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Hub and Spoke Airport Networks and State Airport Infrastructure Spillovers: A Spatial Econometrics Approach

Jeffrey P. Cohen* and Catherine J. Morrison Paul**

Abstract

In recent years, many hubs in the highly interdependent U.S. air transport network have become congested, leading to delays for business travelers and freight shipments. Recent events in this industry may have temporarily reduced this congestion, but contributed to other types of disruptions. Since delays and disruptions at one node of the network exacerbate problems throughout the system, airport infrastructure expansion to enhance traffic flows and security in large hubs may confer substantive spillover benefits in the form of travel-time savings and reliability. This may in turn translate into increased worker productivity and shipping efficiency, and thus lower costs, for manufacturing firms. In this paper we evaluate the impacts of such spillovers, by applying spatial econometrics techniques to a cost function framework, using state-level data on airport and highway infrastructure, and manufacturing production. We find that increasing own-state airport infrastructure tends to generate cost-saving benefits for the state's manufacturing industry, primarily due to non-production labor- and materials-savings. However, airport expansion in connected hubs has an even greater impact, implying an important externality component of such investment. Also, unless airport expansion is accompanied by highway infrastructure investment, congestion seems to counteract the associated benefits, especially in large-hub states with less than 5 percent of the nation's passenger enplanements.

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Introduction

Subsequent to federal air deregulation, the U.S. air transport system has evolved into a highly interdependent network where passengers and freight are transported through “large hubs”, from remote “spokes” or other large hubs, on the way to their final destinations (Morrison and Winston, 1985, and Baily, 1993). However, in recent years many large hubs have become congested, leading to frequent delays for business travelers and disruptions of freight shipments. In turn, major expansion projects have been undertaken by many airports to reduce congestion, improve amenities, and generally enhance air travel flow. Security and safety concerns arising from recent terrorist events may have temporarily reduced the congestion problem, but have raised other issues of reliability and safety. Expenditures to deal with these problems will also affect the travel experiences of business passengers, and the maintenance of travel service flows for both people and goods.

A recent article by the Associated Press (July 23, 2001) emphasizes that interruptions of air travel services are a broad ranging, or “coast-to-coast” problem. It documents that: “More than one-quarter of flights into 11 of the nation’s busiest airports were at least 15 minutes late during the first five months of the year.” More recently, after a security breach at the Atlanta airport, the *Atlanta Journal and Constitution* (November 17, 2001) reported that “Hundreds of flights around the country were canceled or delayed… (and) dozens of planes heading to Atlanta were diverted to other airports.” These and many similar recent scenarios underscore that congestion or security issues, combined with the hub and spoke structure of the network, cause delays and disruptions to spillover across airports. Through these interdependencies, airport infrastructure choices in one state will have impacts on the flow of travelers and freight throughout the system. They may also have associated effects on other components of the transportation system, such as highway networks that may experience increasing congestion with airport expansion.

The network structure of the U.S. air transport system, and its linkage with highways serving airport hubs, make these issues well suited for evaluation using a production model allowing for spillovers. For this study we thus apply spatial econometrics techniques to a cost function-based framework incorporating spatial external effects, to analyze cost or productivity spillovers from state airport infrastructure and other transport network interdependencies. The model represents the production structure of state-level manufacturing industries, and the cost-impacts of higher transport infrastructure levels, taking capital fixities, profit maximization behavior, and imperfect competition into account.

We accommodate two forms of spatial linkages through the structural and stochastic specifications. First, we adapt the cost function framework to recognize that airport infrastructure stocks may play the role of “free inputs” in the cost structure of manufacturing firms. Through this mechanism, airport expansions in own and neighboring states, which reduce congestion constraints in the airport network, will directly generate industry cost savings in a particular state. Second, we adapt the stochastic specification to recognize a spatial autoregressive structure from interdependencies of states with their neighbors, in terms of the airport network, as in the spatial econometrics literature.

We also recognize differences among states with and without large hubs, since one might expect travel-time savings to accrue to industry employees in states with large hubs, but the story might be quite different in other states. In fact, increases in large hub states’ airport infrastructure stocks may provide relocation incentives to gain better access to the rest of the network for workers who often travel, thus limiting labor markets and increasing costs for firms in more remote states.

