Blue-sky Thinking: Connectivity Impacts on Regional Economies and Innovation in the United States*

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Abstract

How do connections enabled by commercial aviation affect long-run economic growth and innovation? This paper studies the effects of aviation connectivity on regional economies in the United States. I construct a novel set of instruments based on the historical institutional and physical requirements for expanded air connectivity. To account for the network nature of aviation infrastructure, I use an improved measure of aviation activity—the Global Connectivity Index developed by Allroggen et al. (2015). This measure captures accessibility enabled by aviation better than passenger and departure numbers used in prior work. After accounting for endogeneity, I find that a 1% increase in a core-based statistical area (CBSA)'s Global Connectivity Index is associated with an increase in long-term total personal income by 1.7% and 6 more granted patents. For a CBSA like Myrtle Beach, SC, with a connectivity index close to the mean connectivity levels of CBSAs, a 1% increase in connectivity would bring about $218 million in total income over a two-decade period. Finally, I find that the impact of connectivity on regional economies is significantly more pronounced in the largest 100 cities, while these effects vanish in smaller cities. This paper shows, for the first time, the impact of aviation connectivity on innovation and provides suggestive evidence for aviation's role in strengthening agglomeration economies.

Keywords: aviation, connectivity, regional economies, innovation, economic complexity

JEL Classification: O31, O33, R11, R15, R42, R58, N72

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1 Introduction

Although aviation has played an integral role in the globalization of the world economy, economists have little understanding of how aviation affects regional economic growth and innovation (Belobaba, 2016; Bednarek, 2016). To date, few studies have shown the effect of aviation on regional outcomes. Much like other forms of transportation, aviation provides positive externalities in enabling knowledge spillovers, such as those through networks and sociocultural exchanges and interactions. But aviation does so across unprecedented distances. At the same time, aviation provides a local amenity value for residents who are able to reach other places with ease, and for tourists to travel to a city and benefit its local economy. The endogeneity between air activity and regional economics presents a significant identification challenge.

The aviation sector has been estimated to account for 3.4% of world GDP without accounting for the spillovers (Belobaba, 2016; ATAG, 2014). While it has been observed that a 5-6% growth in aviation is associated with a 2-3% annual GDP growth rate worldwide, this only represents an anecdotal relationship—it remains unclear the extent to which aviation contributes to long-term growth (Belobaba, 2016). In the United States, the aviation sector is an important part of the economy, accounting for 5% of the U.S. economy—$1.6 trillion in total economic activity and for 10.6 million jobs in 2016. Civil aircraft manufacturing is also the top net exporter in the U.S. with a positive trade balance of $59.9 billion. Between 2012 and 2014, the real primary output of civil aviation grew at an average of 3.3% per year while the economy grew at an average of 2% per year (Federal Aviation Administration, 2016).

The causal effect of aviation on economies remains to be soundly identified. Building upon earlier studies on investment and return on infrastructure, this paper investigates the causal relationship between aviation connectivity and regional economic growth using a new measure of aviation connectivity, a novel set of instrumental variables based on institutional and physical constraints, and—for the first time—measures connecting aviation and local innovation. This research contributes to the empirical work on the economics of agglomeration and transportation.

Empirical work on aviation and growth poses a significant econometric challenge due to endogeneity and limited data availability. The most recent work by Campante and Yanagizawa-Drott (2017) was able to exploit variation due to regulatory and technological constraints, which provided a discontinuity between city pair connections to identify long-distance impacts of aviation. However, a major limitation of this approach is its restriction to large cities that serve international aviation markets. Secondary cities serviced by convenient domestic links are not included. Thus, there remains a gap in understanding aviation's impact in regional economies, especially domestically.

Other researchers making use of regulatory changes include Blonigen and Cristea (2015), who used the 1978 Airline Deregulation Act as a quasi-natural experiment to find significant impact of aviation on income growth. However, it is unclear if the increase in air activity and competition as a result of the regulatory change is directly related to a locality's economic performance in the first place. I provide additional information on the causal links between aviation and growth in this paper.

Existing approaches adopting instrumental variables focused on employment impacts but painted a mixed picture. Sheard (2015) and McGraw (2015) focused on the historical plans such as the 1944 National Airport Plan and historical air mail routes to instrument for future air service. Sheard (2015) found significant increases in employment shares in tradable services and limited effects on local employment levels. McGraw (2015) found strongest employment effects in non-tradable businesses and the professional services sector and no growth in wages. LeFors (2014) used through-traffic shares to instrument for air accessibility, though the connecting passenger share in a locality may be inherently correlated with growing hub strength and economic conditions as major airlines schedule more connections.

The contributions of this paper are four-fold. First, I construct a new set of instrumental variables for air connectivity based on institutional and physical prerequisites. Second, I improve upon measurement by adopting a connectivity measure instead of using passenger or departure numbers used in prior work. Third, I connect aviation's impact to innovation in the form of patent activity for the first time. Finally, I demonstrate that the positive benefits of aviation connectivity are disproportionately larger in larger cities. Overall, these results add to the work on the long-run impacts of transportation infrastructure, provide new evidence on the knowledge capital impacts of aviation, and contribute to the literature on agglomeration economies and transportation.

To estimate the relationship between connectivity and long-term growth, I consider the ingredients for expanded air activity based on the institutions and physical requirements in the past. In the 1930s and 1940s, the construction and operation of air traffic control (ATC) facilities were determined by geographic and technological constraints. Absent navigational computers, radio control and landmarking became essential for a flight to cross the country. Airports that were en-route between the coasts possessed significantly more ATC infrastructure. Additional air connections were more likely in these airports.

Prior work on aviation and regional economic growth has used passenger and aircraft movement numbers to measure aviation activity. These approaches introduced significant measurement error because of aviation's nature as a network. For instance, the number of departures is biased in explaining local economic growth because these flights contained transiting passengers. In addition, some cities are better connected to the world through convenient air links to major cities. To correct for these biases, I use a novel connectivity measure developed by Allroggen et al. (2015) that takes into account routing directness (including transfer time), frequency, and destination market quality.

I find significant impacts of a city's air connectivity on its long-run income and employment growth. I also find small but significant increases in innovation as measured through granted patents. A 1% increase in a core-based statistical area (CBSA)'s Global Connectivity Index is associated with an increase in long-term total personal income by 1.7% and 6 more granted patents. Further, I provide suggestive evidence for aviation's role in strengthening agglomeration economies, as aviation tends to disproportionately benefit larger cities.

This research has the potential to inform strategic policies in aviation planning, including decisions on airport expansion, the addition of new routes, and companion investments in innovation hubs and business parks. Expansion and investment in airports are among policy priorities debated in many cities, while some cities debate constructing additional airports. In the U.S., airports that have reached and exceeded their designed capacity are undergoing expansions, such as New York's LaGuardia Airport (LGA). Internationally, the third runway expansion proposal for London Heathrow (LHR) has made headlines in British politics, and the debates continue today despite the Parliament's approval for the project (BBC News, 2018). In Hong Kong, the issue of the third runway expansion also entered the political stage within the Legislative Council in the past years (South China Morning Post, 2017). Increasing air capacity is a priority for many, and especially for the airlines, who argue that boosting runway capacity is necessary in order for the city to remain competitive in tourism (South China Morning Post, 2016). Clearly, understanding aviation's impact on regional economies is of significant policy interest. This also provides prima facie evidence that aviation is valuable.

An additional example on how aviation connectivity could be an important determinant of economic growth and innovation is the recent expansion and headquarter search decisions by large corporations such as Amazon. In Amazon's Request for Proposals to Metropolitan Statistical Areas (MSAs) in search for their HQ2, aviation connectivity was mentioned specifically as a criteria, including direct flights to major cities as well as ease of access to an international airport as core preferences (Amazon, 2017). Other major companies, such as Boeing, and other biotechnology firms, have also made similar moves or expansion decisions in recent years. Airport expansion advocates have long justified investments with "if you build it, they will come."

This research is also relevant in considering the impacts of climate change on critical infrastructure and regional economies. Recently, the city of Osaka in Japan experienced severe Typhoon damage to its aviation infrastructure. Osaka Kansai International (KIX) was flooded and damaged when Typhoon Jebi hit, with traffic of the airport interrupted for almost three weeks. The interruption affected tourism reputation, business connections, and added pressure to train networks and other airports that were already at capacity in the region (Nikkei Asian Review, 2018b,a). The question of defensive and adaptation investments for airport infrastructure in face of climate change is becoming increasingly relevant. Understanding the connectivity impacts of aviation would be of prime importance in justifying policy decisions, especially for vulnerable infrastructures such as Kansai, which was built on reclaimed land and continues to sink every year.

The paper is structured as follows. In Section 2 I provide the context of the literature on transportation and growth. In Section 3 I outline two theoretical models motivating the empirical strategy. In Section 4 I describe the data sources and the construction of the set of instrumental variables. I describe the main results in Section 5 and conclude in Section 6.

2 Literature

In the late 1980s and the early 1990s, important literature explored the worthiness of investments in public infrastructure, such as road, highways, and telecommunications. These work showed that such investments such as in transportation infrastructure have significant effects on economic growth (see Canning and Fay, 1993; Aschauer, 1989; Wylie, 1996). One approach to study the effects of transport infrastructure on economic growth is to estimate the social rate of return. Using panel data on roadway coverage as well as regional economic data, Canning and Fay (1993) estimated the returns from investing on U.S. road building. Wylie (1996) found consistent results in Canada with Aschauer's work on the U.S. with high rates of return for public infrastructure investments, and perhaps at even higher magnitudes. Winston (1991) cautioned against simple spending and argued for efficient transportation investments and pricing on roads and airports using optimal capacity, pricing, and congestion analysis. The issue of airport capacity, congestion, and pricing was of particular interest as the U.S. aviation industry had just been deregulated. Allroggen (2013) and Redding and Turner (2015) offer comprehensive reviews on the broader literature in transportation and regional economic development.

The relationship between transportation and urban growth has been of renewed interest in recent years with the advances in identification methods including instrumental variable approaches, regression discontinuity, event study, and other reduced form derivations from general equilibrium models. The emerging literature has studied highways, railroads, and most recently began on aviation.

Studies on the economic impacts of highways include one by Duranton and Turner (2012), who estimated the effect of interstate highways on growth of U.S. cities using an instrumental variable approach, using past highway system plans and old railroad maps to instrument for observed highway provision. They found that employment would increase 1.5% over a 20-year period with a 10% increase in the initial stock of highways, adding sound empirical basis to the theoretical models on cities and public infrastructure provision.

Rigorous analysis on the subject of rail provision and urban economic growth also emerged. Haines and Margo (2008) examined the relative impact of gaining access to railroads in the 1850-1860 period and found increased urbanization and service sector employment gains. Donaldson (2018) used archival data in India to study the railroad network's impact on regional economies in the colonial era. He found significant decreases in income and interregional trade. Donaldson and Hornbeck (2016) examined the historical impact of railroads on the U.S. economy, focusing on aggregate agricultural sector impacts in the 1890s. They measured constructed a network database of rail and waterways to measure market access and calculate transport costs. They found significant impacts of railroad on agricultural land value: removing rail would decrease land value by some 60%, and such losses cannot be mitigated by a substitute transport mode such as through canals or roads.

Aviation infrastructure differs from roads significantly. Roads provide fixed connections between places physically connected to the road, while aviation provide non-stop or multi-stop connections between airports depending on available routes. Operating aircrafts, in comparison to personal vehicles, requires much higher entry costs and economies of scale. Previous work have studied local effects of aviation, such as on urban growth, labor market, regional output, as well as pollution and health (see, for example, Brueckner, 2003; Allroggen and Malina, 2014; Schlenker and Walker, 2016). Other attempts in establishing causal links between aviation and growth or trade costs have largely rested on using air passenger or freight volume (see Anderson and Wincoop, 2004; Button and Yuan, 2013; Redding and Turner, 2015). There has also been cross-sectional analysis using networks (Guimerà et al., 2005). Brueckner (2003)'s seminal work offers a cross-section analysis using hub as an instrument and finds that expansion of airports would raise service-sector employment significantly, though whether hub status is endogenous to regional economies is subject to debate.

The application of instrumental variable approaches to estimate the impact of transportation on regional outcome can be summarized in three broad approaches. First, one could make use of the past planning of the infrastructure network system (where the realized form may differ) to generate variation in the observed infrastructure in the future. Such plans are likely independent of future regional growth. Second, one could similarly make use of historic routes that pre-date the new transportation infrastructure, such as historical transport routes to generate the quasi-random variation in observed infrastructure. Third is the idea of the inconsequential place or "accidental" infrastructure, such as a highway placed between place A and B and an exit was created in between as incidental infrastructure provision, which generates variation in observed infrastructure in these "en-route" places (Redding and Turner, 2015).

LeFors (2014) made use of through traffic share (i.e., connecting passengers as a fraction of all passengers) and Herfindahl index for the carrier concentration of passengers departing from the city as instrumental variables for air access for the city. However, through traffic share could violate exogeneity assumptions because large hubs with strong economic performances are automatically likely to have higher through traffic shares due to the hub-and-spoke nature of most of the U.S. air carriers. An important innovation in this work is the construction of an ”air accessibility” measure, which was calculated as the weighted average of the populations of every other city, with the weights being a function of the inverse cost of traveling to each city by air, where costs include average fare and mileage measures. This alternative measure of aviation activity is important because of the bias introduced by using passenger numbers or number of aircraft movements, which ignores the network nature of aviation and overweigh the impact of the large hub because transiting passengers' effects may be included.

However, in the LeFors approach, only realized itineraries and fares are included in the construction of the air access measure; only MSA pairs within the U.S. were considered; and opportunity cost of time as well as the network and codesharing features of aviation were not included. This paper instead employs an improved measure of air connectivity developed by Allroggen et al. (2015), which was constructed with all scheduled passenger flights, one-stop possibilities with codesharing and accounting for transfer times, thus significantly improves upon the measure used in LeFors to capture the potential connectedness through aviation.

Sheard (2014) and Sheard (2017) used the 1944 National Airport Plan in the U.S. to instrument for current airport size and distribution, akin to the "plans" approaches seen in the literature studying other transportation mode's effects on regional outcome. The use of the airport plan was novel in that the potential planned costs of the airport also generated variation in the value of the added airport in the future. Flight volume was the instrumented variable of interest. Sheard (2014) found positive effects of aviation on service sector employment but no effect on other sectors and Sheard (2017) found increases in traffic as a result of increases in the number of airports, both using the historical plan instrument. A potential concern herein is theoretical: using the number of departures as a measurement for aviation activity suffers from substantial bias as outlined above, ignoring the transiting passengers and the network nature of aviation.

