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Airport Infrastructure, Network Air Services and the Economic Benefits of Air Transport

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Abstract
This paper explores the impact of changes to measures of domestic and international air service connectivity on a metric of productivity for a sample of U.S. industries. The objective was to better understand the value of the U.S. air transportation network. We find that different types of connectivity affect different industries in substantively different ways. We find that not only are the metrics different but their relative importance or weight is quite different as well. Changes to productivity cab fit into the category of wider economic benefits and the paper explores the differences between catalytic effects and wider economic benefits.

Introduction

A substantial research effort has focused how much public capital has contributed to economic growth. This initially had been stimulated by two factors. First, public capital spending as a proportion of GDP had fallen from 1971-1990 and second, the decrease in public capital spending in the U.S. was claimed to have contributed to the productivity slowdown which occurred in the 1970s and 80s. Using U.S. data for 1949-1985 Aschauer (1989) found the elasticity of aggregate multifactor productivity with respect to increases in the public capital stock to be 0.4; a 10 percent increase in the stock of public capital would increase multifactor productivity by 4 percent, an enormous impact. Early in this literature studies using aggregate data found similarly large impacts to Aschauer but such large impacts were found to be fraught with problems (see Gramlich (1994).

In a 1998 survey that examined the relationship between public capital and economic growth, Sturn et al. (1998) found a wide range of estimates in the literature. In some cases, the marginal product of public capital was found to be [much] higher than private capital (Aschauer, 1989), about equal to the marginal product of private capital (Munnell, 1990), in some cases values were well below the return on private capital Eberts (1986) and there were instances in the literature where the return on public capital was negative; Hulten and Schwab (1991). This literature which focused on macro measures and generally treated public capital as entering the aggregate production function. It could do so by entering directly or by affecting multifactor productivity $\phi(G_t)$; where G_t is some measure of public capital stock at time t, Q_t is some measure of aggregate output, K_t is a measure of non-residential private capital stock, and L_t is a measure of labour input.

$$Q_t = \phi(G_t)h(K_t, L_t, G_t) \quad (1)$$

This specification treats public capital symmetrically with other inputs, private capital, labour and perhaps transportation, a special type of pubic capital.

This literature evolved to consider the *flow of services* from the capital stock rather than focus on the stock itself. If transportation infrastructure is separated from other public capital, the transportation services would be a function of the available capacity of infrastructure and the capacity of vehicles, generally private, utilizing it. Technology could enter either as factor neutral or factor augmenting. This characterization would be represented as:

$$Q_t = h_i \phi^i [K_i, L_i, T_i(MV_i, G)] \quad (2)$$

where transportation services (T_i) in industry i are a function of motor vehicle capacity (MV_i) and public capital infrastructure capacity (G); see Nadiri and Mamuneas (1996) and Fernald (1999).

The locational aspect of public capital was the next evolution, recognizing transportation public capital was part of a network industry. Companies manufacturing hard goods (e.g. manufacturing) had a transportation/inventory strategy that would include accumulation as well as distribution centers which may be located in adjacent jurisdictions.[1] Therefore, the amount of transportation public capital available in the adjacent jurisdiction should enter the relationship to account for spillover effects; see Cohen & Morrison Paul, 2004, Gillen et al. 2004, Garrison et al. 2003 and Gillen 1997. Thus (2) could be adjusted as:

[1] In terms of the air mode, such an adjacent jurisdiction may be in another country.

$$Q_{i,l1} = h_i \phi^i [K_i, L_i, T_i(MV_i, G_{l1}, G_{l2})]$$

where $Q_{i,l1}$ is the output of industry i in location 1 and it is impacted by, among other factors, the amount of public capital capacity in location 1 and in location 2.

The ‘public capital’ literature continued to expand along a number of paths. The way in which public capital was defined, how to calculate the public capital stock and the difficulty of measuring public capital across countries due to differences in prices across countries; how a project is financed or if it is a public-private partnership will affect how efficient the investment is. Pritchett (1996), for example, claims a public capital stock constructed on the basis of cumulative investment will be overvalued.

The production function and cost function approaches are described in Gillen (1996, 2000), Sturm et al. (1998) and Rump and de Hahn (2000). The production function approach was driven in part by data availability but it had a number of significant problems. First, there was an issue of reverse causation on both the demand and supply side; potential feedback between income and capital stock and the feedback between income and the demand for infrastructure. The solution seemed to be in ramping up the sophistication of the econometrics as various authors tried estimating panel or simultaneous equation models or using instrumental variables; see Rump and de Hahn (2000) for a detailed survey. The shift to a cost function approach was motivated in part by greater opportunity to use more sophisticated functional forms with the attractive feature that the substitutability between factors could be explored. This was important in establishing whether public capital drove out private capital and whether public capital was enhancing employment or not. Cohen and Morrison Paul (2004) provide an excellent illustration of cost function estimation using data for 48 contiguous states over the period 1982-96. The modelling incudes spillovers by considering both intra and inter-state effects; interestingly, in their work, they measure the impact of public capital ignoring spillovers is a cost elasticity of -0.15 but including spillovers it increases to -0.21.

An important conclusion from the literature on public capital is there is heterogeneity in terms of impacts; the effect of public capital will differ across regions and sectors. Not unsurprisingly, the impact will depend on how much public capital is available and whether changes are incremental and how technology is affected – consider how smart rods might affect the returns to road capital. It is the two features of network effects or spillovers and the differences in services that stimulate this paper.

In this paper I do two things. First, I explore the impact of public capital by considering how the public capital is used, that is, at the flow of services on the public capital stock and secondly how connected the network is so as to implicitly include the spillovers. The empirical example I use is the U.S. aviation network and domestic connectivity as well as connectivity to international destinations. These empirical results lead naturally to the second contribution which is to attempt to differentiate between wider economic benefits and catalytic effects of public capital with specific reference to the aviation sector.