Although our initial focus is on airport interdependencies, as an alternative scenario we augment our definition of the transport network by recognizing the role of highway infrastructure. Airport infrastructure expansion without additional investment in highways may cause delays and disruptions for business travelers driving to and from these airports, as Cohen (1997) suggests has recently occurred in many large-hub states. Thus, we incorporate the constraining effect of the existing highway infrastructure – or the complementary contribution of enhanced highway networks – to assess how time delays from "intermodal" congestion may affect manufacturing industries' costs.

Our empirical results reveal substantive impacts from air transport network linkages, and support our treatment of spatial interdependencies. Large hub airport expansion appears to have a significant direct cost-savings effect on own-state manufacturing production, but an even greater indirect cost-effect for firms in other large-hub states. These impacts are most evident for smaller large hubs; states with the largest hubs exhibit little cost-response from own-state airport development, and are less sensitive to neighboring hub airport expansion. These patterns imply an important external or public good[1] aspect of airport infrastructure investment, from reductions in bottlenecks and enhancement of the free flow of business travelers and freight from and into states with large hubs. The cost-savings associated with own- and linked-state hubs arise from both greater productivity of non-production workers (who are more likely to travel on business), and reduced materials expenditures (via lower transport costs or improved inventory management). Subsequent capital investment is also implied, which is consistent with the resulting growth of manufacturing industries.

For states without large hubs, cost savings also arise from own-state airport investment, but the impact is smaller, and no clear impact is apparent from expansion of large hubs in other states. These effects appear to be primarily associated with non-production worker cost-savings. Also, when highway linkages are recognized, we find that increased airport infrastructure investment in large hub states is actually cost-enhancing without corresponding highway infrastructure investment. This seems attributable to greater highway congestion, and associated increases in freight transport costs for manufacturing industries; little impact on the cost-savings benefits for business travelers is evident.

The Motivation, Model and Measures for our Analysis

The Issue

A delay resulting from congestion or security problems at one node in the U.S. air transportation network often results in delays for connecting passengers throughout the system. An increase in airport infrastructure stocks that reduces congestion in states with “large hubs”[2] (hereafter referred to inter-changeably as “hubs”) may thus be expected to confer productivity spillover benefits upon firms. This may occur through various mechanisms, such as impacts on business employees who frequently travel, or on shipments from input suppliers.

In particular, such effects may take the form of reduced travel-time and frustration for workers, or enhanced efficiency and reliability of freight shipments, that in turn generate production cost-savings. Time savings for leisure travelers could even improve productivity, since individuals will be more rested and productive upon their return to work if they do not encounter major air traffic problems. Cost savings may also arise if breakdowns in the smooth transition of materials from suppliers, due to congestion or other disruptions, are reduced by airport improvements. These types of linkages were underscored by recent terrorist attacks, and subsequent disruptions of passenger travel central to business practices in our “new economy”, as well as air shipping flows crucial for modern inventory systems.[3]

Travel time- or transport- and thus manufacturing cost-savings from airport infrastructure investment imply productivity externalities or spillovers across states. Airport improvements to limit congestion in one hub state could result in interstate productivity spillovers, lowering manufacturing costs for firms in other states connected or linked through the airport network. Externalities may also arise from interdependencies with other parts of the public transport network, such as highways. An analysis of the state-level cost structure of manufacturing production, and the cost-impact of enhanced services from own- and connected-state airport infrastructure and other aspects of the transport network, has the potential to provide insights about such cost effects.[4]

The impacts of own- and neighboring-state highway investment on manufacturing productivity have been explored in studies such as Cohen and Paul (2001a). Although such linkages could potentially work through the labor force via enhanced mobility and thus productivity, the primary focus of most studies of public highway investment is the shipment of goods between states, and thus more directly transport costs. The resulting productivity effects have sometimes been explored using cost function models of production processes, as in Morrison and Schwartz (1996) and Cohen and Paul (2001a), but have more often been represented using first-order (Cobb-Douglas) production function models (Holtz-Eakin and Schwartz, 1995, Kelejian and Robinson, 1997, and Boarnet, 1998).

In either of these contexts, the impacts of highway infrastructure are represented in terms of external (“free input”) productive effects from public infrastructure investment.

However, capturing cost-impacts and implied behavioral responses through a cost-based optimization framework seems particularly informative. Thus, we use such a framework to pursue our analysis of productivity spillovers from airport interdependencies. Combining information on the airport and highway components of transport networks in such a model allows examination of both the cost-savings from reduced airport congestion associated with airport expansion, and potential cost increases from resulting highway congestion.