McGraw (2015) takes the approach of using historical routes as instruments for future air service. He constructed instrumental variables based on the air mail routes of 1938 as well as the locations of emergency air fields to instrument airport location and found significant effects on non-tradables sector employment growth. He found no effects on wage growth, suggesting the gains through aviation accrued to employers and businesses but not to employees. A major limitation of

McGraw's approach also lies in measurement: the existence of an airport is the measurement used for aviation activity in this study, which does not account for the network nature of aviation or the magnitude of the potential connections an airport provides. Using connectivity measures would improve upon the estimation considerably, as it would capture the magnitude of aviation activity.

Sheard (2015) used the variation in airport size driven by overall changes in the air travel network to instrument for air activity, thus employing a Bartik-like instrument. He instrumented airport size by constructing air traffic categories for aircraft, airline, and ranges, and then appending national growth onto these variables, whereby the category growth rates are orthogonal to local factors, particularly when local traffic growth is being excluded in the calculation of the national time trend.

The estimation of aviation's impact on regional economies is not limited to instrumental variable approaches. Recent work by Blonigen and Cristea (2015) provides a quasi-natural experiment by exploiting the 1978 Airline Deregulation Act in the U.S. to study the effects of air traffic changes to local population, income, and employment. While the authors found significant income impacts among MSAs, the deregulation could arguably have had uniform effects on all MSAs[1], and that the resultant increase in air activity and competition could be argued to be directly related to a locality's economic performance in the first place, placing the identification strategy in scrutiny. The air traffic measurement focuses on domestic passenger enplanement, which excludes the connectivity enabled by the network nature of aviation with one-stop flights, the quality and economic potential of the destinations, as well as the contribution of international connections to the local economy.

In the most recent work by Campante and Yanagizawa-Drott (2017), the authors uses a regression discontinuity design that exploits the regulatory and technical constraints of connecting city-pairs world-wide that are over 6000 miles apart; over time, direct air connections between cities below this threshold increased but city-pairings outside of this threshold did not. The authors identified significant, positive impacts to local economic activity as measured by night-lights, as well as positive impacts to capital flows. However, while the study is successful in its identification, several limitations remain. First, it would be difficult to understand regional and local economic impacts of aviation for smaller cities that do not have the requisite size and market to have direct

[1]The authors also noted that smaller cities' air services were reduced but partially preserved through the Essential Air Services program.

connections even if they fall within 6000-mile city-pairings. The analysis is thus restricted only to large international city-pairs. Second, although the approach does include some network-based measurement of aviation such as network centrality in addition to the existence of a direct connection between city pairs, it neglects the structure of commercial aviation and thus the magnitude of aviation impacts on economies, because frequency, convenience, and one-stop itineraries are not taken into account. The Global Connectivity Index (GCI) used in this paper do take these factors into account when measuring aviation connectivity of an airport.

Very few studies have extended the analysis of aviation infrastructure and regional economies to investigate the potential for knowledge spillovers and innovation. Catalini et al. (2016) studied the effect of the entrance of low-cost carrier Southwest Airlines[2] on chemistry research collaborations. The authors used a difference-in-difference framework to find a 50% increase in collaboration between scientists residing in these Southwest connected city-pairs. These allude to the innovation and knowledge spillover impacts that are induced by aviation, which have not been quantified previously. A recent paper by Dong et al. (2018) studies the high-speed rail connection's impacts on high-skilled teamwork and face-to-face interactions also using research publications and citations as a measurement for knowledge co-production.

This paper contributes to three stands of literature. First, it contributes to the broader literature on transportation and urban growth by providing additional empirical evidence from aviation infrastructure. In particular, the paper introduces new instrumental variables that are based on institutional and physical prerequisites to enhanced air connectivity, and uses a measure of aviation that better captures the network nature of the industry, taking into account the link and destination quality as well as one-stop flights. Second, it is the first study on the effects of aviation infrastructure on innovation activity as measured by filed and granted patents, extending the literature on regional outcomes to measuring knowledge accumulation through enhanced interaction. Third, it adds to the agglomeration economies literature by demonstrating the varied effects of aviation on cities of different sizes, whereas most previous work focused on large metropolitan areas.

[2]Though not officially a hub-and-spoke airline, it is debated whether Southwest falls into the category for low-cost carriers today. The point-to-point system still forms focus cities and unofficial hubs, including Chicago, Denver, and Baltimore, where itineraries are also sold between connecting flights.

3 Theory and Empirical Strategy

Aviation could impact a city's economy in two main ways. First, the presence of aviation connections add to the *amentiy* value of a city. Residents have added convenience of reaching other places, meeting friends and family from afar, and making new connections in their city via increased tourism. Thus, aviation connectivity enters as a positive factor in a locality's quality of life and thus in one's utility function. Second, aviation also enhances *productivity* in several ways. Aviation lowers costs of transfer and transport, especially for perishable products and inputs. Most importantly, it lowers the cost of interaction between people, thus increasing human capital stock, levels of interactions and exchange, and technology diffusion. Thus, aviation accelerates trade and agglomeration effects by connecting people, thereby increasing productivity. Glaeser and Kohlhase (2003) provided a theoretical framework for the significant reduction in transport costs leading to a change in city function - where people meet and contact one another. Productivity becomes a function of agglomeration as there are returns to people being able to interact. We add to this idea but amending the model with the fact that people - who require face-to-face interactions - are now able to meet at lower costs and at much higher speeds and lower opportunity costs as a result of aviation connectivity.

Two theoretical frameworks formally describe processes of urban economic growth and idea exchange prompted by aviation. Firstly, an intuitive argument can be made that the presence of aviation improves the happiness or utility of people living in the urbanity, since they have access to aviation services and the opportunity to be connected to another place with ease. For businesses, this means that firms have access to more markets, more clients, and can readily meet others in the presence of aviation connectivity. Thus, a city's income (which can be reflected through wages) and employment levels could be positively influenced by aviation connectivity. Secondly, we may perceive aviation connectivity instead as an enhancement in the knowledge sharing process. Having good connections to other places may mean that businesses are likely to encounter more production-improving ideas; it could also reduce the time and cost they need to interact with and process different ideas, given that good air connections exist. Thus, aviation can induce economic growth in the city through enhancing this knowledge network. These two different, yet related, models provide the theoretical foundation of this paper. They each lead to a similar equation describing the relationship between growth and aviation connectivity, which we estimate in the later sections.

In particular, the first framework is based upon the set-up followed by Blonigen and Cristea (2015), which augments Glaeser et al. (1995)'s model by adding air traffic growth to local amenity and to productivity. Essentially, aviation is seen to provide exogenous positive changes in productivity as well as a local amenity that factors into individuals' utility function. The simple urban growth model provides a reduced form equation for growth in population and wages with a linear relationship with aviation activity. The second framework is based upon Davis and Dingel (2012)'s spatial knowledge economy model that formalizes how interaction and idea exchange lead to tradables productivity. The spatial knowledge economy model is augmented by introducing aviation connectivity in several ways. First, better aviation connectivity can increase the probability of tradables producers to encounter one another. Second, better connectivity reduces time spent on interactions, which can be allocated to produce the higher-value output. Finally, connectivity can be introduced as an endogenous variable determined by the economic agents.

Urban Growth Framework

This subsection reiterates Blonigen and Cristea (2015) closely in order to provide the theoretical context to compare the results of employing the connectivity measure in place of air traffic variables and to check for robustness. Their framework augments the set-up in Glaeser et al. (1995) by introducing air services as a productivity shifter and local amenity. We employ the same model but replace air traffic with air connectivity measure for the metropolitan areas to better capture spatial spillovers.

Metropolitan statistical areas (MSAs) share common pools of labor and capital and are considered open economies. Differences in regional growth cannot therefore come from savings rates or exogenous labor supply changes. Cities differ in productivity and quality of life.

In this framework, the total output of a metropolitan area be given by the level of productivity within MSA i at time t, multiplied by the labor force raised to a national production parameter in location i at time t. Individuals earn the marginal product of labor as their wages, with normalized output prices. The model also assumes a quality of life measure that captures socio-economic factors specific to a location that is declining in the size of the city. Individuals derive utility from their labor income and the enjoyed quality of life, entering as a product.

Assuming free labor mobility across cities, each individual's utility equals the reservation utility levels at any city at any time in equilibrium. Thus, utility grows at a common rate across cities where population growth is adjusted each period to reflect changes in productivity and local amenities. This means that population and wage changes can be expressed as log-log equations in terms of changes in productivity Z_i and local amenity Q_i in the city i. By substitution, an equation relating growth of wages and population with city characteristics can be derived. Specifically, proceed by assuming a vector of city characteristics, X_{it}, for each MSA i at time t that determines the growth of both productivity Z_{it} and local amenity/quality of life Q_{it}. Moreover, the model includes a measure for air transport services as a potential growth driver for productivity and local amenity, but denoted here c_{it} as the aviation connectivity offered by the MSA i's airports at time t, giving us:

$$\log\left(\frac{Z_{i,t+1}}{Z_{it}}\right) = (X_{it})'\gamma_1 + \beta_1 \log\left(\frac{c_{i,t+1}}{c_{it}}\right) + \nu_{it}$$
$$\log\left(\frac{Q_{i,t+1}}{Q_{it}}\right) = (X_{it})'\gamma_2 + \beta_2 \log\left(\frac{c_{i,t+1}}{c_{it}}\right) + \upsilon_{it}$$

By substitution we may derive the reduced form for log growth rates as:

$$\dot{L}_i = \tilde{\beta}_1 \dot{c}_i + X'_{i,T_0}\tilde{\gamma}_1 + \epsilon_{it} \tag{1}$$

$$\dot{W}_i = \tilde{\beta}_2 \dot{c}_i + X'_{i,T_0}\tilde{\gamma}_2 + \xi_{it} \tag{2}$$

with $\tilde{\gamma}_1$, $\tilde{\beta}_1$, $\tilde{\gamma}_2$, $\tilde{\beta}_2$ are to be estimated empirically. The key hypothesis is that improved connectivity will yield increased population growth, per capita and regional income levels, employment, and other measures of changes in regional economic activity; subject to time-invariant city characteristics. Appendix B details the derivations.

Connectivity in a spatial knowledge economy

In this subsection, I adapt an idea-exchange model developed by Davis and Dingel (2012) and augment it by introducing aviation connectivity. The model makes explicit that knowledge gained in interacting with others, in exchanging ideas, is not costless. There is time-opportunity cost involved. The model also assumes tacit nature of knowledge, requiring physical interaction or face-to-face communication, and as such, cities are the loci of these interactions. Finally, labor is heterogeneous and continuously distributed.

The spatial knowledge economy involve individuals consuming three goods: tradables, non-tradable services, and non-tradable housing. The indirect utility function is given by

$$V(p, I) = I_c - p_{s,c}\bar{s} - p_{h,c}$$

where consumers have income I, face prices p in city c, expend on $\bar{s}$, the non-tradables, and the remaining income on tradable (numeraire). Consumers are perfectly mobile across sectors and across cities; their choices of location and occupation maximize $V(p, I)$.

Assuming non-tradables are produced at uniform levels of productivity, for a mass of worker L with heterogenous abilities $z \sim \mu(z)$, low ability people in this model will specialize in non-tradables by comparative advantage. In the tradable sector, producers can gain knowledge to increase productivity and individual productivity in tradables $\tilde{z}(z, Z_c)$ is thus increasing in z and dependes on the set of learning opportunities available in the city, Z_c, such as availability to interact with others.

Tradable producers have one unit of time to divide between production (β units of time) and interaction ($1 - \beta$ units of time). An agent with ability z produce tradables output

$$\tilde{z}(z, Z_c) = \max_{\beta \in [0,1]} \beta z(1 + (1 - \beta)GZ_c z)$$

G denotes the productivity benefits of learning, which is common to all cities to reflect gains from interactions. When G is higher, knowledge from interaction raises productivity more.

The opportunity to learn and interact within a city Z_c is determined by random-matching processes where producers take time to encounter and exchange ideas, and we augment the original model with the connectivity of the city to other places (thus have higher exposure to possible ideas). Thus, Z_c is defined as follows:

$$Z_c \equiv m(M_c, A_c)\bar{z}_c$$

where m the probability of encounter and an increasing function of its two arguments, M_c the total time spent by producers in interacting, A_c denotes the aviation connectivity measure for the city, $\bar{z}_c$ the city's expected ability levels.

With this augmentation we treat A_c as an exogenous feature of the city c not determined by consumers or producers in this model. We can proceed to solve for the equilibrium in the set of cities with population L for the equilibrium prices, locations, time spent on sectors, occupations.

In the above augmentation we treat aviation as having no effect on the choice of time to interact: aviation simply improved probability of encounters. However, one can expect improved connectivity also reduces the time producers need to interact for exchanges. So in the next modification we further introduce aviation as a factor that reduces the total time spent interacting, i.e.

$$M_c = f(L, \beta, \mu(z, c), A_c)$$

This means that more time can be spent on production with higher connectivity in addition to aviation providing more amenity in city c. This leads to higher output levels.

Finally, an ideal augmentation would introduce aviation as an endogenous variable by adding air services as a sector. This is likely to complicate the model and be difficult to solve, but essentially the air sector produces products that add to local amenity as well as reduces tradables' production and interaction costs. Thus, the economy will allocate efficiently the ideal proportions of labor to each sector to maximize output. Multiple equilibria is expected.

With the equilibria in mind, we specify a linear model of Z_c as follows:

$$Z_c = \gamma_0 + \gamma_1 A_c + \gamma_2 M_c(\bar{z}_c) + X_c' \vec{\gamma} + \epsilon_c$$

where A_c denotes the aviation connectivity measure for the city, $M_c(\bar{z}_c)$ the total time spent by producers in interacting, which is an increasing function of the city's expected ability, X_c the vector of city-characteristics that determine whether a positive learning environment is provided, and ϵ_c the error that also captures the stochastic idea matching process.

Further, let us assume that patent registration to be a measure of an idea's fruition (Z_c) and labor effort in the research and development (R&D) departments/sectors as $M_c(\bar{z}_c)$. We can then empirically estimate the coefficients γ. This means that we estimate, in the cross-section, whether aviation connectivity, investment in R&D efforts, and various city-based qualities affect the learning environment - the number of patents registered in the particular city c. The expected sign of γ_1 is positive, to reflect that innovation (and thus the spatial knowledge economy) is positively stimulated by improved air connectivity. Holding all else constant, the equilibrium conditions include aviation connectivity, where increases in A_c should, ceteris paribus, lead to increases in production of tradables. We also estimate a similar model with growth rates of patents and innovation and connectivity changes, whereby the time-invariant city characteristics would drop out. This model thus adapts a spatial knowledge economy to derive a basic relationship between aviation connectivity and innovation.

Empirical Strategy

The key challenge to estimate the effects of aviation and local development empirically is endogeneity: clearly, economic growth causes investment in airports, route licensure, and bid for take-off/landing slots. Such simultaneity thus may bias the estimates for marginal impacts of aviation on the economy. Using instrumental variables would be one valid approach, in lieu of taking increased aviation activity as exogenous. IVs such as historical routes or plans have been considered in the past. Various studies have also included country and year fixed effects to de-trend macroeconomic environments at play. Aforementioned studies use flight traffic, passenger or freight volume (McGraw, 2015; Sheard, 2014, 2015; Blonigen and Cristea, 2015)or in rarer cases accessibility (LeFors, 2014) as the measurement for aviation activity.