Aviation Infrastructure

The economic contribution of airports is traditionally approached by assessing the activities that occur on-airport and/or on account of airports as a consequence of spending for aviation services and for aviation facilities. For example, typical economic impact studies assess the jobs, wages and business sales that are attributed to: airport construction and facility maintenance; on-airport administration, government activity and commerce that serves aircraft, crew and pilots, passengers, and the general public (such as medical evacuation); spending by visitors who arrive through airports; and in some cases, off-airport businesses that rely on air cargo and business travel. The sum of these activities form the regional, state, and sometimes national economic impacts attributed to airports. However, all these airports are knit together, directly or indirectly, to form a network and airlines deliver air transport services over the networks. Transport is a derived demand so business people travel to enhance profit, tourists travel to increase utility and cargo moves for consumption and as intermediate inputs in production. In all cases the movement adds economic value. The question is if there is additional value to the region served by an airport from increased connectivity in the airline network serving the airport over and above the direct economic impacts of airport activity measured by standard economic impact assessments.

Airports, communities, and airlines all would like to better understand the contribution of air service to local, regional and national economies, the economic benefits of the connectivity provided by the airline network have often been overlooked. This network is a key component of transportation infrastructure that allows business travelers to meet existing and new customers, expand markets, and generate efficiencies in terms of scale, scope and agglomeration economies. Improvements in the connectivity provided by the airline network widen the available markets, potentially leading to higher revenues and higher returns on investment.

The question being addressed here is not whether improvements in airline connectivity increase access to the airline network. At this point in the development of the U.S., European and developed economies aviation systems, everyone has access to the airline network in one way or another. Rather the objective was to understand how changes in air service connectivity between airports, regions, or countries would affect the level of economic output, specifically how changes in airline network connectivity improve productivity and hence the ability of the economy to increase real output. An additional question was whether connectivity affected industries in the same way.

With the expansion of global trade and increasing globalization of the supply chains, growing evidence is showing that increased connectivity in the air transport network is a significant asset that enhances productivity and improves the performance of an economy, region or firm. Over time, air transport markets have grown and the broader airline network has resulted in productivity enhancements to firms and industries directly from scale and agglomeration effects but also by increasing the productivity of other factors of production, notably labor (Graham, 2007). For example, the addition of new nonstop flights in markets not previously served with direct flights can reduce the time required to make a business trip in those markets, freeing time for other activities.

Productivity can be expressed in terms of a single factor, *e.g.* labor productivity, or in terms of many or multiple factors, such as labor, raw materials, energy, and capital, termed multifactor productivity (MFP). MFP is a more comprehensive measure of productivity than a simple single factor productivity measure such as labor productivity. The approach used here was to use a measure of MFP for different industries and link this to different measures of air service connectivity as well as other standard economic variables that would be expected to affect MFP. A sample of 11 industry sectors was analyzed for 20 metropolitan areas and four points in time (1995, 2000, 2005, 2010). The selection of metropolitan regions was designed to capture different types of airports including large hubs, smaller hubs, non-hubs and airports that had been de-hubbed. Cumulatively, these regions represented 21 percent of the U.S. population and 23 percent of the U.S. gross domestic product (GDP) in 2010. The linkages explore how the change in air service connectivity affects productivity, in this case multifactor productivity, and how the change in productivity in turn increases real GDP which serves as a measure of the value provided by the airline network.

Multi Factor Productivity

The literature that examined the broader definitions of public capital, beyond transportation infrastructure, to understand how public capital contributed to productivity improvements and economic growth and how public capital was a complement to or substitute for other factor inputs including labor, private capital and energy among others was discussed earlier. A smaller literature has sought to identify the linkages between the investment in [highway] infrastructure and changes in productivity or cost efficiency. Keeler and Ying (1988) measured how the U.S. interstate highway system led to significant improvements in productivity in trucking. Shirley and Winston (2004) examined how highway investments led to changes in firms' inventory policies and estimated inventory savings of some $0.4 billion.

More recently there have been papers that have investigated the linkages between agglomeration and productivity (Graham, 2007) and the catalytic effects of aviation (Intervistas, 2006). The International Air Transport Association (IATA) has developed a connectivity indicator based on the number of seats offered on scheduled flights between a given origin and the destinations served by direct flights from that origin, where an origin is typically a specific airport but could be a multi-airport region or even a country. The number of available seats from a given origin to each destination is weighted by the size of the destination airport (in terms of number of passengers handled in each year). The weighting gives an indication of the economic importance of the destination airport and the number of onward connections it can provide.[2]

Improvements in air service connectivity can be viewed as having similar effects to technology or process innovations in that, like most innovations, they increase the productive *capacity* of the economy. Changes in connectivity can result from a number of differing actions or investments. For example, a country could change its approach to negotiating air service bilateral agreements so that each new bilateral agreement is an 'open skies' arrangement that leads to more capacity, more airlines entering the markets, more markets served with direct flights, and more competitive fares between countries. Increased connectivity could also result from airlines expanding air service in response to investments in aviation infrastructure such as increased airport capacity through additional runways and larger terminals to accommodate more carriers and flights or by modernizing air traffic control infrastructure and procedures to reduce congestion. In addition, connectivity could change as airlines change services offered in response to changing technologies of industry production, increasing globalization of industries, or changing economic geography in the United States.

Better understanding of these linkages will make it possible to measure the value of an investment in new airport infrastructure beyond the traditional standard economic impact model and determine the return on investments to support expanded airline networks and improved air

[2] As applied by IATA, the connectivity indicator is based on the number of scheduled seats to each destination on direct flights for the first week in July for the year in question.

service connectivity. Although airports cannot provide new air service directly, they can provide the supporting facilities and encourage the airlines to offer more service.