A cost-based framework is particularly applicable to issues about airport interdependencies if one explicitly recognizes the spatial or network dimension using spatial econometrics methods. Spatial econometrics techniques are designed to represent geographic or other horizontal interdependencies. For example, in the early literature in this area, Case, Hines, and Rosen (1993) examine how (a weighted average of) other states' public spending patterns affect a given state's expenditures on the same types of public investments.[5] Cohen (2001) similarly tests for interdependencies in states' airport spending choices. Although neither of the estimating models in these studies is embedded in an optimizing framework, the methods used may be adapted to a model of cost relationships for optimizing firms, to facilitate analyzing cost-effects from airport infrastructure investment.

Also, in these types of studies the term "neighbor" may encompass several types of characteristics in addition to sharing a geographic border. This is important for the extension of these ideas to evaluate the cost-impacts of airport network improvements, since airport linkages have more a network than a geographical dimension. In the case of airports, two states that share a common border are likely to have less connection with each other than two distant states that both have large hubs within their borders. The linkage involves the number of person trips between a particular state and hub states in the airport network web.

The model used for our analysis is thus based on a cost-function representation of manufacturing production, adapted to incorporate spatial inter-relationships through both external shift factors (reflecting linkages between public infrastructure and industrial productivity, and among components of the transport network), and spatial econometrics adaptations. The development of this framework is the focus of the next sub-section.

The Empirical Model

The representation of manufacturing industries' cost and production structure, and their reliance on external "public" or "free" inputs, may be accomplished using a cost function framework recognizing external cost impacts as shift factors. To model and measure the relationships discussed above, we estimate such a function using state level data for the manufacturing sectors of the 48 continental United States (1982-1996).

The total cost function has the general form $TC = VC(Y,\mathbf{p},\mathbf{x},\mathbf{r}) + \Sigma_k p_k x_k$, where Y is state-level manufacturing output, **x** is a vector of quasi-fixed inputs (here private capital, K), **p** is a vector of variable inputs (here non-production labor, NL, production labor PL, and materials, M), and **r** is a vector of external shift variables. For our purposes, the components of **r** include not only a standard time counter, t, but also the own-state airport infrastructure stock, I, and (a weighted average of) other hub states' airport infrastructure stocks, G. In our extension incorporating highway stocks we also include own-state highway infrastructure, B, as an **r** component.[6]

I, G and B are therefore "free inputs" to manufacturing firms' production processes in own- and neighboring- or connected-states, in the sense that they have a productive and thus cost impact but are not internally chosen (and paid for) inputs. They are instead external factors that act as shift variables because improved transport services potentially save time for business travelers, and enhance transport efficiency for materials, thus lowering production costs and improving productivity and profitability.

We assume the short run cost structure may be approximated by a Generalized Leontief (GL) variable cost (VC) function similar to that used by Cohen and Paul (2001b). The GL form is desirable for our purposes since it is flexible, and incorporates optimizing behavior on the part of manufacturing firms, thus allowing us to represent firms' behavior in response to changes in airport infrastructure through first- and second-order cost elasticities. Such a VC(·) function can be formalized as:

$$\begin{aligned} 1)\quad VC(Y,K,\mathbf{p},\mathbf{r}) = {} & \Sigma_q\Sigma_i\, \delta_{qi}\, p_q\, DUM_i + \Sigma_q\Sigma_b\, \alpha_{qb}\, p_q^{.5}\, p_b^{.5} + \Sigma_q\, \delta_{qY}\, p_q Y + \Sigma_q\, \delta_{qK}\, p_q K \\ & + \Sigma_q\Sigma_n\, \delta_{qn}\, p_q\, r_n + \Sigma_q p_q(\delta_{YY}\, Y^2 + \delta_{YK}\, K\cdot Y + \Sigma_n\, \delta_{nY}\, r_n Y + \delta_{KK}\, K^2 + \Sigma_n\, \delta_{nK}\, r_n\, K \\ & \quad + \Sigma_n\Sigma_m\, \delta_{nm}\, r_n r_m)\ , \end{aligned}$$

where q and b denote the variable inputs (NL,PL,M), and m and n the components of the **r** vector (I,G,B,t). Given the constraints on adjustment of private capital, as suggested by Cohen and Paul (2001b), this function represents short run cost minimizing behavior.[7]