Following the theoretical framework, the equation of interest is

$$y_i = \alpha + \beta c_i + \boldsymbol{x}'_{2,i}\gamma + \epsilon_i \tag{3}$$

where y is our outcome variable of interest in region i, such as patents, number of new companies, and quaternary sectoral employment. c is our connectivity measure, $\boldsymbol{x}_{2,i}$ is the set of control variables and ϵ the errors. Since c is likely endogenous, we perform 2SLS using an instrument for connectivity. We first regress connectivity on the instrumental variable z and some other controls:

$$c_i = \phi + \eta z_i + \boldsymbol{x}'_{1,i}\delta + u_i \tag{4}$$

and obtain predicted connectivity values $\hat{c}$. We then use $\hat{c}$ in Equation (1) where we regress outcome variables y on the predicted connectivity values $\hat{c}$. Identification thus requires two conditions - the relevance and exogeneity conditions: one being that the instrument has to be correlated with our independent variable, i.e. $\eta \neq 0$, and the other being that the instrument must be exogenous to the outcome.

Because of instrumental variable data availability - being a static construction, the empirical model in this paper takes the following reduced form

$$\Delta y_{i,1990-2012} = \alpha + \beta c_{i,2012} + \boldsymbol{x}'_{2,i}\gamma + \epsilon_i \tag{5}$$

The reduced form equation is an regression of the change in long-term (2-decade) change in income, employment, and patent activity[3] on aviation activity as measured by aviation connectivity. The geospatial unit is at the core-based statistical areas (CBSA) including large and small metropolitan and micropolitan areas. The connectivity measure at year 2012. c is then instrumented by the constructed instruments, such as air traffic control status in 1938. The set up allows for robustness test to be performed using lagged socioeconomic variables (e.g., in 1970) and using selected instruments in other works (e.g., 1944 National Airport Plan). In the following section, I describe in detail the data sources and the construction of the new set of instrumental variables.

4 Data and Construction of IVs

4.1 Dependent variables

The dependent variables of interest include, in addition to the outcome economic variables cited in the literature, measures for innovation. At the county and MSA level, business and socioeconomic data are readily available from the U.S. Census Bureau and the Bureau of Economic Analysis

[3]Because the patent data is only available up to 2010, we use the change in patent activity from 1990-2010 and the GCI scores in 2010 instead for the patent regressions.

datasets (CA1, CA5N, CA25N, CA30 Regional Income Data). These variables include population, personal and per capita income, and employment from 1970-2012. Select variables contain sectoral details and breakdowns at the 2- and 3-digit NAICS code level. The data is then combined with the geospatially integrated connectivity data at the CBSA level.

As a proxy for innovation we include data includes the number of patents registered in the region during the time period of interest. A patent database made available by Lai et al. (2011) contains collated data from the Patent and Trademark Office (raw registration data from 1975-present) as well as the National Bureau of Economic Research's Patent Data Project. The data is at the inventor-patent level with addresses and zip codes with the granted year of the patent. The data is unique in that we are able to capture not just the first inventor recorded on the patent but also the addresses of all the collaborators within the patent. This is particularly relevant for studying aviation connectivity impacts, as we are interested in the knowledge spillovers and co-creation. Using this new patent dataset, I geospatially and temporally sorted the inventors and collaborators by year and CBSA, with zip code to CBSA correspondence performed using QGIS. Both the sum of all unique patents (location defaulted to the first-named filer) and the sum of all inventor addresses in each available year were concatenated. These two measures of innovation via patents granted from CBSAs are then used as outcome variables to see if connectivity has measurable, significant impacts on innovation after accounting for endogeneity. The innovation sector data is important to move beyond looking at semi-direct economic effects of aviation.[4]

4.2 Independent variable: Global Connectivity Index

Networks are increasingly being considered as important frameworks in understanding various economic behaviors (Guimerà et al., 2005; Jackson, 2014). Network measures consider the complexity of connections between places or nodes rather than simply using the existence of a connection or the simple flow between places. Transportation modes such as aviation inherently enable *accessibility*, and the nature of aviation as a network of flights has important implications in how we measure the impact of aviation in a city.

In the transportation literature, *accessibility* includes the set of cumulative opportunities avail-

[4]In future work, I intend to extend the analysis to the collaboration and citation networks of the patents; in this paper, we restrict the first analysis to the stock of ideas or innovation as measured by inventor-patent filings and collaborator activity.

able to a place, the transport costs between places, the gravity of the destinations, and the utility derived from connecting to these places. Accessibility can be summarized in the equation below:

$$AC_i = \sum_{j=1}^{N} g(W_j) \cdot I_{ij}(\tau_{ij}) \tag{6}$$

The interpretation is straight-forward. The accessibility of place i is a function of the sum of the set of all possible j destinations' attractivity $g(W)$ multiplied by the interaction weight between the partners I. The attractivity of a destination can be thought of as the destination quality, the opportunities it offers economically, or city function. The interaction weight between the partners is a decreasing function of an interaction resistance factor τ between the place i and j. If the cost or distance between the two places are high, such as through increased travel time, less options and substitutes, low level of directness, then the interaction resistance is high, thus lowering the interaction weight between these partners (Allroggen, 2013). The accessibility measure captures how an infrastructure reaches other places, rather than just providing the sheer volume of traffic.

Allroggen et al. (2015) developed a new metric for measuring connectivity using route schedules published by the Official Airline Guide with the above accessibility measure in mind. The data on GCI is available from 1990-2012. Compared to previous constructed measures, the GCI improves upon the methodology by incorporating network theory, gravity of destination quality, directness of routes, and sensible opportunity costs including transfer time.

The Global Connectivity Index (GCI) is constructed as follows:

$$GCI_a = \sum_{r \in R_a} \alpha_r f_r w_{d_r} \tag{7}$$

where a denotes airport, d the destination airports, $r \in R$ a route within the set of all routings, α directness, f the frequency and w the destination quality. This new measure offers a better view of the network access of aviation compared to just passenger volume for example, which gives rise to measurement error by disregarding connections, directness, layover times as opportunity costs, and destination access. The are four primary ingredients to the measure: the itinerary between airports, the frequency and the directness of the routing, and the destination quality.

Itinerary First, whether a link between an airport and another is identified using Official Airline Guide data. The set of routings derived are distinguished by two types: non-stop routings without stops and one-stop routings. Multi-segment flights are treated as separate non-stop connections. One-stop routings are identified with two scheduled flights and a transfer layover at another airport. Two rules are used to determine the possible one-stop routing set. A minimum of 30 minutes of connection time is needed, and only single-airline operated flights or flights with codesharing are included. Because of strong disutility of connections between completely unconnected airlines (no delay or missed connection protection, through-bag check, etc.), these are excluded from the one-stop analysis.

Frequency and directness Second, the frequency of the routing is calculated on an annual basis using the aggregate number of days on which routing r is operated, where multiple frequencies are counted as separate days. This reduces seasonality bias (where some routings see more operations per day in the summer season, for example). Directness is especially important for one-stop routings and is calculated for one-stop flights and then compared to the non-stop flight using the ratio of total travel time between the routing and the (hypothetical) non-stop. Layover time and flight durations are included in this consideration, which are both relevant.[5]

Destination quality Finally, the value of the air connection is also taken into account, akin to the attractivity in the accessibility model mentioned above. This is calculated using a distance decay function of the gridded population data from LandScan adjusted for wealth differences and gives a measurement of the relative quality of the destination market.

The resultant index is available at the non-stop and one-stop levels from 1990-2012. Allroggen et al. (2015) provides the full detail on the construction of the GCI on a global scale.

The GCI is then converted into the aggregated CBSA-level connectivity measure c_i by geospatially locating the airports into the CBSA. Figure 1 shows the airport-CBSA correspondence for parts of the United States. The shaded polygons are the shapes of each CBSA in the United States, and the green icons indicate the airports that are located within a CBSA. Note that it is possible for

[5] For example, one can fly from New York to Hong Kong, via Chicago, San Francisco, or London, amongst other options. The directness is normalized to 1 for the non-stop flight, and the rest of the routings are compared against the non-stop. Flight duration is going to be highest via London in this example, thus having the highest detour factor and the lowest directness as compared to the other routings mentioned.

one CBSA to contain more than one airport. In such cases, GCI scores are summed linearly within these CBSAs. Of the 929 CBSAs in the United States, there are 1039 airports that fall within 549 CBSAs, as there are a number of CBSAs that contain no airports in its defined geography.

Figures 2 and 3 illustrate the Global Connectivity Index (summed non-stop and one-stop indicies) for New York City and Atlanta respectively. We make several initial observations. While Atlanta Hartsfiled-Jackson International is the largest U.S. airport by traffic, the New York Metropolitan area has the highest combined traffic and passenger numbers. Connectivity is much higher in the New York area as compared to Atlanta, a three-fold difference - as compared to passenger numbers, where Atlanta lies between 40 and 50 million and the NY combined close to 60 million passengers enplaned. This is because of the position of New York as a link to many European and Asian destinations via direct flights, as well as direct access to large European hubs with many codeshare partners, which Atlanta lacks in comparison. Using just passenger numbers would neglect the network nature of the aviation industry and introduce bias in the effects of passenger numbers in local growth.

While connectivity and passenger number trend similarly, there are marked differences between them. For example, connectivity decreased significantly in the recession of 2008-2010, which could be due to a reduction in direct routes to international destinations and the fact that many U.S. airlines suffered significant losses. However, passenger numbers did not decrease as much, which could be due to the practice of "capacity discipline" and efforts to increase load factors as means to improve profitability.[6] Using pure passenger numbers thus would fail to account for the actual loss of convenience of the direct routings that existed at 2007, for instance.

4.3 Instrumental variables

While a number of studies in the existing literature have since on constructing instruments based on historical plans or policies, fraction of connecting passengers, concentration of passengers originating from urban areas, or national trends (LeFors, 2014; Sheard, 2014, 2015; Blonigen and Cristea, 2015), this paper uses historical socioeconomic data to instrument for future connectivity. A valid instrument for the Global Connectivity Index (GCI) in the present (in 2012) would need to correlate

[6] U.S. airlines also underwent a subsequent period of consolidation, first with Delta's merger with Northwest, United and Continental's "merger of equals", Southwest and AirTran, American Airlines and U.S. Airways, and most recently, Alaska and Virgin America

with connectivity today but not with the outcome variable of interest.

I construct a set of new instruments based on the ingredients and prerequisites to future air connectivity. First, there are important institutions that led to the addition of future air connectivity in cities. Aviation safety relied on proper air traffic control, air traffic control facilities were initially constructed at airports in the U.S. to ensure air traffic can be directed appropriately. In addition, because of rapid construction and upgrade of air facilities and storage during WWII, the military also played a significant role in developing the future air connectivity of many cities. These institutions thus were important prerequisites for future air connectivity and were unlikely to be correlated with future economic growth and innovation. Second, there are historical amenities cities provided in the late 19th century into the early 20th century that may have provided the initial impulse for air services. The changing structures of the U.S. railways also created demand and substitution effects with the aviation sector. These historic amenities thus have effects on the future air service of a city, but the effects of such amenities need not persist with economic growth. Finally, building and expanding upon an airport requires land - flat land, open surfaces, a proximity to the urbanity, as well as existing transport linkages. Historical land use and the natural terrain of a city may dictate whether it would have high levels of air services in the future.

4.3.1 Instrumental variables: Institutions

Before deregulation of aviation, commercial aviation was run in prescribed routes. The Civil Airways of the United States was designated in the Civil Air Regulations Part 160, which gives the designated air routes operating at the time. In the early days of aviation, air traffic controllers stood in a prominent location and used colored flags to communicate with pilots. These were quickly replaced by light guns, where a colored beam of light is signaled to the aircraft, which are still used today at most control towers. Radio control was then added to enable direct communication between the pilot and the control tower. The dawn of advanced instrumentation and ground-based radio navigation aids did not replace air traffic control needs - where most aircraft flew under the “see and be seen” principle. As airport congestion became an issue and the risk of mid-air collisions caused fear, air traffic control became all the more important for the existence and sustainability of an air industry (Nolan, 2011) .

In 1934, the Bureau of Air Commerce was created by Congress to be part of the Department of

Commerce, responsible for the nation's airway traffic. Of particular importance traffic control that helped separate aircraft between airports. Airway traffic control units (ATCUs) were developed initially at the request of the Bureau of Air Commerce by the airlines because of Depression-era budget issues. In 1937, Department of Commerce began to acquire the ATCUs and converted them into airway traffic control stations (ATCSs) with the staff that had been performing air traffic control in the locations before. Standardized air traffic control rules followed thereafter. The ATCUs and ATCSs, as well as the radio stations, later evolved and became the air traffic control centers of the nation (Nolan, 2011).

In Figure 5, the Smithsonian archived map of the Civil Airways of the United States in 1938 documented the ATCSs and radio stations across the United States (U.S. Department of Commerce - Bureau of Air Commerce, 1938). The existence and location of control airports were not only in major airports: because air traffic had to make it between the coasts, and that visual flight rules with radio communication were the norm, airports located en-route also needed air traffic control facilities. The map designated the ATCSs, which are among the larger stations first to be converted to be under Federal control, as well as the existing radio station facilities. The existence of ATC infrastructure and expertise was both a function of institutions and the incidental geography that formed the civil airways of the U.S., but should plausibly not be correlated with future growth and innovation. Using this map in Figure 5, I constructed binary variables recording the control airport status in a city, as well as the type of air traffic control offered (ATCSs or radio stations) as well as their operating frequency, to generate quasi-random variation in future air connectivity. Areas with existing ATC facilities were more likely to receive higher air connectivity as a result. This is plausible because ATC development stagnated as a result of the war, and that the modernization in ATC technologies has been slow. Cities already equipped with the existing infrastructure and institutions for aviation safety were likely to receive more connectivity through aviation.

In the years that follow, World War II made a significant impact on American aviation landscapes. The military used aircrafts to transport people and supplies and most flights in the nation became military in nature. The federal government exerted large public expenditure in upgrading airports to serve military needs; airports both large and small became vastly improved. Military facilities thus likely coincided with airport existence in order for supplies and troops to be deployed. After the war, many military air bases and airfields were then designated as surplus airfields. The military airfields either provided new locations for airports or prompted the construction of new airports (Bednarek, 2016). A prominent example for an airfield that was converted into new post-war airport would be Chicago's O'Hare, replacing Midway as the main airport for Chicago, thereby increasing the future connectivity of Chicago to meet post-war demands. Using the U.S. Census Military Installation National Shapefile[7] I construct a proxy for military facilities that are reasonably related to aviation activity from an institutional standpoint as outlined above. The counts of military installations are spatially concatenated into CBSAs and summed using QGIS software.