Agglomeration effects are one potential source of increased productivity that could be influenced by increased air service connectivity. Agglomeration economies are externalities that can result in a shift in firms' cost functions. Such shifts can occur because the concentration of spatial activity leads to more efficient transportation connectivity between these concentrations and markets; both for receiving goods and services needed for production and for sales to end users. Graham (2007) reports some examples of the elasticity of productivity with respect to a measure of agglomeration based on employment concentration for several industry groupings, including transportation, storage and communication (elasticity of 0.223), banking, finance and insurance (0.237), and business services (0.224).[3]

Aviation, Connectivity and Productivity

Productivity is an important measure of the state of the economy at different levels: firm, industry, sector and the broad macro economy. It measures the efficiency with which outputs are produced with a variety of inputs, including different types and skills of labor, private and public capital of different vintages (old and new machines, for example), the different types of energy used, such as coal, natural gas, oil, or nuclear, the materials used, such as basic raw materials (*e.g.* iron ore) or semi-manufactured goods (such as wiring harnesses in cars), and land. A major factor that determines changes in productivity is the technology used and whether the technology is factor augmenting or factor neutral. Factor-neutral technical change means that any change in technology affects each factor of production or each input in the same way so relative input factor productivity does not change. Factor-augmenting technical change means that the change in technology affects the contribution of one or more factors to productivity more than other inputs, so relative input factor productivity will change.

Multifactor productivity is the ratio of the output index to a weighted average of the input indices. There are two approaches to measuring marginal factor productivity (MFP). In the growth accounting methodology (see Solow, 1957), MFP is typically estimated as a growth rate. In the second approach, the Törnqvist methodology, MFP is calculated as an index number (level), which is obtained by dividing an output index by a combined input index (see Hulten (2001). A Törnqvist formula expresses the change in multifactor productivity as the difference between the rate of change in output and the weighted average of the rates of change in the inputs, (see Arnaud *et al.* (2011). The outputs and inputs are typically measured in constant dollars to allow quantities measured in dissimilar units to be combined. The MFP values used in the analysis described in this paper were developed using the Törnqvist methodology.

Output of an industry, as well as inputs, may change in quality over time. This quality change must be considered in any measurement. If the measures are expressed in constant dollars, it is possible to adjust for quality change by incorporating it into the price index used for the deflation. In the index approach, the inputs in the MFP estimate are weighted, where the weight of each input is the share of the input in the total cost of the production for the economic unit being considered. The weights indicate the relative importance of each input in production and

[3] Graham's measure of agglomeration used employment data at a small zone level to calculate an "effective density of employment" for each zone by dividing the employment in the zone by the equivalent radius of the zone (the radius of a circular zone of the same area) and adding the employment in surrounding zones, each divided by the distance of the zone from the zone in question.

are used to estimate the contribution of each input to changes on MFP or the increase in inputs needed for a given change in output.

Any change in output(s) is a result of a number of different changes, including changes in the quantity of inputs or changes in the productivity of the inputs (MFP). Factor or input productivity can change as a result of a number of influences. Technology can change which can allow one factor to be more productive. It can also occur if the workforce develops new skills through, for example, education. The relative changes in outputs and inputs over time provide the analytical framework used to estimate MFP.

At any point in time MFP can be affected by the technology being used. For example, some airlines may fly newer, more fuel-efficient aircraft while other airlines continue to operate older, less expensive equipment, or the entire airline industry may start using self-service check-in kiosks. The technology utilized will affect the MFP function that predicts the output for a given mix of inputs.

Increases in MFP have important benefits for the economy and society. Productivity increases result in more output being produced with the same or fewer inputs. Therefore, other things being equal, increases in productivity result in some combination of lower prices, higher employee compensation, or larger differences between total revenues and total costs, hence higher profits. The output increases are a direct contribution to economic growth. The increase in real incomes contributes to a rising standard of living.

MODEL AND DATA

The research approach was based on an empirical model that examines how changes in air service connectivity result in improved productivity. The model specification is:

$$MFP_i = \emptyset(CN', Z') \tag{1}$$

where multifactor productivity in industry sector *i* is a function of a vector of connectivity measures, CN', and a vector of other economic factors, Z'.

Regression equations were developed to implement the model in equation (1) for each industry sector in a region and the set of air service and other economic variables for that region. These models were specified as:

$$lnMFP_i = \alpha + \sum_j \beta_j \, lnCN_j + \sum_m \gamma_m \, lnZ_m + \epsilon \tag{2}$$

where the CN_j are the different measures of air service. The variables included in the Z_m vector were the overall labor productivity index for the region, regional population, aggregate output for the region (measured by GDP), and year dummy variables for 2000, 2005 and 2010. These variables were designed to capture factors that can influence the MFP growth in a given industry.

The data selected for exploring the relationship were developed for the airports serving a sample of U.S. metropolitan regions (see TABLE 1), a set of foreign international hubs that link the U.S. economy to the rest of the world, and eleven industry sectors (TABLE 2) based on the North American Industry Classification System (NAICS), for the years 1995, 2000, 2005 and 2010. Ten industry sectors for which sector-specific models were developed were chosen on the basis of the likely role of air travel in sector productivity. The other industry sectors were combined into a single model for "other" sectors. These airports were selected in order to include a variety of types and sizes of airports: gateway airports, airline hubs, large, medium, small, and non-hub airports, and airports that had formerly been an airline hub but had been de-hubbed. We also wanted a geographic spread to represent the entire domestic U.S. travel market as closely as possible. The international airports used to measure international connectivity from the sample of U.S. airports were: Amsterdam, London Heathrow, Frankfurt, Munich, Paris Charles de Gaulle, Madrid, Hong Kong, Singapore, Shanghai, Beijing, Dubai, Seoul Incheon, Tokyo Narita, Copenhagen and Rome. These were chosen as they are the largest 15 international airline hubs outside the U.S. that provide air service connectivity to the rest of the world as well as being major international destinations in their own right.

