n}{n-1}}}\right) \geq 0 \qquad (1)$$

As $y^j(p) \equiv 1 - F(\epsilon(p, q^j))$, it follows directly from (1) that $\epsilon(p, q^2) \geq \epsilon(p, q^1)$, i.e. for any market clearing price $p$ it takes a higher demand shock in order to clear the post-OSA market. Then because $\epsilon(p, q^2) \geq \epsilon(p, q^1)$ and $\rho(e, q^j)$ is given implicitly by $\epsilon(\rho(e, q^j), q^j) = e$, it follows that $\rho(e, q^2) \leq \rho(e, q^1)$. This completes step one for the composition effect. Note that as $y^1(p) - y^2(p) \geq 0$ for all $p$ it follows directly that the change in the composition of the flight offerings results in a lower minimum of the price support, $\underline{p}^2 < \underline{p}^1$. Note also that the difference $y^1(p) - y^2(p)$ is increasing in the additional cost of indirect flights, $\lambda_C$, and in the preference for direct over indirect flights, $(1/\alpha)$.

For the entry effect portion of step one, letting $y^2(p|n_D)$ be defined as

$$y^2(p|n_D) = \frac{\lambda_D + \lambda_C}{\overline{p}\alpha} \left[\frac{\overline{p}D(\overline{p})}{pD(p)}\right]^{\frac{n_D+n_I}{n_D+n_I-1}} - \frac{1}{n_D+n_I-1} \frac{\int_p^{\overline{p}} \left(n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right) D'(r)\left(rD(r)\right)^{\frac{1}{n_D+n_I-1}}\,dr}{(pD(p))^{\frac{n_D+n_I}{n_D+n_I-1}}}$$

we have that $\frac{\partial \Delta(\overline{p}|n_D)}{\partial n_D} = 0$ and

$$\begin{aligned}\frac{\partial y^2(p|n_D)}{\partial n_D} &= \frac{\lambda_D + \lambda_C}{\overline{p}\alpha} \left[\frac{\overline{p}D(\overline{p})}{pD(p)}\right]^{\frac{n_D+n_I}{n_D+n_I-1}} \ln\left[\frac{\overline{p}D(\overline{p})}{pD(p)}\right] \left(\frac{-1}{(n_D+n_I-1)^2}\right) \\ &+ \frac{1}{(n_D+n_I-1)^2} \frac{\int_p^{\overline{p}} \left((1-n_I)\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right) D'(r)\left(rD(r)\right)^{\frac{1}{n_D+n_I-1}}\,dr}{(pD(p))^{\frac{n_D+n_I}{n_D+n_I-1}}} \\ &+ \frac{-1}{(n_D+n_I-1)^3} \frac{\int_p^{\overline{p}} \left(n_D\lambda_D + n_I\left(\frac{\lambda_D+\lambda_C}{\alpha}\right)\right) D'(r)\left(rD(r)\right)^{\frac{1}{n_D+n_I-1}} \left(\ln(pD(p)) - \ln(rD(r))\right) dr}{(pD(p))^{\frac{n_D+n_I}{n_D+n_I-1}}} \leq 0\end{aligned}$$

and it follows directly that $\frac{\partial \underline{p}^2(n_D)}{\partial n_D} < 0$. As $y^2(p|n_D) - y^2(p|n_D+1) \geq 0$, we can argue along the same lines as for the composition effect that $\rho(e, q^2|n_D+1) \leq \rho(e, q^2|n_D) = \rho(e, q^2)$. Note also that the difference $y^2(p|n_D) - y^2(p|n_D+1)$ is increasing in the additional cost of indirect flights, $\lambda_C$, and in the preference for direct over indirect flights, $(1/\alpha)$. This completes step one.

We now move on to step two, $Q^2(\rho(e, q^2|n_D+1)|n_D+1) \geq Q^1(\rho(e, q^1))$ for all $e$. First, note that $1 - y^2(\rho(e, q^2|n_D+1)|n_D+1) = 1 - y^1(\rho(e, q^1)) = F(e)$ and so

$$\begin{aligned}y^2(\rho(e, q^2|n_D+1)|n_D+1) &\equiv \frac{\lambda_D + \lambda_C}{\overline{p}\alpha} - \int_{\rho(e,q^2|n_D+1)}^{\overline{p}} \dot{y}^2(p|n_D+1)dp = \\ y^1(\rho(e, q^1)) &\equiv \frac{\lambda_D + \lambda_C}{\overline{p}\alpha} - \int_{\rho(e,q^1)}^{\overline{p}} \dot{y}^1(p)dp \qquad (2)\end{aligned}$$

Then, from (2) we have that

$$\int_{\underline{e}}^{\overline{e}} -\dot{y}^2(\rho(e, q^2|n_D+1)|n_D+1)de = \int_{\underline{e}}^{\overline{e}} -\dot{y}^1(\rho(e, q^1))de \qquad (3)$$

which implies that

$$\int_0^e -\dot{y}^2(\rho(e, q^2|n_D+1)|n_D+1)de = \int_0^e -\dot{y}^1(\rho(e, q^1))de \qquad (4)$$

Next, recall that

$$q^j(p) = D(p)\dot{x}(p) = D(p)\left(\frac{-\dot{y}^*(p)}{F'(F^{-1}(1 - y^*(p)))}\right)$$

or equivalently

$$q^j(\rho(e,q^j)) = D(\rho(e,q^j))\left(\frac{-\dot{y}^*(\rho(e,q^j))}{F'(e)}\right) \tag{5}$$

Combining (4) and (5) we have

$$\int_0^e D(\rho(e,q^2|n_D+1))\left(\frac{-\dot{y}^2(\rho(e,q^2|n_D+1)|n_D+1)}{F'(e)}\right)de \geq \int_0^e D(\rho(e,q^1))\left(\frac{-\dot{y}^1(\rho(e,q^1))}{F'(e)}\right)de \tag{6}$$

that is $Q^2(\rho(e,q^2|n_D+1)) \geq Q^1(\rho(e,q^1))$ for all $e$. This completes step two, and thus we have that moving from pre- to post-OSA, the average ticket price falls.

The proof that the average consumer welfare increases follows along similar lines. Letting $\hat{\rho}(e,q^j) = D^{-1}\left(\frac{Q^j(\rho(e,q^j))}{e}\right)$, the average consumer welfare is calculated as

$$\int_0^{\overline{e}}\int_{\hat{\rho}(e,q^j)}^{\overline{p}} eD(p)dpF'(e)de$$

which after an integration by parts can be written as

$$\int_0^{\overline{e}} eD(\hat{\rho}(e,q^j))F(e)de = \int_0^{\overline{e}} Q^j(\rho(e,q^j))F(e)de$$

Then, because $Q^2(\rho(e,q^2|n_D+1)) \geq Q^1(\rho(e,q^1))$ for all $e$, it follows directly that moving from pre- to post-OSA, the average consumer surplus increases.