4.3.2 Instrumental variables: Historic amenities

In addition to important institutions that pre-dated increased aviation connectivity, I consider the presence of historic amenities, which include old travel destinations and railway traffic. Historic travel destinations from the late 1800s into the early 1900s could be argued to provide the conditions for the creation of future air service in these places first. Just because a place was a destination for tourist in the distant past does not mean the place would not decline economically in the future, and the attraction and travel demand could also wane as a result. Therefore, a distant-past measurement of tourism could reasonably be argued to be exogenous to growth in income and innovation in the far future. To construct such a variable, I sampled a variety of historical travel guides for the Untied States as a whole. I use a prominently used travel guide by Baedeker published in 1904 to construct a variable for tourism in the United States (Baedeker, 1904). In Figure 7 you can see a sample map of New York City found in the 1904 travel guide. I use a variety of indicators for travel in this old travel guide, including the existence of a city map, a city chapter, as an origin/destination in travel instructions, as well as the page span of the mention of the city in the table of contents to construct the variable for historic amenity in the form of travel.

Next I turn to the historical and early geography work as alluded to by Bednarek (2016) on the subject of passenger growth and economic development. Taaffe (1956) was one of the first studies that connected aviation activity and urban patterns, focusing on describing patterns rather than on demonstrating causality (Bednarek, 2016). Two of Taaffe's observations were as follows. First, there are a set of cities that are located inside another major city's "traffic shadow," where residents have a readily available substitute airport too close-by, thus hindering air service growth there. For

[7]The data is available for download at Data.gov and at the Census website.

example, Milwaukee sits in the traffic shadow of Chicago and thus would receive less growth in air services as a result of its location proximity. Taaffe constructed a map of the designated traffic shadow versus non-shadow cities, with traffic shadow defined as within 120-highway miles in 1950. The cities that happen not to be located in a traffic shadow then has the higher potential to grow in air services in the years that followed. Using these maps in Appendix C, I construct a variable for whether a city was designated by Taaffe's definition of traffic and non-traffic shadow cities as an instrument for future air connectivity. If cities' location with the shadow are assumed not to correlate with future innovative patterns, then we could plausibly use the traffic shadow definition to instrument for future air connectivity.

The second main observation of Taaffe's was related to the rail: he posited that places that received overnight rail service from New York, Chicago, and D.C. were subjected to the highest level of surface competition. Beyond this zone, air transport would have a clear advantage. I construct based on Taaffe's map on rail overnight zones, as well as an additional dataset from passenger rail service for a variable that included the overnight rail services and whether rail service was lost or reduced in frequency between 1962 and 1971. This variable would predict future air service increases due to lack of surface competition and to the demand to compensate for lost rail service as a result of rail sector restructuring. The maps used for the construction of these variables are available in Appendix B.

4.3.3 Instrumental variables: Physical constraints

Because of the physical constraints of building airports, expanding airports, constructing new runways and terminals, I also include additional physical geography variables as instruments for future air connectivity, including the average slope within a CBSA using SRTM digital elevation data calculated in Google Earth engine and historic land use data (1970) from the USGS. Both datasets were concatenated and averaged or summed over a CBSA using Google Earth Engine and ArcGIS respectively. If a CBSA has a very steep terrain and scarce land available for transport infrastructure development, then aviation connectivity is unlikely to be high.

5 Results and Discussion

The equation of interest is equation 5, the reduced form relationship between long-run changes in regional economic growth and innovation as a function of connectivity. I use a two-staged least squares model to estimate the effect of air connectivity on these outcomes using an instrumental variable approach. The connectivity of a city is instrumented using a set of historical institutional and physical variables. Table 1 reports the summary statistics of the key variables used in the models. The changes long-term change in socioeconomic outcomes are between a two-decade period from 1990 to 2012; the inventor and patent data are reported from 1990 to 2010. The mean changes between these two time periods for all CBSAs are presented in Figures 8 and 9.

In Tables 2 and 3, the odd columns report the first-stage results as well as the Sanderson-Windmeijer (SW) F statistics, in order to show the relevance of the chosen instruments, generally taken as an F-stat >10, where a high F-stat rejects the null hypothesis that the coefficients in the first stage are not significantly different from 0. A low F-stat would indicate a potential weak instruments problem, where the instrument fails to explain variation in the instrumented variable, in this case, Global Connectivity. The even columns report the second-stage results of the 2SLS model, where the instrumented values for connectivity are used in the model to estimate the impact of connectivity on regional growth and innovation. In an over identification model, the Hansen J-statistic is reported, where the null hypothesis is that the instruments are indeed exogenous. The J-stat p-value helps us determine whether or not we fail to reject the null to give us results with an exogenous instrument. A J-stat p-value greater than 0.10 would provide evidence for exogeneity of the instruments in the over identification model. These are reported for all second-stage results with an over identification case in Tables 3 to 6. Robust standard errors are used.

Table 2 considers the outcome variable of income change between 1990 and 2012 with connectivity in 2012. The preferred instruments for institutional prerequisites are used here, which are the air traffic control variation and military installments. These instruments are individually demonstrated to be valid in the first-stage. We find a significant impact of connectivity robust to both specifications of instruments. Take the example of the first model (results displayed in columns (1-2)), which uses air traffic control status to instrument for 2012's level of connectivity. The coefficient of 1245.7 is positive and significant, meaning that the higher the connectivity levels in 2012, the higher growth in income occurred between 1990 and 2012. Interpreting this strictly in the linear sense, a city that has a 100-unit higher level of the global connectivity index can be associated with a higher level of long-term total personal income by up to $124,570,000. The effect of military installments is qualitatively similar. Employment level changes were included as controls to ensure that the income changes are not purely due to more people being employment.

Table 3 considers again the changes long-run income. In this specification, we use additional instruments to include both the preferred instruments above, as well as the historic amenity variable for tourist attraction as measured by a historic guidebook, and the initial transport land use coverage in 1970. The two sets of instruments are valid with F-stats >10, and the instrumented GCI has a significant impact to long-run income growth. Interpreting this strictly in the linear sense, a city that has a 100-unit higher level of the global connectivity index can be associated with a higher level of long-term total personal income by up to $217,940,000. In Table **??** (in the Appendix), I also report the statistics of the Anderson-Rubin test for weak instruments.

Table 4 reports the second-stage only results, where all columns are using the same first stage with three instruments (air traffic control, military installments, and historic amenity) in an over identification model, with the exception of column 4, where historic amenity is dropped. Column 1 repeats the results for the second stage in column 2 of Table 3 for comparison. Column 2 uses GMM in the estimation and find a slightly lower magnitude of the estimated coefficient. Columns 3 and 4 differ by the set of instruments used for estimating the effect of connectivity on employment changes. I find a significant and positive increase of connectivity on employment of up to 234 jobs for a 100-point increase in connectivity levels. The exogeneity criterion for employment was fulfilled at the 0.05 level. Columns 5-6 report the results for patent activity, with column 5 the set of all inventors filed or granted a patent, and column 6 using just the first inventor addresses. I find up to 6 new patents (patent-inventor) for a city with an increase in 100 points in the GCI, and the effect is positive and significant.

Table 5 reports the results on service sector income and employment, as well as the service sector's share in income and employment. Connectivity is not a significant factor in explaining long-run changes in service income and employment shares. I find significant and positive results for service employment in the order of 192 jobs for 100 point increases in GCI.

Table 6 reports the second-stage only results, where all columns are using the same first stage with three instruments (air traffic control, military installments, and historic amenity) in an over identification model. The odd columns are for the largest 100 cities by population rank, and the even columns are for the population rank greater than 300 (i.e., the smallest 268 CBSAs). An important result is shown in this table. For income, connectivity has a strong positive and significant effect in the largest 100 cities, but this effect dwindles in the smaller cities, with a coefficient that is 7.5 times smaller albeit significant at the 0.05 level. Employment level changes are also significant for the largest 100 cities; the magnitude for the smaller cities is also smaller but with less stark of a difference than in the income effect of connectivity. As for innovation, using the data on the changes in inventors that are included in filed and granted patents, the largest cities benefit positively in innovation from air connectivity, while the smallest cities actually see a small negative effect (with the linear model being a poor model explaining the variation among the small cities given the R^2 value). Overall, this suggests that connectivity impacts on income are far more significant in the largest cities, and the marginal impact of connectivity is non-linear with respect to city size. This lends empirical support to the increasing returns to scale to city size for interaction and knowledge accumulation. The employment impacts exhibit a similar trend but the differences in magnitude for employment are less stark and perhaps not statistically different between the larger and smaller city sets. The results on innovation is also striking in that the largest cities see most of the positive invention benefits due to connectivity, and the marginal impact of connectivity to smaller cities are close to none or even slightly negative, lending strong support to the agglomeration economies of knowledge.

6 Conclusion

Commercial aviation is an important determinant of regional economic activity. According to the FAA, some 2.6 million passengers fly in and out of U.S. airports every day (Federal Aviation Administration, 2017). Aviation enables us to interact with other people that are distant, and new ideas form as a result. Few studies have investigated the spillover impact of aviation connectivity on long-run economic growth and innovation. The fact that aviation activity itself is endogenous with local economic conditions presents a challenge for empirical identification of the causal impacts. I use a novel set of instruments based on the institutional and physical prerequisites to air development and an updated measure of aviation connectivity that takes into account the network nature of the industry to show the magnitude of aviation connectivity's impact on regional economies. I also show for the first time the impact of aviation on regional innovation as measured by patent and inventor activity. Furthermore, I find evidence supporting the agglomeration economies. The marginal connectivity impacts on regional economies are much larger in bigger cities and diminish with city size; innovation impacts of aviation vanish in the smallest cities.

This paper improves upon measurement in two ways. First, the new set of instruments focus on the plausible institutional and physical requirements for aviation development, which had immediate consequences in the operation, financing, and improvement of aviation infrastructure. These included the historical air traffic control infrastructure as well as proximity to military installations, as well as other physical and amenity factors. The preferred instrument of air traffic control infrastructure demonstrated exogeneity as a valid instrument. Second, aviation connectivity is measured using the Global Connectivity Index, which accounts for the network nature of the aviation industry and reduces bias introduced by using pure passenger numbers or the number of departures, which may include transiting passengers. In this new measure, both the link and destination quality are considered. The spillover impacts of aviation is most plausibly due to the kind of connection one has in a city - not just the sheer number of departures available.

Using an instrumental variable approach, I find a significant impact of connectivity on long-run economic growth. A 100-point increase in a city's Global Connectivity Index increases the long-term income of a city by $217,940,000 and brings an additional 234 jobs. To provide more context, consider a city like Myrtle Beach, SC that has a connectivity index close to the mean connectivity levels of all core-based statistical areas (CBSAs). Given the GCI Index for Myrtle Beach, a 100-point increase in the connectivity index would represent or require a 1.03% increase in air connectivity. For reference, the total employment levels in 2012 for Myrtle Beach was 189,007 and total personal income was at $12,517,846,000. Applying the marginal effects computed above, the hypothesized 100-point increase (1.03%) represents a marginal effect of 1.74% in total income and 0.12% in employment for the mean-connectivity city.

The second contribution of this work is the demonstration of a positive effect of aviation connectivity on innovation, where a 100-point increase in connectivity brings about 6 new inventors getting patented, and 2 new unique (first-inventor level) patents. This provides the first evidence on the innovation impact of large-scale transport infrastructure, enabling interactions that otherwise would not have taken place, or would have been much more costly. Indeed, innovation is not perfectly measured by patenting activity; many facets of economic complexity in innovation should be considered (see Hidalgo (2015)).

Of the CBSAs studied, this research also finds evidence to support agglomeration economies. Large cities have higher connectivity benefits: the magnitude and significance of connectivity impacts to the top 100 CBSAs in the U.S. are pronounced; these effects vanish when we study the smallest of the CBSAs with airports. The magnitude difference is particularly large in total income and innovation activity, suggesting that the value added by connectivity is embodied in the value of the knowledge sector and not the strongest through the number of people employed; employment differences were notably less stark. This provides evidence to the following: (1) there are non-linear impacts of connectivity to different city sizes and (2) there may be threshold effects of connectivity—a city will need to acquire a certain level of base connectivity beyond which connectivity has positive externalities and persistent impacts in the local economy. These results support the increasing returns to scale of connectivity, knowledge, and innovation.

This paper provides some evidence to support policies that aim to increase aviation connectivity in different regions. In particular, the use of air connectivity in this research implies that cities and regional governments could aim beyond merely increasing passenger numbers or the number of flights. Adding new connections to large hubs can allow the city to enjoy large connectivity benefits; passengers thereby benefit from more one-stop flights, lower layover times, and codesharing opportunities. Adding new direct flight destinations can improve nonstop connectivity significantly, bringing about connectivity-driven spillover impacts to a region. Regional governments can also support connectivity-based growth by investing in airport infrastructure (both on-airport and companion transportation networks), zoning and development of business or tech hubs, and other companion investments. These actions would lower entry costs and attract air services. In addition to market demand studies, stakeholders should take into account the connectivity-driven impacts when considering actions to expand air services. An example of an airport that has actively worked with airlines to increase connectivity would be Boston Logan, which has seen additions or revivals of many direct flights to international destinations in recent years, especially the "long and skinny" routes as they call them in the industry, long-haul medium demand routes that are now economical to service using the new Boeing 787s and the Airbus A350s. Airport incentives and concessions could easily be paid off and justified through impacts in the regional economy.

Future work could improve upon measurements of innovation and economic complexity and investigate how aviation interact with these factors. Patent and journal article citation *networks* are possible avenues of pursuits. The interactions between raising connectivity, inducing new demand, and competition are also poorly understood; methods in political economy or industrial organization could be applied to better understand these complexities. Regional inequality and environmental implications of aviation could also be studied using a modified version of the approach in this work. The improved understanding of aviation's impact in our economy and society is particularly relevant today, as attention is being paid to the highly international and emissions-inducing sector.

References

Allroggen, F. (2013). Fördert ein leistungsfähiges Verkehrssystem die wirtschaftliche Entwicklung? Ein Überblick. *Zeitschrift für Verkehrswissenschaft*, 84(3):2–43.

Allroggen, F. and Malina, R. (2014). Do the regional growth effects of air transport differ among airports? *Journal of Air Transport Management*, 37:1–4.

Allroggen, F., Wittman, M. D., and Malina, R. (2015). How air transport connects the world - A new metric of air connectivity and its evolution between 1990 and 2012. *Transportation Research Part E: Logistics and Transportation Review*, 80:184–201.

Amazon (2017). Amazon HQ2 Request for Proposal. Technical report, Seattle.

Anderson, J. E. and Wincoop, E. V. (2004). Trade Costs. *Journal of Economic Literature*, 42(3):691–751.

Aschauer, D. A. (1989). Is public expenditure productive? *Journal of Monetary Economics*, 23(2):177–200.