TABLE 1 Airports Selected for the Analysis

Code	Airport/region	Multi-airport Regions
SF Bay	*San Francisco Bay Area*	SFO, OAK, SJC
Chicago	*Chicago metropolitan region*	ORD, MDW
ATL	Hartsfield-Jackson Atlanta International Airport	
CVG	Cincinnati/Northern Kentucky International Airport	
STL	Lambert-St. Louis International Airport	
PIT	Pittsburgh International Airport	
RDU	Raleigh-Durham International Airport	
DEN	Denver International Airport	
Phoenix	*Phoenix metropolitan region*	PHX, AZA
SLC	Salt Lake City International Airport	
Boston	*Boston metropolitan region*	BOS, PVD, MHT
PHL	Philadelphia International Airport	
DTW	Detroit Metropolitan Wayne County Airport	
SAN	San Diego International Airport	
PDX	Portland International Airport	
TPA	Tampa International Airport	
MCI	Kansas City International Airport	
TUL	Tulsa International Airport	
SAT	San Antonio International Airport	
BNA	Nashville International Airport	
Airports in the Four Multi-Airport Regions		
SFO	San Francisco International Airport	
OAK	Oakland International Airport	
SJC	Mineta San Jose International Airport	
ORD	Chicago O'Hare International Airport	
MDW	Chicago Midway Airport	
PHX	Phoenix Sky Harbor International Airport	
AZA	Phoenix-Mesa Gateway Airport	
BOS	Boston Logan International Airport	
PVD	Theodore Francis Green State Airport (Providence)	
MHT	Manchester-Boston Regional Airport	

TABLE 2 Eleven Industry Sectors Included in the Modeling

NAICS Code	Sector	Specific Sector Model	"Other" Sector Model
11	Agriculture, Forestry, Fishing and Hunting		11
21	Mining, Quarrying, and Oil and Gas Extraction		11
22	Utilities		11
31-33	Manufacturing	1	
42	Wholesale Trade	2	
44-45	Retail Trade		11
48-49	Transportation and Warehousing		11
51	Information	3	
52	Finance and Insurance	4	
53	Real Estate and Rental and Leasing	5	
54	Professional, Scientific, and Technical Services	6	
55	Management of Companies and Enterprises	7	
56	Administrative and Support and Waste Management and Remediation Services	8	
61	Educational Services		11
62	Health Care and Social Assistance		11
71	Arts, Entertainment, and Recreation	9	
72	Accommodation and Food Services	10	
81	Other Services (except Public Administration)		11
92	Public Administration		11

Estimating Regional MFP Values

Measures of multifactor productivity (MFP) are available by industry over time at the national level from the U.S. Bureau of Labor Statistics (BLS). We were also able to assemble data at the metropolitan statistical area (MSA) level that allowed us to calculate a measure of labor productivity for each industry sector for a given MSA.

However, we do not have MFP measures by industry at the MSA level. The national MFP measures were translated to the MSA level in the following way.

Define MFP_i^N as the multifactor productivity measure for industry sector *i* at the national level and, define $\hat{L}_i = Q_i / L_i$ as a measure of labor productivity for industry *i* where Q is a measure of output and L is some measure of labor input (hours or numbers of employees). Further define $\hat{L}_i^k$ as the labor productivity measure of industry *i* in region *k* based on data for relevant MSAs.

We know that labor productivity is a significant component in the MFP measure. Therefore, we assumed that the MFP at the regional level and MFP at the national level for a given sector are both proportional to the respective labor productivity:

$$MFP_i^k = \beta^k \cdot \hat{L}_i^k \quad (3)$$

$$MFP_i^N = \beta^N \cdot \hat{L}_i^N \quad (4)$$

Further assuming that $\beta^k = \beta^N$ gives:

$$MFP_i^k = \left(\hat{L}_i^k \big/ \hat{L}_i^N \right) \cdot MFP_i^N \quad (5)$$

Hence MFP at a regional level may exceed or be lower than MFP at the national level for a given industry. It may be, for example, that industry i in region k has a higher labor productivity than for the nation as a whole, thus $\hat{L}_i^k$ would be greater than $\hat{L}_i^N$ and hence MFP_i^k would be greater than MFP_i^N. Therefore MFP_i^k for each industry varied across the MSAs in the analysis.

This approach effectively assumes that differences in MFP for a given industry across regions in a given year are proportional to differences in labor productivity, and thus the empirical estimates are largely measuring the effect of changes in air service on labor productivity, although the measures of MFP at a regional level account for differences in MFP at a national level over time. Thus, the model does not account for differences in MFP at a regional level that are due to differences in productivity of factors other than labor. However, since technology is widely available and access to capital is fairly consistent from region to region, it was assumed that any differences in the contribution of these factors to MFP at a regional level are likely to be fairly minor. Also, changes in air service connectivity primarily affect labor productivity.

Values for the MFP for each sector at the national level were obtained from the U.S. Bureau of Labor Statistics. Data on output and employment by sector at both the national level and regional level for the 20 regions were obtained from the Bureau of Labor Statistics Regional Economic Accounts. Several of the larger regions consist of more than one MSA, so the data at the MSA level were combined to give regional totals.

Air Service and Other Variables

The air service variables constructed for each airport in the 20 regions are shown in

TABLE **3**, with the means and standard deviations of these variables across the regions in the sample for each year. These variables were chosen to measure the level of air traffic activity at each airport as well as provide different measures of airline network connectivity and to distinguish between domestic and international connectivity. Flight departures, total passengers (enplaned and deplaned), and airfreight tonnage are annual totals. The percentages of world GDP served by flights at different frequencies are based on the total GDP of countries with airports that are served by non-stop flights at the frequency in question, irrespective of the geographical size of the country or the number of airports within each country that are served at the relevant frequency.

The air service measures included the number of destinations served by non-stop flights from each airport at different frequencies, as well as the number of domestic airline hubs and major international hub airports served by non-stop flights. No attempt was made to measure the number of destinations that could be reached by making flight connections, since this would essentially cover all possible destinations, although the number of airline hubs than are served by non-stop flights is a measure of the number of destinations that can be reached with a single flight connection.