ATAG (2014). Aviation benefits beyond borders. Technical Report April.

Baedeker, K. (1904). *The United States: With an Excursion into Mexico*. Karl Baedeker, Leipzig, 3rd edition.

BBC News (2018). Heathrow Airport: Cabinet approves new runway plan.

Bednarek, J. R. (2016). *Airports, Cities, and the Jet Age: US Airports Since 1945*. Palgrave Macmillan, New York.

Belobaba, P. (2016). Introduction and Overview. In Belobaba, P., Odoni, A., and Barnhart, C., editors, *The Global Airline Industry*, chapter 1, pages 1–18. Wiley, 2nd edition.

Blonigen, B. A. and Cristea, A. D. (2015). Air service and urban growth: Evidence from a quasi-natural policy experiment. *Journal of Urban Economics*, 86:128–146.

Brueckner, J. (2003). Airline Traffic and Urban Economic Development. *Urban Studies*, 40(8):1455–1469.

Button, K. and Yuan, J. Y. (2013). Airfreight Transport and Economic Development: An Examination of Causality. *Urban Studies*, 50(2):329–340.

Campante, F. and Yanagizawa-Drott, D. (2017). Long-Range Growth: Economic Development in the Global Network of Air Links. *The Quarterly Journal of Economics*, (December):qjx050.

Canning, D. and Fay, M. (1993). The Effect of Transportation Networks on Economic Growth. *Columbia University Department of Economics Discussion Paper 9293*, (May).

Catalini, C., Fons-Rosen, C., and Gaulé, P. (2016). Did Cheaper Flights Change the Geography of Scientific Collaboration?

Davis, D. R. and Dingel, J. I. (2012). A Spatial Knowledge Economy. *NBER Working Paper*, (18188).

Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*.

Donaldson, D. and Hornbeck, R. (2016). Railroads and American economic growth: A "market access" approach. *Quarterly Journal of Economics*.

Dong, X., Zheng, S., and Kahn, M. E. (2018). The Role of Transportation Speed in Facilitating High Skilled Teamwork. *National Bureau of Economic Research Working Paper Series*, No. 24539.

Duranton, G. and Turner, M. A. (2012). Urban growth and transportation. *Review of Economic Studies*, 79(4):1407–1440.

Federal Aviation Administration (2016). The Economic Impact of Civil Aviation on the U.S. Economy. (November):36.

Federal Aviation Administration (2017). Air Traffic By The Numbers.

Glaeser, E. L. and Kohlhase, J. E. (2003). Cities, regions and the decline of transport costs. *Papers in Regional Science*.

Glaeser, E. L., Scheinkman, J. A., and Shleifer, A. (1995). Economic growth in a cross-section of cities. *Journal of Monetary Economics*, 36(1):117–143.

Guimerà, R., Mossa, S., Turtschi, a., and Amaral, L. a. N. (2005). The worldwide air transportation network: Anomalous centrality, community structure, and cities' global roles. *Proceedings of the National Academy of Sciences of the United States of America*, 102(22):7794–7799.

Haines, M. R. and Margo, R. A. (2008). Railroads and local economic development: The United States in the 1850s. In *Quantitative Economic History: The Good of Counting*.

Hidalgo, C. (2015). *Why Information Grows: The Evolution of Order, from Atoms to Economies*. Basic Books.

Jackson, M. O. (2014). Networks in the Understanding of Economic Behaviors. *The Journal of Economic Perspectives*, 28(4):3–22.

Lai, R., D'Amour, A., Yu, A., Sun, Y., and Fleming, L. (2011). Disambiguation and Co-authorship Networks of the U.S. Patent Inventor Database (1975 - 2010).

LeFors, M. (2014). The Role of Air Accessibility in Urban Development. *Journal of Operational Research Society*.

McGraw, M. J. (2015). Perhaps the Sky's the Limit ? Airports and Employment in Local Economies.

Nikkei Asian Review (2018a). Closure of Japan's gateway to Asia risks denting tourism boom.

Nikkei Asian Review (2018b). Kansai Airport to reopen runway flooded in powerful typhoon.

Nolan, M. S. (2011). Chapter 1 History of Air Traffic Control. In *Fundamentals of Air Traffic Control*, chapter 1, pages 1–43. International Code Council and Delmar, Clifton Park, 5th edition.

Redding, S. J. and Turner, M. A. (2015). Transportation Costs and the spatial organization of economic activity. *Handbook of Urban and Regional Economics*, pages 1339–1398.

Schlenker, W. and Walker, W. R. (2016). Airports, air pollution, and contemporaneous health. *Review of Economic Studies*, 83(2):768–809.

Sheard, N. (2014). Airports and urban sectoral employment. *Journal of Urban Economics*, 80:133–152.

Sheard, N. (2015). Airport Size and Urban Growth. Technical Report November, Norwegian University of Science and Technology.

Sheard, N. (2017). Airport consolidation and the provision of air services. *Journal of Air Transport Management*, 60:31–44.

South China Morning Post (2016). Hong Kong airlines push for more late-night and early-morning flights.

South China Morning Post (2017). Hong Kong transport chief confident in Airport Authority plan to raise HK$69 billion in loans for third runway.

Taaffe, E. J. (1956). Air Transportation and United States Urban Distribution. *Geographical Review*, 46(2):219–238.

U.S. Department of Commerce - Bureau of Air Commerce (1938). Civil Airways of the United States [photograph archived at the National Air and Space Museum].

Winston, C. (1991). Efficient Transportation Infrastructure Policy. *Journal of Economic Perspectives*, 5(1):113–127.

Wylie, P. J. (1996). Infrastructure and Canadian economic growth 1946-1991. *Canadian Journal of Economics*, 29(1):350–355.

Figures

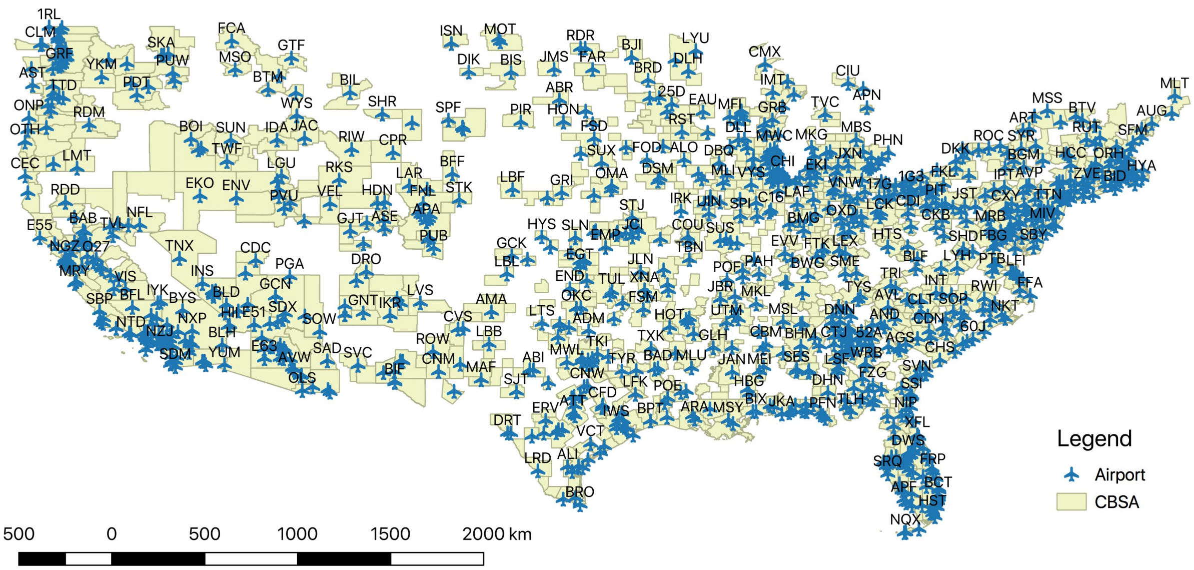


Figure 1: CBSA-Airport Correspondence in the U.S.

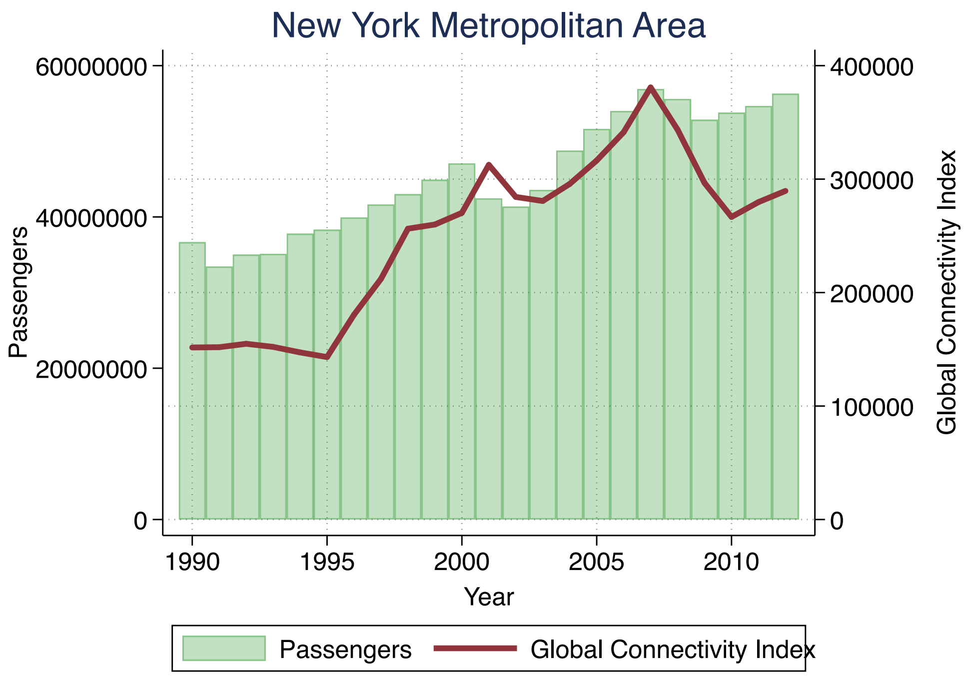


Figure 2: Connectivity Index and Passenger Numbers: New York City

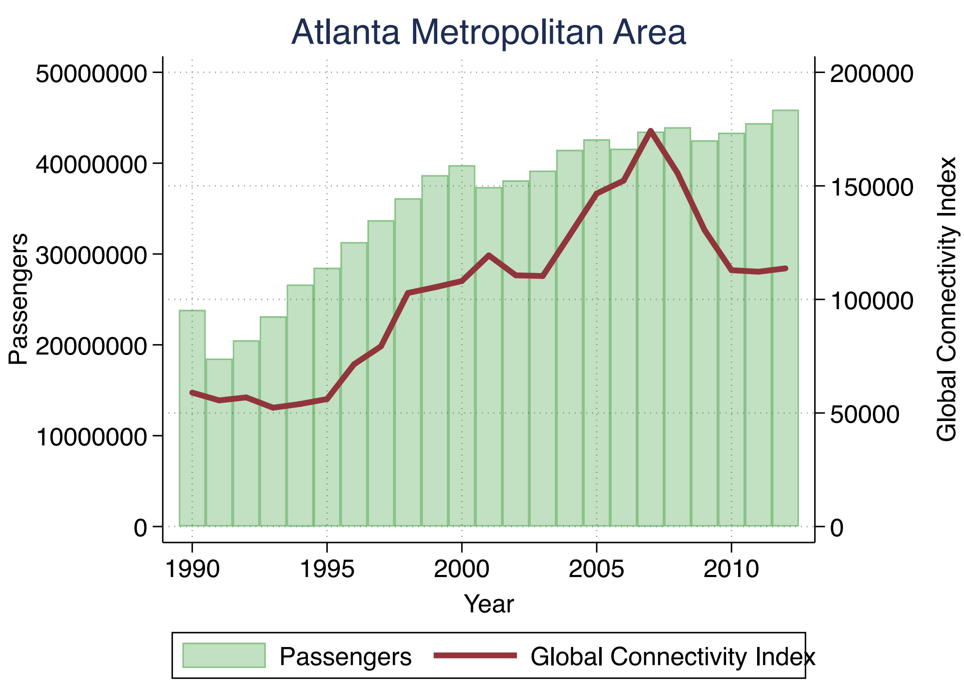


Figure 3: Connectivity Index and Passenger Numbers: Atlanta

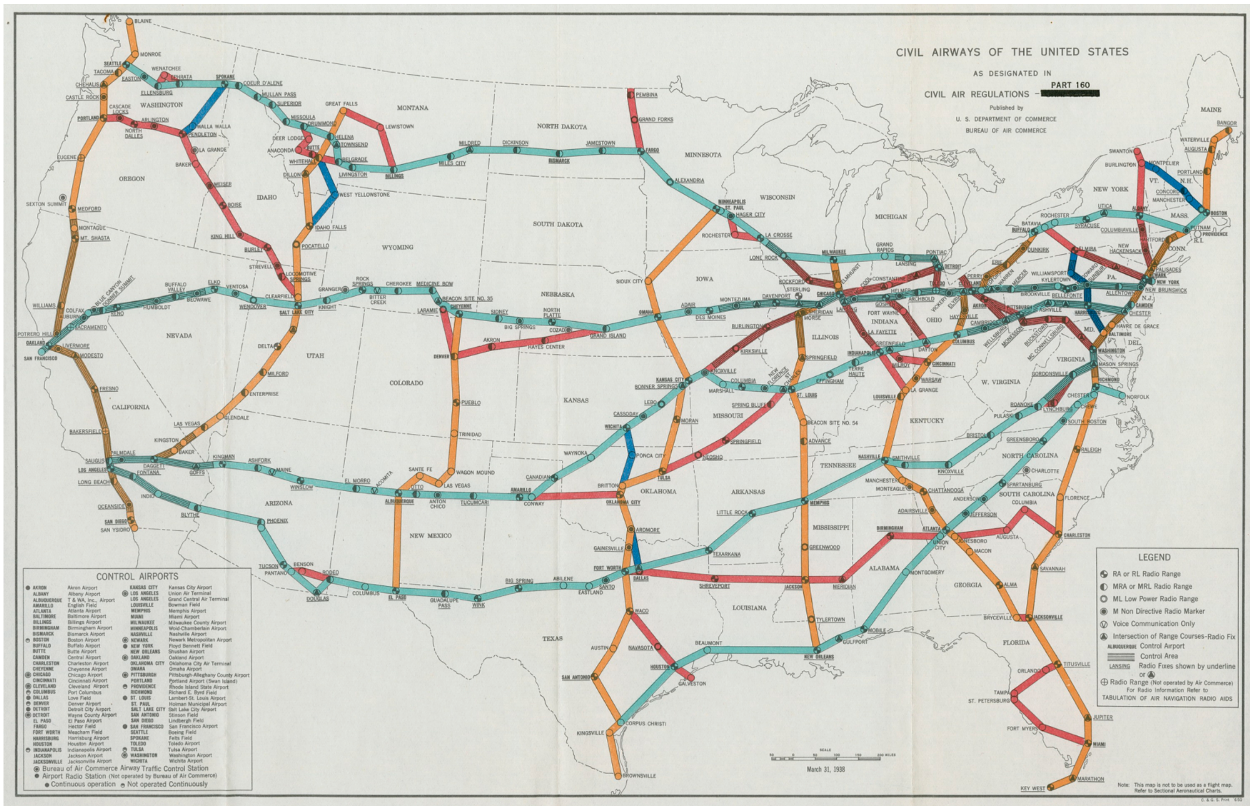


Figure 4: Map of Control Airports for Air Traffic Control in the Civil Airways of the United States (U.S. Department of Commerce - Bureau of Air Commerce, 1938)

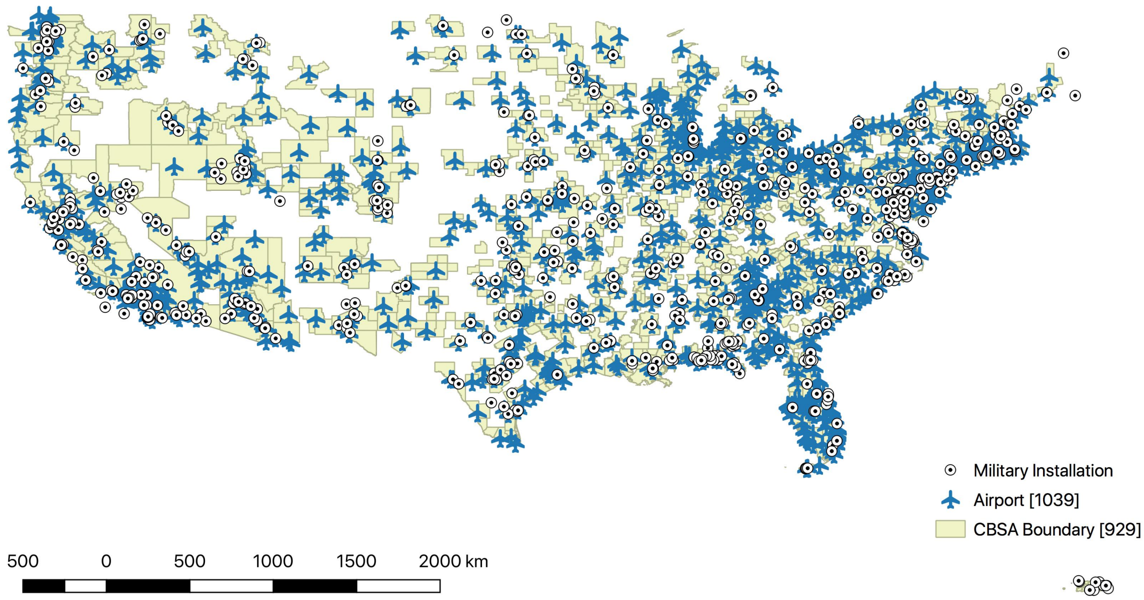
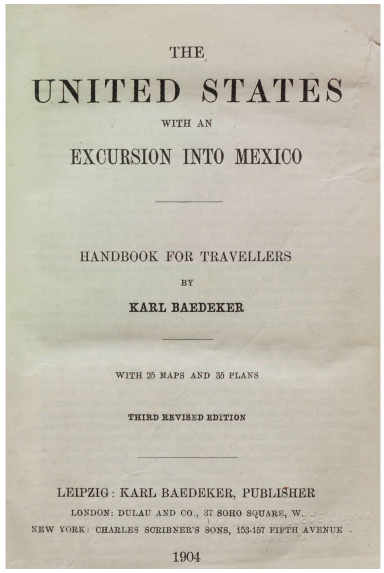


Figure 5: Military Installations within the U.S.



THE

UNITED STATES

WITH AN

EXCURSION INTO MEXICO

HANDBOOK FOR TRAVELLERS

BY

KARL BAEDEKER

WITH 25 MAPS AND 35 PLANS

THIRD REVISED EDITION

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1904

Figure 6: Cover of Baedeker's Travel Guide to the U.S. (1904)

Figure 7: Map of Manhattan in Baedeker (1904)

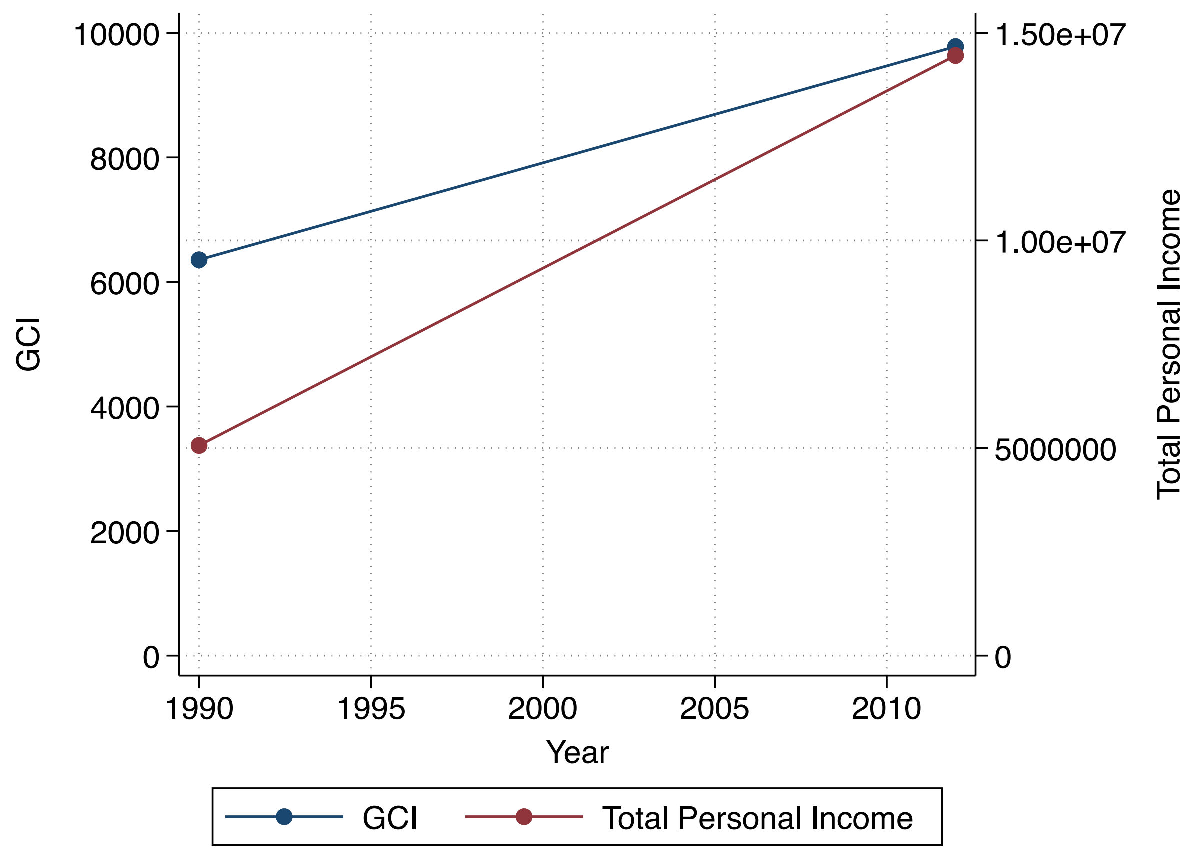

Figure 8: Changes in income and GCI, 1990-2012

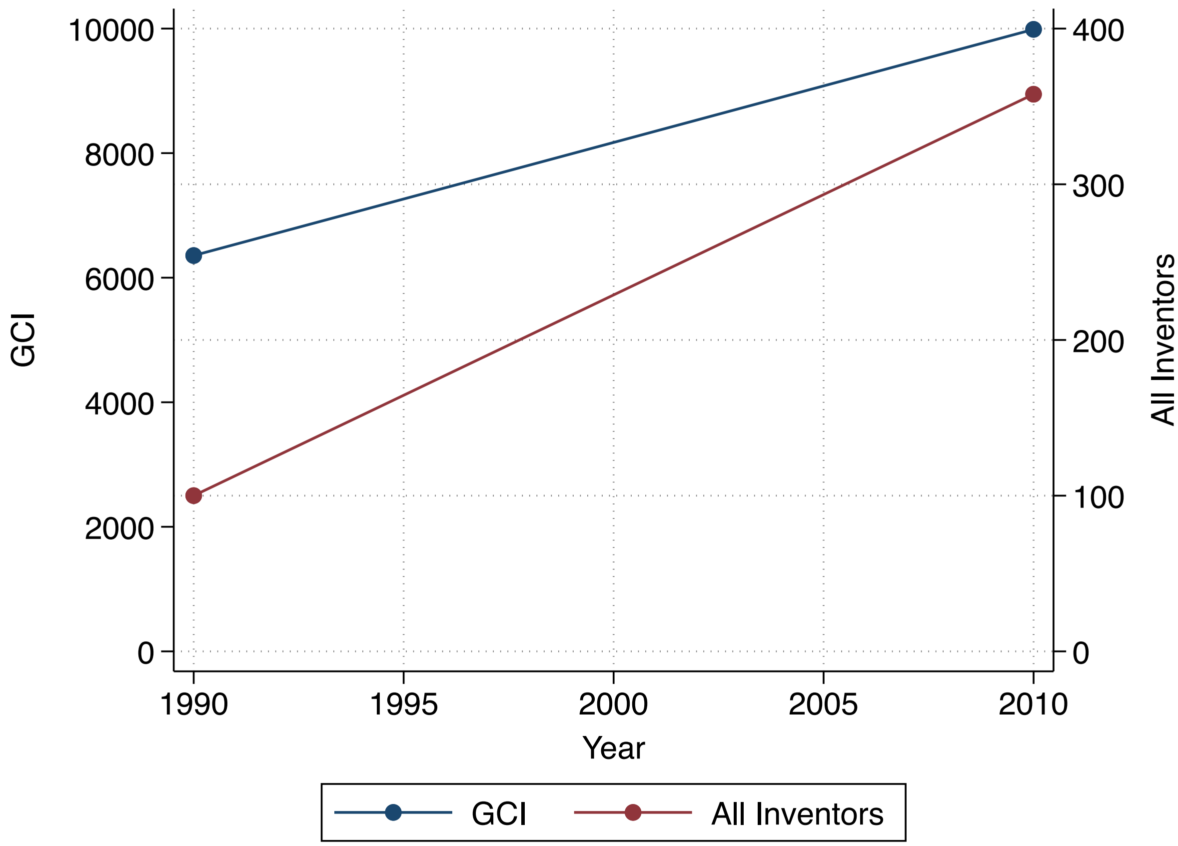

Figure 9: Changes in all inventors and GCI, 1990-2010

Tables

Variable	Obs	Mean	Std. Dev.	Min	Max
Δ Income	917	9391682	3.67e+07	160485	7.11e+08
Δ PC Income	917	21230.48	7172.985	5746	108436
Δ Population	917	68790.63	243730	-108613	2666322
Δ All Inventors	791	286.673	1554.557	-256	25869
Δ Unique Inventors	755	101.679	553.369	-165	9697
Δ Emp	917	43038.9	151761.9	-18091	2006308
Δ Service Y	917	2532183	1.08e+07	-238455	2.19e+08
Δ Service M	917	18924.61	75540.58	-12014	1318711
2010 GCI Sum	549	9987.173	25619.07	0	266668.4
2012 GCI Sum	549	9780.069	26055.13	0	289574.5
ATC Control Airport	549	.117	.364	0	2
Military Installment	917	.812	2.362	0	31
Overnight Rail Reach	66	.788	.713	0	2
Reduction in Rail	115	1.843	1.467	-1	6
Slope	915	3.94	3.666	.409	22.79
% of Transport Landuse 1970	914	.004	.004	0	.026

Table 1: Summary Statistics of Key Variables

	(1) 1.Stage 2012 GCI	(2) 2.Stage Δ Income	(3) 1.Stage 2012 GCI	(4) 2.Stage Δ Income
ATC Control Airport	22012.2***			
	(3819.8)			
Δ Emp	0.0969***	64.01†	0.110***	76.66
	(0.0109)	(34.75)	(0.0120)	(48.09)
2012 GCI Sum		1254.7***		1149.9***
		(154.2)		(282.2)
Military Installment			1383.3***	
			(342.7)	
SW F statistic	33.21		16.29	
SW p-value	1.38e-08		0.0000622	
J stat p-value				
N	549	549	549	549
Partial R^2	0.305		0.0886	
R^2		0.893		0.891

Standard errors in parentheses
Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics
Even columns show second-stage
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2: 2SLS: Change in total personal income (1990-2012) - Preferred Instruments

	(1) 1.Stage 2012 GCI	(2) 2.Stage Δ Income	(3) 1.Stage 2012 GCI	(4) 2.Stage Δ Income
Attraction	1069.0***		1292.4***	
	(178.8)		(263.0)	
Military Installment	770.7***		996.3***	
	(224.4)		(215.6)	
ATC Control Airport	15172.5***			
	(3275.4)			
Δ Emp	0.0800***	-4.092	0.0886***	-47.66
	(0.00812)	(32.24)	(0.00847)	(52.69)
2012 GCI Sum		1818.4***		2179.4***
		(344.4)		(514.7)
% of Transport Landuse 1970			434339.3**	
			(146873.9)	
SW F statistic	22.25		18.71	
SW p-value	1.33e-13		1.48e-11	
J stat p-value		0.238		0.282
N	549	549	546	546
Partial R^2	0.495		0.388	
R^2		0.874		0.841

Standard errors in parentheses
Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics
Even columns show second-stage
† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: 2SLS: Change in total personal income (1990-2012)

	(1)	(2)	(3)	(4)	(5)	(6)
	Δ Income	Δ Income (GMM)	Δ Emp	Δ Emp	Δ All Patent	Δ Unqiue Patent
2012 GCI Sum	1818.4***	1336.8***	2.335***	1.839***		
	(344.4)	(190.5)	(0.550)	(0.405)		
Δ Emp	-4.092	23.52			-0.00204	-0.000332
	(32.24)	(27.29)			(0.00189)	(0.000625)
Δ Population			0.443***	0.478***		
			(0.0392)	(0.0332)		
2010 GCI Sum					0.0612***	0.0181**
					(0.0167)	(0.00552)
J stat p-value	0.238	0.238	0.0947	0.0552	0.104	0.172
N	549	549	549	549	496	482
R^2	0.874	0.876	0.969	0.972	0.377	0.365

Standard errors in parentheses

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: 2SLS: Second Stage Results

	(1)	(2)	(3)	(4)
	Δ Service Y	Δ Service M	Δ Service Y-Share	Δ Service M-Share
2012 GCI Sum	-16.50	1.920**	-0.000000876†	-3.50e-08
	(72.80)	(0.595)	(0.000000511)	(0.000000164)
Δ Income	0.300***		4.14e-10	
	(0.0364)		(2.69e-10)	
Δ Emp		0.238***		1.79e-08
		(0.0618)		(2.04e-08)
J stat p-value	0.262	0.227	0.249	0.0749
N	157	549	157	549
R^2	0.964	0.911	-0.103	-0.00166

Standard errors in parentheses

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: 2SLS: Change in Service Sector Outcomes between 1990 and 2012. Tourism/Attraction IV for Service Income replaced by Traffic Shadow

	(1) Δ Income	(2) Δ Income	(3) Δ Emp	(4) Δ Emp	(5) Δ All Inventors	(6) Δ All Inventors
2012 GCI Sum	2039.1***	274.9*	2.550***	1.948*		
	(383.7)	(131.0)	(0.577)	(0.859)		
Δ Emp	-9.819	62.41***			-0.00210	0.00177***
	(33.16)	(12.35)			(0.00206)	(0.000536)
Δ Population			0.444***	0.473***		
			(0.0371)	(0.0326)		
2010 GCI Sum					0.0622**	-0.00749†
					(0.0209)	(0.00449)
N	100	268	100	268	100	217
R^2	0.847	0.470	0.957	0.646	0.264	-0.0846

Standard errors in parentheses

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: 2SLS Results: Large vs Small Cities - mulitple equilibria?