Air service data only counted scheduled service, and the number of non-stop flight departures in a market and the number of destinations served only counted service by airlines operating at least 50 flights annually to a given destination. This was done to exclude occasional seasonal service or flights that made unscheduled technical stops (*e.g.* diversions or refueling stops), which appear in the U.S. DOT airline data. In counting the number of airlines or the percentage of flights by the dominant carrier at an airport, regional affiliates were considered to be part of the mainline carrier. However, airlines in global alliances were counted as separate airlines, since their presence at an airport generally results in greater network connectivity. Flights to Canada were included in international service.

The analysis did not include variables measuring changes in industry concentration directly because at the level of a given airport the effect of such changes would be reflected in the number of airlines in relation to the other air service variables and there was no attempt in the analysis to consider the distribution of air service between different airlines.

In addition to air service variables, the regression models of MFP included regional population to control for size differences between the regions and dummy variables for three of the four years used in the analysis to capture temporal effects. Regional population data were obtained from the U.S. Bureau of Economic Analysis, which uses U.S. Census Bureau midyear population estimates.

MODEL ESTIMATION RESULTS

TABLE 4 lists the results of the regressions for the 11 industry sectors across the 20 regions in the sample. Coefficients in bold are statistically significant at least at the 90 percent confidence level; adjusted R^2 and log-likelihood values are shown in the bottom rows. The degree of explanatory power ranges from a low of 64 percent for the Arts, Entertainment, and Recreation sector to a high of 92 percent for the Information sector.

The set of variables of most interest are those that measure the effect of air service connectivity. There are several categories of variables that sought to reflect both domestic and international connectivity. These included the number of departures, the frequency of non-stop flights in different markets, and the degree of connection of each region to the world economy. The important result from the table is that aviation networks connect different industries in different ways and the relative effect of improvements in connectivity on MFP varies across industries as well. For example, increasing the number of domestic non-stop destinations has more than twice the effect on MFP for manufacturing as for wholesale trade, with a model coefficient (elasticity) of 0.034 versus 0.015. We can see from the statistically significant coefficients in TABLE 4 that service frequency and having direct flights to a large number of destinations have a statistically significant effect on productivity in most industry sectors examined, the number of domestic airline hubs served has a statistically significant effect on productivity in the Information, Finance and Insurance, Professional, Scientific, and Technical Services, Management of Companies and Enterprises, and Arts, Entertainment, and Recreation sectors, while the number of airlines affects productivity for only two sectors: Manufacturing and Wholesale Trade.

TABLE 3 Summary Statistics for Airport Air Service Variables Used in Regressions

	1995		2000		2005		2010	
Air Service Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Number of airlines	18.25	12.79	19.20	14.79	19.50	14.77	17.45	13.48
Flights by dominant carrier	52%	21%	52%	22%	49%	22%	44%	20%
Total non-stop flight departures								
Domestic	138,992	105,285	159,329	117,204	180,435	129,056	154,895	129,024
International	4,245	4,993	7,272	9,814	7,880	8,239	9,405	12,533
Domestic airline hubs served with non-stop flights	24.95	9.49	28.50	11.63	28.55	11.43	28.95	10.66
Non-stop destinations served								
Domestic	69.50	37.81	74.30	41.55	88.55	47.24	82.85	50.39
International	10.20	9.81	12.20	14.21	14.05	15.36	15.80	19.94
Percent of world GDP served by								
Non-stop flights	22%	24%	26%	25%	24%	23%	22%	22%
At least daily non-stop flights	16%	21%	21%	22%	20%	22%	17%	20%
2 or more daily non-stop flights	7%	13%	10%	16%	11%	15%	9%	13%
Total airfreight (metric tons)								
Enplaned Domestic	26,200	28,764	24,715	25,691	116,503	113,613	92,384	75,869
Enplaned International	31,595	64,291	42,161	82,885	42,569	92,839	43,424	95,478
Deplaned Domestic	26,103	25,927	25,695	26,194	124,665	108,816	98,510	73,129
Deplaned International	28,120	60,630	54,227	113,480	60,217	136,591	55,384	131,683
International hubs served								
At least daily non-stop flights	1.35	2.03	2.25	3.21	2.45	3.62	2.60	3.94
3 or more daily non-stop flights	0.35	0.81	0.55	1.23	0.55	1.23	0.50	1.10
Total passengers (000)								
Domestic	20,499	16,495	25,434	19,607	26,387	21,609	24,744	21,395
International	1,191	1,629	2,069	2,987	2,072	2,755	2,273	3,352
Domestic non-stop destinations								
2 or more daily non-stop flights	53.20	32.16	60.70	37.05	70.15	41.47	60.10	41.38
5 or more daily non-stop flights	25.50	21.52	29.55	22.31	35.15	27.10	29.10	26.38