Appendix A. Theory

The following expands upon the Urban Growth Framework as described by Blonigen and Cristea (2015) based on the work by Glaeser et al. (1995) to motivate the causal link between aviation connectivity and regional growth. This model in particular assumes aviation enters both as an amenity to individuals and as a productivity-enhancing factor.

Metropolitan statistical areas (MSAs) share common pools of labor and capital and are considered open economies. Differences in regional growth cannot therefore come from savings rates or exogenous labor supply changes. Cities differ in productivity and quality of life.

Let the total output of a metropolitan area be given by

$$Y_{it} = Z_{it} f(L_{it})$$

where Z_{it} denotes the level of productivity within MSA i at time t, L_{it} denotes the level of population in MSA i at time t. $f(.)$ is a Cobb-Douglas production function and is common across cities, where

$$f(L_{it}) = L_{it}^{\alpha}$$

with α a national production parameter.

Individuals who work earn the marginal product of labor as their wages, with normalized output prices:

$$W_{it} = \alpha Z_{it} L_{it}^{\alpha-1}$$

And quality of life captures socio-economic factors specific to a location that is declining in the size of the city:

$$\Lambda_{it} = L_{it}^{-\delta} Q_{it}$$

where $\delta > 0$ and Q_{it} a vector capturing the variety of local conditions.

Individuals derive utility from their labor income and the enjoyed quality of life, entering as a product:

$$U_{it} = W_{it} \Lambda_{it}$$

Assuming free migration - labor mobility across cities, each individual's utility equals the reservation utility levels at any city at any time in equilibrium, so $U_{it} = U_t$, $\forall i$. Therefore, for each city,

$$\begin{aligned} \log\left(\frac{U_{t+1}}{U_t}\right) &= \log\left(\frac{W_{i,t+1}}{W_{it}}\right) + \log\left(\frac{\Lambda_{i,t+1}}{\Lambda_{it}}\right) \\ &= \log\left(\frac{Z_{i,t+1}}{Z_{it}}\right) + (\alpha - \delta - 1)\log\left(\frac{L_{i,t+1}}{L_{it}}\right) + \log\left(\frac{Q_{i,t+1}}{Q_{it}}\right) \end{aligned}$$

where the left-hand side of the equation is the same for all MSAs. Thus, utility grows at a common rate across cities where population growth is adjusted each period to reflect changes in productivity and local amenities. This enables us to express population growth rate as:

$$\log\left(\frac{L_{i,t+1}}{L_{it}}\right) = \frac{1}{1-\alpha+\delta}\Big[\log\left(\frac{Z_{i,t+1}}{Z_{it}}\right) + \log\left(\frac{Q_{i,t+1}}{Q_{it}}\right)\Big] + \kappa_t$$

where $\kappa_t \equiv \log(U_{t+1}/U_t)/(\alpha-\delta-1)$, a constant.

The following equation can then by derived by taking annual growth rate of the wages equation and substituting the population growth rate above to yield:

$$\log\left(\frac{W_{i,t+1}}{W_{it}}\right) = \frac{1}{1-\alpha+\delta}\Big[\delta\log\left(\frac{Z_{i,t+1}}{Z_{it}}\right) + \log\left(\frac{Q_{i,t+1}}{Q_{it}}\right)\Big] + \omega_t$$

where $\omega_t \equiv (\alpha-1)\kappa_t$, a constant.

We will also assume a vector of city characteristics, X_{it}, for each MSA i at time t that determines the growth of both productivity and quality of life. Moreover, we include a measure for air transport services as a potential growth driver for productivity and local amenity, but we will denote c_{it} as the aviation connectivity offered by the MSA i's airports at time t, giving us:

$$\log\left(\frac{Z_{i,t+1}}{Z_{it}}\right) = (X_{it})'\gamma_1 + \beta_1\log\left(\frac{c_{i,t+1}}{c_{it}}\right) + \nu_{it}$$
$$\log\left(\frac{Q_{i,t+1}}{Q_{it}}\right) = (X_{it})'\gamma_2 + \beta_2\log\left(\frac{c_{i,t+1}}{c_{it}}\right) + \upsilon_{it}$$

By substitution we may derive the reduced form for log growth rates as:

$$\dot{L}_i = \tilde{\beta}_1\dot{c}_i + X'_{i,T_0}\tilde{\gamma}_1 + \epsilon_{it}$$
$$\dot{W}_i = \tilde{\beta}_2\dot{c}_i + X'_{i,T_0}\tilde{\gamma}_2 + \xi_{it}$$

with $\tilde{\gamma}_1$, $\tilde{\beta}_1$, $\tilde{\gamma}_2$, $\tilde{\beta}_2$ the parameters derived from the model structure. We thus now can proceed to estimate the parameters of interest, $\tilde{\beta}_1$ and $\tilde{\beta}_2$, and hypothesize that improved connectivity will yield increased population growth, per capita and regional income levels, employment, and other measures of changes in regional economic activity.

Appendix B. Data - Additional Maps for Data Construction

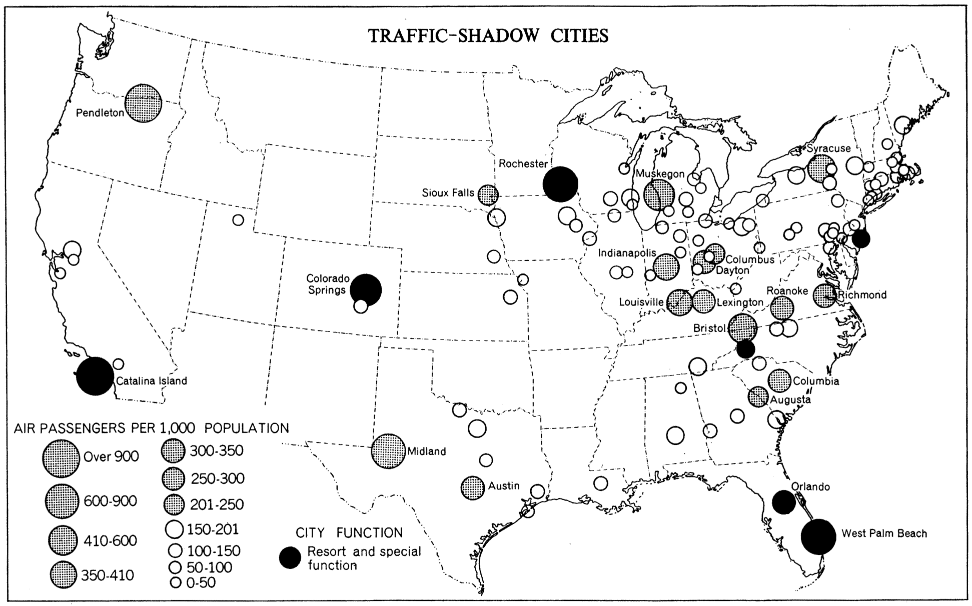

Fig. 5—Passenger indexes of those cities within 120 highway miles of a larger city or metropolitan area. Named and shaded cities are those with high indexes (more than 201). Resort and special-function cities are black; the five named are high-index, the unnamed (Atlantic City and Asheville) low-index cities.

Figure 10: Traffic Shadow Cities (Taaffe, 1956)

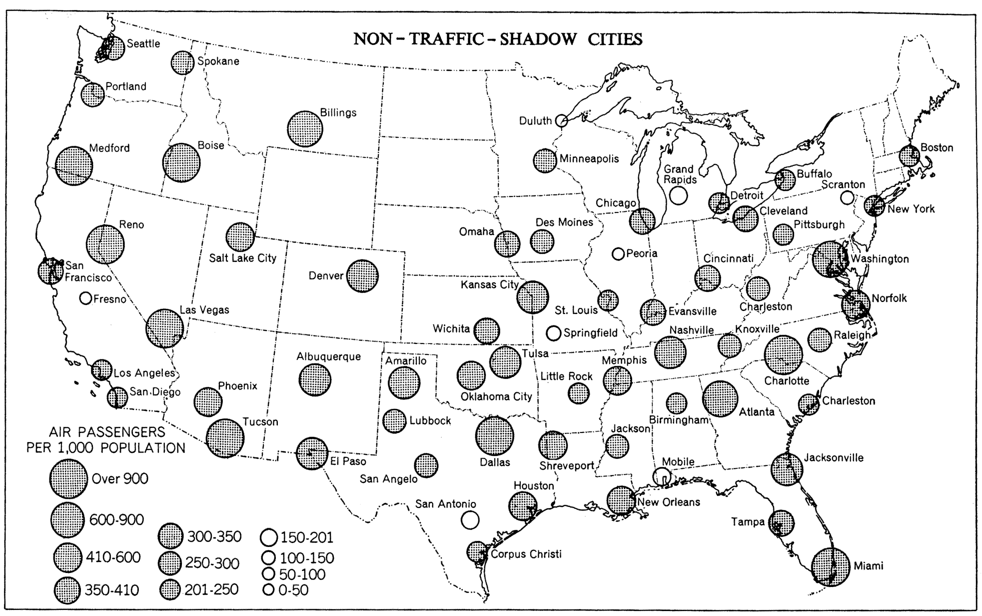

Fig. 6—Passenger indexes of those cities which do not have a larger city or metropolitan area within a radius of 120 highway miles. All cities are named, but only high-index cities are shaded.

Figure 11: Non-Traffic Shadow Cities (Taaffe, 1956)

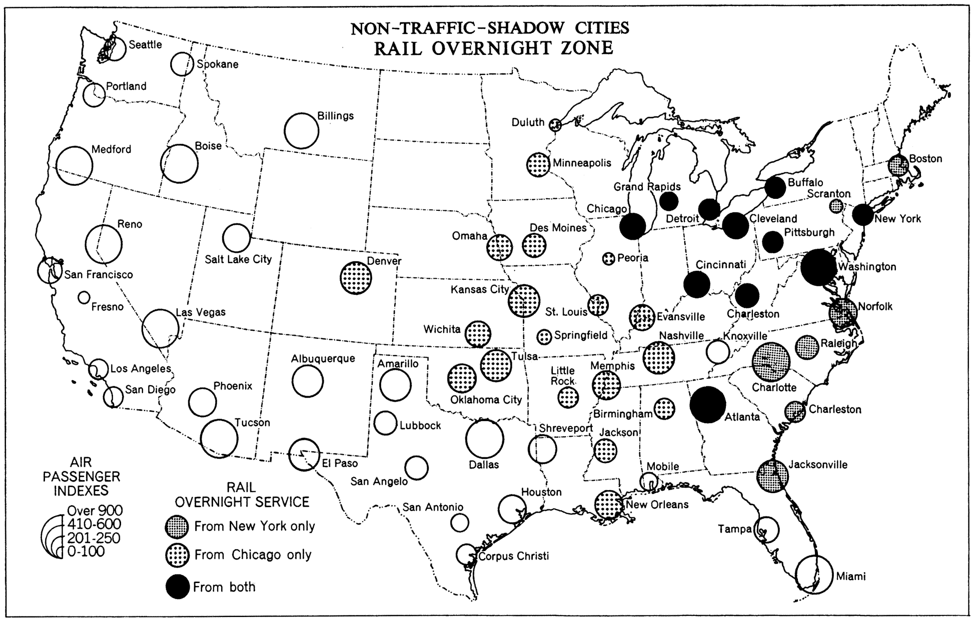

Fig. 8—Rail overnight service from New York or Chicago, here defined as that service which comes within at least one hour of a 4:00 p.m. departure and a 9:30 a.m. arrival, local standard time. (Source: "Official Guide of the Railway and Steam Navigation Lines of the United States . . .", National Railway Publishing Co., New York, 1951.)

Figure 12: Overnight Rail and Rail Replacement - Taaffe 1956

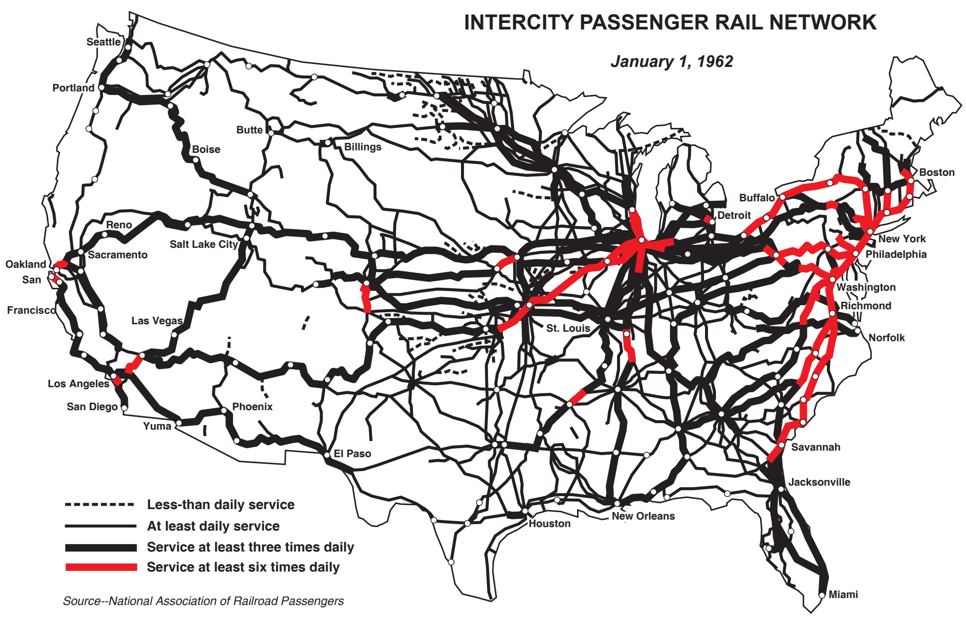

Figure 13: Overnight Rail and Rail Replacement - National Assoc. of Railway Passengers

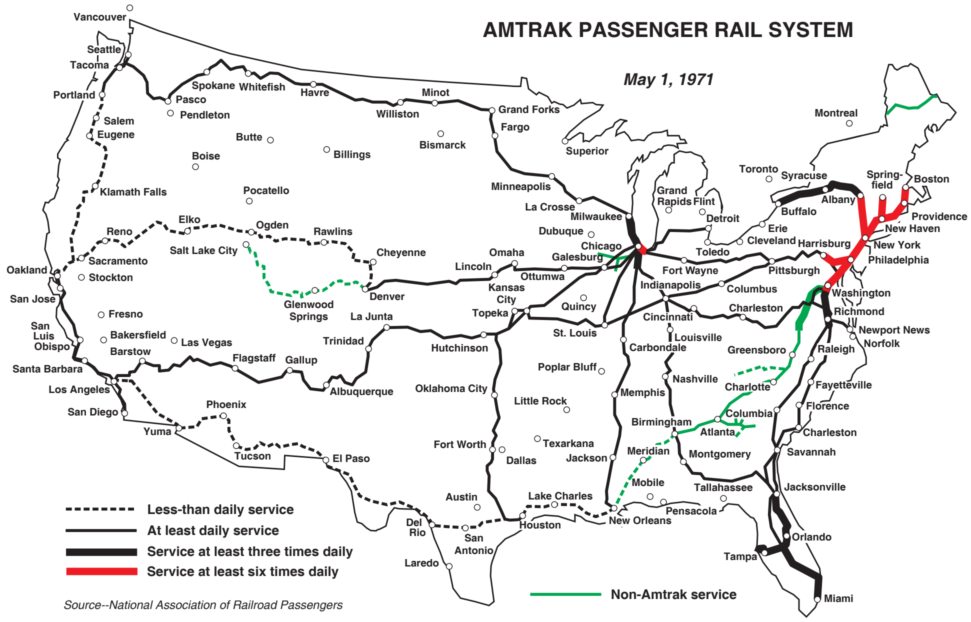

Figure 14: Overnight Rail and Rail Replacement - National Assoc. of Railway Passengers

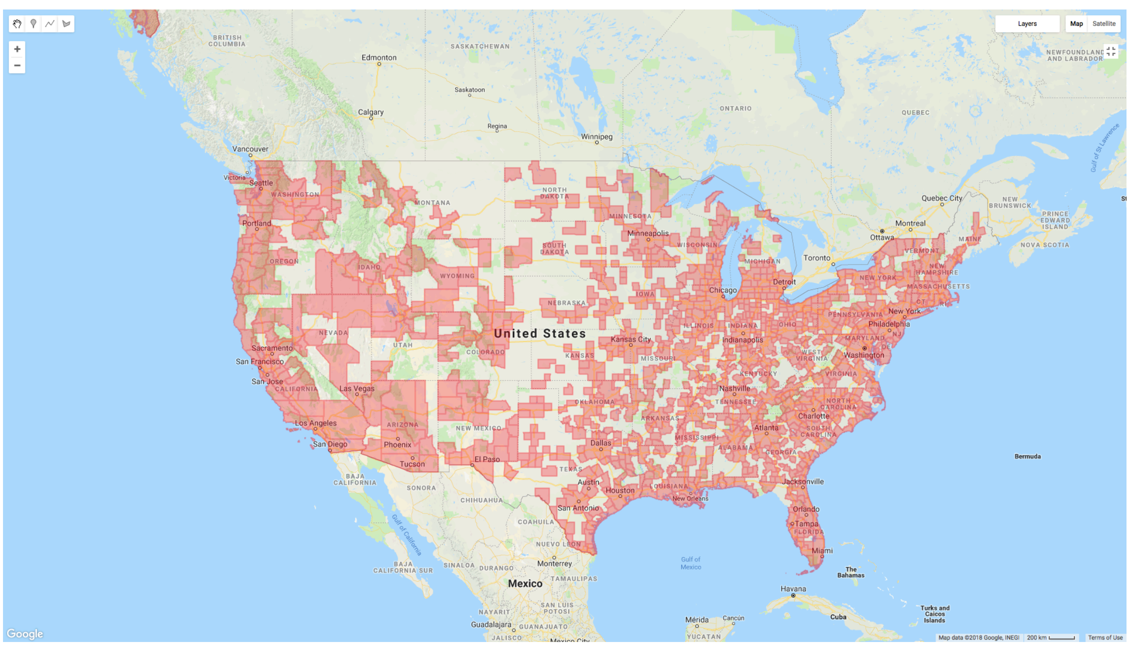

Figure 15: Concatenating USGS DS 240: Enhanced Historical Land-Use and Land-Cover Data 1970 and SRTM Digital Elevation Data V4 - Google Earth Engine

Appendix C. Robustness - Additional Checks

	(1) 2012 GCI Sum	(2) Δ Income	(3) 2012 GCI Sum	(4) Δ Income
Attraction	1069.0***		1292.4***	
	(178.8)		(263.0)	
Military Installment	770.7***		996.3***	
	(224.4)		(215.6)	
ATC Control Airport	15172.5***			
	(3275.4)			
Δ Emp	0.0800***	-4.092	0.0886***	-47.66
	(0.00812)	(32.24)	(0.00847)	(52.69)
2012 GCI Sum		1818.4***		2179.4***
		(344.4)		(514.7)
% of Transport Landuse 1970			434339.3**	
			(146873.9)	
AR F statistic		19.45		23.01
AR p-value		5.39e-12		4.93e-14
J stat p-value		0.238		0.282
N	549	549	546	546
Partial R^2	0.495		0.388	
R^2		0.874		0.841

Standard errors in parentheses

Odd columns show first-stage results with Anderson-Rubin first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Adding Anderson-Rubin (1949) Weak Instrument Test

	(1) 2012 GCI Sum	(2) Δ Income	(3) 2012 GCI Sum	(4) Δ Income	(5) 2012 GCI Sum	(6) Δ Income
Attraction	1316.4***		1230.5***			
	(317.6)		(252.3)			
Traffic Shadow	0		-12020.9***			
	(.)		(2728.4)			
Overnight Rail Reach	6504.5					
	(4587.1)					
Δ Emp	0.0862***	-50.51	0.0835***	-29.82	0.0817***	-13.39
	(0.00968)	(56.29)	(0.00923)	(44.48)	(0.0112)	(39.54)
2012 GCI Sum		2489.0***		2140.3***		1900.0***
		(579.4)		(484.2)		(385.1)
% of Transport Landuse 1970			1025134.0**			
			(389988.4)			
National Airport Plan					0.00154**	
					(0.000474)	
Military Installment					552.4	
					(370.7)	
SW F statistic	13.92		14.87		14.87	
SW p-value	0.0000105		1.55e-08		1.55e-08	
J stat p-value		0.0429		0.0105		0.203
N	65	65	157	157	517	517
Partial R^2	0.414		0.436		0.436	
R^2		0.869		0.854		0.855

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 8: Robustness: Varying instrument sets, including ones in the literature

	(1) 2012 GCI Sum	(2) Δ Income	(3) 2012 GCI Sum	(4) Δ Income	(5) 2012 GCI Sum	(6) Δ Income
Traffic Shadow	-9108.7**					
	(3221.6)					
Military Installment	1299.2*		1532.8*		1291.1*	
	(584.7)		(619.9)		(608.9)	
Slope	93.70		44.93		1060.6	
	(588.7)		(593.3)		(1096.7)	
Δ Emp	0.0998***	109.2†	0.105***	30.14	0.102***	28.75
	(0.0140)	(59.97)	(0.0140)	(56.88)	(0.0130)	(36.06)
2012 GCI Sum		920.7**		1645.6***		1766.9***
		(344.9)		(405.0)		(384.8)
Reduction in Rail			1967.2			
			(2063.8)			
Overnight Rail Reach					14405.5**	
					(5319.2)	
SW F statistic	5.158		3.259		3.259	
SW p-value	0.00201		0.0243		0.0243	
J stat p-value		0.00561		0.0374		0.781
N	157	157	115	115	66	66
Partial R^2	0.102		0.0791		0.0791	
R^2		0.869		0.891		0.910

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 9: Robustness: Varying instrument sets

	(1)	(2)	(3)	(4)
	Δ Service Y	Δ Service M	Δ Service Y-Share	Δ Service M-Share
2012 GCI Sum	8.778	1.138**	-0.000000594	-0.000000231
	(72.91)	(0.424)	(0.000000601)	(0.000000230)
Δ Income	0.287***		3.49e-10	
	(0.0416)		(3.37e-10)	
Δ Emp		0.324***		4.09e-08
		(0.0568)		(2.77e-08)
J stat p-value	0.222	0.350	0.195	0.0135
N	517	517	517	517
R^2	0.964	0.914	-0.0152	-0.00861

Standard errors in parentheses

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 10: Sector Shares: Using 1944 National Airport Plan as part of the IV

Appendix C. Robustness - Results using lagged income and population (in 1970) as IVs

Income, population, and per capita income in 1970 can be argued to correlate with future connectivity, as past income and population are necessary conditions for connectivity in the future through flight routes and connections. However, levels of past income and population need not necessarily affect future *change* or *growth* in income or in innovation. While recognizing that this may not be the best instrument, lagged socioeconomic variables are used as instruments for connectivity for robustness.

	(1) 2012 GCI Sum	(2) Δ Income	(3) 2012 GCI Sum	(4) Δ Income
Income in 1970	0.00220***			
	(0.000604)			
Δ Emp	0.0788***	-91.66	0.0751***	-75.51
	(0.00887)	(65.71)	(0.00872)	(57.02)
2012 GCI Sum		2543.5***		2409.8***
		(611.6)		(544.8)
Population in 1970			0.0113***	
			(0.00272)	
PC Income in 1970			2.356**	
			(0.847)	
SW F statistic	13.31		20.62	
SW p-value	0.000289		2.33e-09	
N	548	548	548	548
Partial R^2	0.472		0.472	
R^2		0.790		0.810

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 11: 2SLS Results: Change in total personal income between 2012 and 1990

	(1) 2012 GCI Sum	(2) Δ PC Income	(3) 2012 GCI Sum	(4) Δ PC Income
Income in 1970	0.00220***			
	(0.000604)			
Δ Emp	0.0788***	-0.00112	0.0751***	-0.00678
	(0.00887)	(0.00344)	(0.00872)	(0.00438)
2012 GCI Sum		0.0586*		0.106**
		(0.0275)		(0.0368)
Population in 1970			0.0113***	
			(0.00272)	
PC Income in 1970			2.356**	
			(0.847)	
SW F statistic	13.31		20.62	
SW p-value	0.000289		2.33e-09	
N	548	548	548	548
Partial R^2	0.472		0.472	
R^2		0.0260		0.0230

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 12: 2SLS Results: Change in per capita income between 2012 and 1990

	(1) 2012 GCI Sum	(2) Δ Emp	(3) 2012 GCI Sum	(4) Δ Emp
Income in 1970	0.00266***			
	(0.000498)			
Δ Population	0.0439***	0.442***	0.0418***	0.446***
	(0.00513)	(0.0532)	(0.00503)	(0.0496)
2012 GCI Sum		2.346**		2.290**
		(0.868)		(0.814)
Population in 1970			0.0136***	
			(0.00216)	
PC Income in 1970			2.180**	
			(0.776)	
SW F statistic	28.49		34.54	
SW p-value	0.000000138		7.55e-15	
N	548	548	548	548
Partial R^2	0.616		0.616	
R^2		0.969		0.969

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 13: 2SLS Results: Change in total employment between 2012 and 1990

	(1) 2012 GCI Sum	(2) Δ Emp	(3) 2012 GCI Sum	(4) Δ Emp
Income in 1970	0.00420^{***}			
	(0.000677)			
Δ PC Income	$0.167^{\dagger}$	-0.00236	0.0710	-0.0211
	(0.0880)	(0.410)	(0.0692)	(0.407)
2012 GCI Sum		6.096^{***}		6.130^{***}
		(0.546)		(0.533)
Population in 1970			0.0210^{***}	
			(0.00295)	
PC Income in 1970			3.746^{**}	
			(1.261)	
SW F statistic	38.49		50.59	
SW p-value	1.09e-09		7.09e-21	
N	548	548	548	548
Partial R^2	0.713		0.713	
R^2		0.787		0.787

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 14: 2SLS Results: Change total employment between 2012 and 1990

	(1) 2012 GCI Sum	(2) Δ All Patent	(3) 2012 GCI Sum	(4) Δ All Patent
Income in 1970	0.00220***			
	(0.000601)			
Δ Emp	0.0785***	-0.00201	0.0748***	-0.00210
	(0.00884)	(0.00158)	(0.00865)	(0.00158)
2012 GCI Sum		0.0613***		0.0621***
		(0.0123)		(0.0126)
Population in 1970			0.0113***	
			(0.00270)	
PC Income in 1970			2.916**	
			(1.083)	
SW F statistic	13.42		19.72	
SW p-value	0.000277		5.81e-09	
N	491	491	491	491
Partial R^2	0.473		0.473	
R^2		0.370		0.369

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 15: 2SLS Results: Change in all inventors granted patents between 2012 and 1990

	(1) 2012 GCI Sum	(2) Δ Unique Patent	(3) 2012 GCI Sum	(4) Δ Unique Patent
Income in 1970	0.00220***			
	(0.000600)			
Δ Emp	0.0785***	0.000239	0.0747***	0.000156
	(0.00883)	(0.000543)	(0.00864)	(0.000540)
2012 GCI Sum		0.0124**		0.0130**
		(0.00480)		(0.00485)
Population in 1970			0.0112***	
			(0.00269)	
PC Income in 1970			3.004**	
			(1.116)	
SW F statistic	13.43		19.76	
SW p-value	0.000275		5.74e-09	
N	479	479	479	479
Partial R^2	0.473		0.473	
R^2		0.306		0.306

Standard errors in parentheses

Odd columns show first-stage results with Sanderson-Windmeijer (SW) first-stage F statistics

Even columns show second-stage

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 16: 2SLS Results: Change unique granted patents between 2012 and 1990

	(1) Δ Income	(2) Δ Income	(3) Δ Emp	(4) Δ Emp
2012 GCI Sum	2459.6***	1147.6***	5.808***	-0.227
	(462.0)	(250.8)	(0.763)	(1.603)
Δ Emp	-55.87	-4.721		
	(43.80)	(25.78)		
Δ PC Income			-1.105	0.269**
			(3.495)	(0.0873)
N	100	267	100	267
R^2	0.797	-2.292	0.698	0.0678

Standard errors in parentheses

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 17: 2SLS Results: Large vs Small Cities