TABLE 4 Estimation Results for Multi-Factor Productivity Regressions

Industry Sector	NAICS 31-33	NAICS 42	NAICS 51	NAICS 52	NAICS 53	NAICS 54
Dependent Variable: Ln MFP for Region **Independent Variable)**	Manufacturing	Wholesale Trade	Information	Finance & Insurance	Real Estate & Rental & Leasing	Professional, Scientific, & Technical Services
Constant	**-1.0913**	**6.4783**	**9.1860**	**0.5697**	**9.0946**	4.5121
Year 2000 Dummy	-0.0546	0.0395	-0.0004	**0.0601**	**0.0223**	**0.0689**
Year 2005 Dummy	0.0608	**0.0657**	**0.2552**	**0.1264**	**0.6151**	0.0151
Year 2010 Dummy	**0.2107**	**0.2486**	**0.3492**	**0.2622**	**0.4221**	0.0115
Ln Regional Population	**0.0037**	**0.0015**	0.0013	**0.0433**	**0.0252**	0.0447
Ln Number of Airlines	**0.0439**	**0.0215**	0.0596	0.0048	0.0797	0.0435
Ln Domestic Flight Departures	**0.0237**	**0.0257**	0.0192	**0.0479**	**0.0213**	**0.0182**
Ln Domestic Airline Hubs Served Non-stop	0.0423	0.6624	**0.0151**	**0.0716**	0.0316	**0.0361**
Ln Domestic Non-stop Destinations	**0.0344**	**0.0152**	0.0074	0.0711	**0.0397**	0.0504
Ln Domestic Destinations with Two or More Daily Non-stop Flights	**0.0991**	0.0607	**0.0121**	**0.0312**	**0.0406**	0.0112
Ln Domestic Destinations with Five or More Daily Non-stop Flights	0.0531	**0.0318**	0.0192	0.0697	0.0256	0.0096
Ln International Flight Departures	0.0163	0.0003	**0.0244**	**0.0132**	0.0039	**0.0262**
Ln International Non-stop Destinations	**0.0479**	**0.0191**	**0.0144**	0.0375	**0.0532**	0.0275
Ln Percent of the World GDP Served Non-stop	0.0174	0.0117	0.0147	0.0911	0.0246	0.0107
Ln Percent of the World GDP Served Daily	0.0263	**0.0214**	**0.0257**	**0.0107**	0.0612	**0.0491**
Ln Percent of the World GDP Served Twice or More Daily	**0.0157**	0.0032	0.0201	0.0072	0.0079	0.0205
No Observations	80	80	80	80	80	80
Adjusted R^2	0.74	0.79	0.92	0.89	0.84	0.81
Log-Likelihood	633.25	449.62	345.76	318.98	329.87	366.77

See notes on next page.

TABLE 4 (cont'd) Estimation Results for Multi-Factor Productivity Regressions

Industry Sector	NAICS 55	NAICS 56	NAICS 71	NAICS 72	NAICS Other
Dependent Variable: Ln MFP for Region **Independent Variable**	Management of Companies & Enterprises	Administration & Support & Waste Management Services	Arts, Entertainment, & Recreation	Accommodation & Food Services	Other[b]
Constant	**1.9440**	**3.9618**	**3.9720**	**5.8501**	**1.2294**
Year 2000 Dummy	**0.0318**	**0.0983**	0.0416	0.0163	**0.8700**
Year 2005 Dummy	0.1104	**0.0130**	**0.0263**	0.0541	**0.0812**
Year 2010 Dummy	0.0287	**0.0112**	**0.0693**	0.1218	**0.5798**
Ln Regional Population	**0.0185**	**0.0004**	**0.0113**	**0.0529**	0.0981
Ln Number of Airlines	0.0152	0.0519	0.0562	0.0161	0.1004
Ln Domestic Flight Departures	0.0843	**0.0104**	0.0817	**0.0001**	**0.0004**
Ln Domestic Airline Hubs Served Non-stop	**0.0106**	0.0226	**0.0093**	0.0456	0.0285
Ln Domestic Non-stop Destinations	**0.0321**	**0.0301**	**0.0132**	**0.0229**	**0.0371**
Ln Domestic Destinations with Two or More Daily Non-stop Flights	0.0151	0.0269	0.0191	0.0153	0.0227
Ln Domestic Destinations with Five or More Daily Non-stop Flights	0.0749	0.0074	**0.0197**	0.0885	0.0452
Ln International Flight Departures	**0.0091**	**0.0211**	0.0217	0.0691	0.0142
Ln International Non-stop Destinations	**0.0227**	**0.0877**	0.0215	0.0526	**0.0136**
Ln Percent of the World GDP Served Non-stop	**0.0203**	**0.0472**	0.0576	0.0231	0.0946
Ln Percent of the World GDP Served Daily	0.0579	0.0357	**0.0399**	**0.0222**	**0.0129**
Ln Percent of the World GDP Served Twice or More Daily	**0.0779**	0.0176	0.0291	0.0883	0.0907
No Observations	80	80	80	80	80
Adjusted R^2	0.85	0.71	0.64	0.74	0.62
Log-Likelihood	352.81	444.81	338.91	282.95	227.13

Notes: a) Bold coefficients are significant at the 90 percent confidence level or higher.
b) "Other" sector includes NAICS codes 11, 21, 22, 23, 44-45, 48-49, 53, 56, 61, 62, 81, 92.

In all cases the estimated coefficients for the regional population are positive and generally significant indicating that the size of the region has an impact on multi-factor productivity. The coefficients for the year dummy variables are positive except in two cases (the values for which are not statistically significant) and generally significant. The values for 2010 are not always larger than for 2000 and 2005 showing that productivity growth has varied significantly across industries as well as over time.

The coefficients can be interpreted elasticities As an example, the results for the Manufacturing sector show that a 1 percent increase in the number of airlines serving a region would lead to a 0.044 percent increase in MFP, while a 1 percent increase in the number of domestic non-stop flight departures would increase MFP by 0.024 percent and a 1 percent increase in the number of non-stop domestic and international destinations served would increase MFP by 0.082 percent (0.034 percent for domestic destinations plus 0.048 percent for international destinations). These results assume that the air service variables are continuous (or have large enough values to be effectively continuous), so it is meaningful to assume a 1 percent increase. Of course, in practice some variables, such as the number of airlines or the number of airline hubs served, generally have relatively small values and can only be increased in discrete increments, as discussed below.

TABLE 5 shows the average elasticity for each statistically significant connectivity measure across industries for each of the airport variables included in the model. On average, considering only values that were statistically significant at the 90 percent confidence level or higher, the number of domestic destinations having two or more daily domestic non-stop flights is the most important connectivity measure affecting productivity. The second most important measure is the number of international non-stop destinations, the third is the number of domestic non-stop destinations, and the fourth is the percentage of the world GDP accounted for by countries that are served by daily international flights. This last variable points out that while adding flights or destinations is important, these flights should be to important destinations in terms of the overall level of economic activity (as measured by GDP) in the regions or countries served by those destinations.

The relative impact of each connectivity measure is illustrated in the fourth column of **Error! Reference source not found.**. The elasticity of each measure is compared to that of the measure with the greatest impact on MFP, namely the number of domestic destinations having two or more daily non-stop flights. If we take the measure with the second highest elasticity (the number of international non-stop destinations), this latter measure would have to increase from its current value by 2.5 times the increase in the number of domestic destinations served by two or more daily non-stop flights to have the same impact on multi-factor productivity. Below these two measures, the connectivity measures fall into two categories, those with elasticities in the range 0.025 to 0.028 and those in the range 0.016 to 0.018. The first category includes measures that reflect daily service to destinations that comprise a high share of the world GDP, the number of domestic destinations served with non-stop flights, domestic destinations having five or more daily non-stop flights, and the number of domestic airline hubs served with direct flights. Each of these measures has about 30 percent of the impact of a change in the number of domestic destinations having two or more non-stop flights. These results also imply that the number of domestic destinations served non-stop and the number served with five or more daily non-stop departures provide about the same amount of connectivity, showing that service frequency is an important aspect of connectivity. The remaining variables have about 20 percent of the impact of the connectivity measure with the greatest impact on MFP. Using the average values displayed in TABLE 5 is useful to gauge the overall effects of each connectivity measure. However, they can be misleading for any particular industry and assessing which variables matter and their relative importance should be based on the elasticity values in TABLE 4.

TABLE 5 Average Values of Air Service Elasticities Across Industries

Connectivity Measure	Elasticity (average)	Rank	Relative Weight
Domestic Destinations with Two or More Daily Non-stop Flights	0.0915	1	1.00
International Non-Stop Destinations	0.0375	2	0.41
Domestic Non-Stop Destinations	0.0284	3	0.31
Percent of the World GDP Served Daily	0.0259	4	0.28
Domestic Destinations with Five or More Daily Non-stop Flights	0.0258	5	0.28
Domestic Airline Hubs Served Non-stop	0.0254	6	0.28
International Flight Departures	0.0182	7	0.20
Percent of the World GDP Served Non-stop	0.0169	8	0.18
Domestic Flight Departures	0.0164	9	0.18
Percent of the World GDP Served Twice or More Daily	0.0161	10	0.18
Number of Airlines	0.0160	11	0.17

TABLE **6** illustrates how these elasticities can be used to measure the impact on economic output, measured by value added, for the year 2010. Based on data for the 11 industries and aggregating across the 20 regions, the increase in each industry's value-added output is calculated for a one percent change in those connectivity measures that were statistically significant for that industry sector. The last row in the table reports the change for the aggregate of the 20 regions (across all 11 industry sectors) of a change in each connectivity measure.

One important point to observe is the relative differences in what were considered the key connectivity measures, based on their elasticity values and the change in value added in response to a one percent change in the different connectivity measures, as indicated in the bottom row of

TABLE **6**. For example, the number of domestic destinations served by two or more daily non-stop flights, the number of international non-stop destinations, and the number of domestic non-stop destinations were estimated to have the highest average elasticities, as shown in TABLE 5.

Examining

TABLE **6** shows that the variables with the largest impacts on value added are the same but their order is reversed, the third largest elasticity has the highest impact in terms of the value added for a one percent change in the variable. The point is that even if the elasticity value is small, the industry sector may be large and the impact of a small change in a large sector can result in a sizable impact on value added. Therefore, when judging the importance of a connectivity variable, looking only at the relative elasticity value would be misleading. One also has to look at the size of the economic sectors where the connectivity variable has an impact.

For example, the number of airlines has the lowest ranked elasticity in TABLE 5, but is ranked seventh of the eleven variables in terms of the value added for a one percent change in the variable (as shown in TABLE 6). Moreover, the elasticity for the number of airlines is 17% of the elasticity for the number of domestic destinations served by two or more daily non-stop flights (as shown in TABLE 5), but TABLE 6 shows the value added across all regions and industries for a one percent increase in the number of airlines is 31% of the value added for a one percent increase in the number of domestic destinations served by two or more daily non-stop flights ($200.5 million compared to $653.8 million).

These results help identify which connectivity measures appear to have the strongest effect on economic output for different industries. In TABLE 5, the number of airlines is ranked 11^{th} in terms of the effect of this connectivity measure on productivity based on the average elasticity values, but this measure has a fairly strong effect on the output of the manufacturing sector, which forms a large proportion of total GDP, accounting for the third largest increase in value added for this sector ($157 million) of all the air service measures, as shown in the row for this sector in

TABLE **6**. Similarly, the number of domestic airline hubs served non-stop, which was ranked sixth overall in TABLE 5, strongly effects the finance and insurance sector, accounting for the highest amount of value added for this sector ($226 million) of all the air service measures. If the number of domestic airline hubs served across the airline network (represented in this analysis by the sample of 20 regions and their airports) were to increase by one percent, the change in value added generated by increased MFP from the enhanced connectivity across all sectors for which this variable was significant (as shown in TABLE 4) would be about $374 million (the total of the relevant column in

TABLE **6**). Hence, if the number of hubs served increased by 10%, the change in value added would be about $3.7 billion. These projected impacts apply to a 20-region area that accounts for slightly less than one-quarter of the U.S. GDP *(5)*.

These calculations assume that the air service variables are continuous measures that can be increased by any amount, although in practice they can only be increased in discrete steps for any given airport. However, a given percent change in air service across all 20 regions could result from a varying change in each region. Thus a 10% increase in the number of domestic airline hubs served non-stop could result from an increase of one hub served at some airports and none at other airports, rather than a varying fraction of a hub served at each airport. An increase in the number of airline hubs served from a given airport is assumed to result from the introduction of non-stop flights to a hub that was not previously served, not from a change in the total number of airline hubs.

TABLE 6 Impact of Changes in Different Connectivity Measures on Industry Output (2010 $M)

Industry	Output over 20 Regions[a]	Number of Airlines	Domestic Non-Stop Departures	Domestic Airline Hubs Served Non-stop	Domestic Non-Stop Destinations	Domestic Destinations with Two or More Daily Non-stop Flights
Manufacturing	$358,857.91	$157.54	$85.05		$123.45	$355.63
Wholesale Trade	$199,956.26	$42.99	$51.39		$30.39	
Information	$158,156.77			$23.88		$19.14
Finance & Insurance	$315,875.87		$151.30	$226.17		$98.55
Real Estate & Rental & Leasing	$444,512.52		$94.68		$176.47	$180.47
Professional, Scientific, & Technical Services	$311,416.85		$56.68	$112.42		
Management of Companies & Enterprises	$80,042.52			$8.48	$25.69	
Administration & Support & Waste Management Services	$108,779.27		$11.31		$32.74	
Arts, Entertainment, & Recreation	$34,213.83			$3.18	$4.45	
Accommodation & Food Services	$87,114.85		$0.09		$19.95	
Other**	$734,242.98		$2.94		$272.40	
Total	$2,833,169.64	$200.53	$453.44	$374.14	$685.55	$653.79

Note: a) Data from Moody's Analytics, Inc. *(5)*.

TABLE 6 (cont'd) Impact of Changes in Different Connectivity Measures on Industry Output (2010 $M)

Industry	Domestic Destinations with Five or More Daily Non-stop Flights	International Non-Stop Departures	International Non-Stop Destinations	Percent of the World GDP Served Non-Stop	Percent of the World GDP Served Daily	Percent of the World GDP Served Twice or More Daily
Manufacturing			$171.89			$56.34
Wholesale Trade	$63.59		$38.19		$6.40	
Information		$38.59	$22.77		$40.65	
Finance & Insurance		$41.70			$33.80	
Real Estate & Rental & Leasing	$48.90		$236.48			
Professional, Scientific, & Technical Services		$81.59			$152.91	
Management of Companies & Enterprises		$7.28	$18.17	$16.25		$14.33
Administration & Support & Waste Management Services		$22.95	$95.40	$51.34		
Arts, Entertainment, & Recreation	$6.74				$13.65	
Accommodation & Food Services					$19.34	
Other**			$99.86		$94.72	
Total	$119.22	$192.11	$682.77	$67.59	$361.46	$70.67

Catalytic Effects or Wider Economic Benefits

The various measures of connectivity illustrate that as connectivity improves there is a positive effect on productivity. The results of the analysis was to discover that different industries achieve connectivity through different mechanisms and have different impacts on measured MFP. The question is how do the results affect investment or policy decisions and what is the mechanism?

Over the last several years there has been significant discussion of what have been termed wider economic benefits and/or catalytic effects of transport improvements (however they might arise). The development of this literature seem to be driven by studies analyzing competing locations for new airports (Heathrow vs Gatwick), ports (London) and headquarter locations (e.g. Amazon). There are some papers that use the terms 'wider economic benefits' synonymously with 'catalytic effects', while others claim they are different (see for example, Forsyth and Niemeier, 2016).[4]

A catalyst is an event, material or person causing a change or acceleration of a change. A report for ACI – Europe (2004) defines a catalytic impact as 'employment and income generated in the economy of the study area by the wider role of the airport in improving the productivity of business and in attracting economic activities such as inward investment and inbound tourism'. Defined in this way these are economic impacts and not wider economic benefits. This interpretation would seem confirmed by Cooper and Smith (2005) who state catalytic impacts are composed of consumer surplus to users, economic spillovers and environmental and social impacts resulting from tourism and trade (demand side) and long run contribution to productivity and GDP growth (supply side). Catalytic impacts are simply external effects that would not have been included in traditional impact models. Whether they could be wider economic benefits depends on whether they have been internalized by markets. If markets are working efficiently all value should be fully reflected in standard economic welfare measures.[5] The trouble it appears is not identifying them but rather measuring them.

Venables (2016) sees wider economic benefits (WEB) as benefits that add social value over and above user benefits, that is over and above consumer and producer surplus. Essentially WEB are those portions of social value going to either consumers or producers that have not been fully internalized due to a market failure of sorts and are therefore externalities. WEBs are additional social benefit or cost not captured by user benefits, they should reflect a general equilibrium net value meaning a benefit in i is not displacing a benefit in j and they should be measurable.

WEBs generally involve a shift in a function. They have the effect of being able to do new things not just existing things better (which should be fully internalized by markets). A transportation investment or policy change or operational decision may result in some technological change, such as information spillovers that are not intermediated through a market. WEBs may create opportunities for agglomeration economies resulting from combining market density and market size. Veneables (2016) identifies such circumstances as giving rise to clusters which result in spillover effects or externalities. Suppliers may not be able to capture all of the gains in the form of producer surplus because of indivisibilities or scale effects. Users may benefit from greater product variety which may not be fully captured in measures of willingness to pay.

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[4] A 2015 report by InterVISTAS done for ACO Europe makes catalytic impacts synonymous with wider economic impacts and this, in my view, is not correct.

[5] Wider economic impacts are Catalytic impacts but catalytic impacts are not necessarily wider economic impacts.

SUMMARY

The objective of this research was to measure how changes in airline network connectivity which may take different forms contribute to changes in productivity in different economic sectors. There was also the question of whether different industries would be impacted in different ways. The approach used in the analysis defined a set of variables that captured the differing aspects of connectivity provided by the airline network. A set of regression models were estimated that related changes in these connectivity measures to changes in multi-factor productivity and hence the resulting changes in real economic or income growth. The results of the analysis provide a means of identifying the relative influence of different measures of airline network connectivity and also show how the effect of different connectivity measures appears to differ across industry sectors. However, the data used in the analysis was limited to a sample of 20 metropolitan regions and 11 broad industry sectors. Therefore, the estimated elasticities should not be seen as holding across all industries within each sector. The results presented in this paper represent a first step in understanding how changes in air service connectivity influence productivity in different sectors of the economy, but more work is needed to refine and extend these results using a more complete set of time series data covering the intermediate years, in order to better account for temporal trends in other factors that may have influenced productivity, and could also include a finer disaggregation of industries within each sector to test the robustness of the results.

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