From duality theory (Shephard's Lemma), the derivative of the cost function with respect to a variable input price reproduces the corresponding optimal input demand, so:

$$\begin{aligned} 2)\quad v_q\,(Y,K,\mathbf{p},\mathbf{r}) = \partial VC/\partial p_q = {} & \Sigma_i\, \delta_{qi}\, DUM_i + .5\ \Sigma_b\, \alpha_{qb}\, p_q^{-.5}\, p_b^{.5} + \delta_{qY}\, Y + \delta_{qK}\, K \\ & + \Sigma_n\, \delta_{qn}\, r_n + \delta_{YY}\, Y^2 + \delta_{YK}\, K\cdot Y + \Sigma_n\, \delta_{nY}\, r_n Y + \delta_{KK}\, K^2 + \Sigma_n\, \delta_{nK}\, r_n K + \Sigma_n\Sigma_m\, \delta_{nm}\, r_n r_m\ , \end{aligned}$$

for q=NL,PL,M. These three equations, combined with the cost function, comprise a system of equations representing variable input demand behavior, given observed Y, K levels.

To also accommodate profit maximization, and allow for imperfect competition, we append an equation to this model representing output supply choice in terms of pricing behavior. This results from the standard expression equating marginal costs (MC) and revenues (MR) for output choice, $MR = p_Y + \partial p_Y/\partial Y \cdot Y = MC = \partial TC/\partial Y = \partial VC/\partial Y$, or:

$$3)\quad p_Y = -\lambda_Y \cdot Y + MC = -\lambda_Y \cdot Y + \Sigma_q\, \delta_{qY}\, p_q + \Sigma_q p_q (2 \cdot \delta_{YY}\, Y + \delta_{YK}\, K + \Sigma_n\, \delta_{nY}\, r_n),$$

where $\partial p_Y/\partial Y$ is assumed to be a parameter, λ_Y.[8] The estimate and significance of this constant, which represents the deviation between (average) output price and marginal revenue (and thus would be zero with perfect competition), yields information on the degree of imperfect competition of manufacturing firms.[9] This equation completes the system of estimating equations for our model.

To estimate such a system of estimating equations, researchers often assume that each equation has a normally distributed error term with mean zero and constant variance. We will call this our "Base" case. However, to represent spatial interdependencies within the stochastic structure we can also allow for the possibility that shocks to states' error terms spill over, at least partially, to other states. This leads to spatial autocorrelation, or spatial autoregressive errors, as developed by Anselin (1988) and Kelejian and Robinson (1997).

This implies that the error specification for the $VC(\cdot)$ function becomes $VC_{i,t} = VC(\cdot)_{i,t} + u_{i,t}$, where $u_{i,t} = \rho_s \Sigma_j w_{i,j} u_{j,t} + \varepsilon_{i,t}$, $-1<\rho_s<1$, $w_{i,i} = 0$, $\varepsilon_{i,t} \sim N(0, \sigma^2)$, and $w_{i,j}$ is the weight that state j has on state i's error term. This expression represents the error term for a particular observation (state-year combination) as a random component, $\varepsilon_{i,t}$, and a component capturing a weighted average of other states' error terms that spill over to the state under consideration. The input equations are analogously adapted to allow for errors of the form

$u_{q,i,t} = \rho_{\eta,q} \Sigma_j w_{i,j}u_{q,j,t} + \varepsilon_{q,i,t}$, where $-1<\rho_{\eta,q}<1$, $w_{i,i} = 0$, and $\varepsilon_{q,i,t} \sim N(0, \sigma_q^2)$. The interpretation is analogous to that for the error term of the VC equation, except that the error term for each input demand equation has its own random component, and the spatial component consists of a weighted average of the error terms for input q for all other states. We will call the system of equations with this error structure incorporated the "Spatial Autoregressive" or SAR case.

To implement the SAR model we need to carefully specify the weights for the error structure, that represent how such shocks are transmitted. We postulate that the shocks spill over between states that interact most extensively in the use of their airports. Thus, a hub state with a relatively large number of person-trips between it and the given state will receive greater weight than hub states with fewer person-trips. Also, since the number of direct trips between non-hub states is relatively small, we focus our attention on person trips between hub states and other states (either hub or non-hub). The same weight structure is used to construct the weighted average of other states' airport infrastructure stocks, G, that enters the cost function directly as a free input.

These assumptions imply that airport infrastructure stocks in hub state j, which shares a large amount of passenger movement with state i, will have a relatively large effect on state i's manufacturing costs. This reflects the notion that improved airports in other large hub states will save time for workers traveling through these states, through a reduction in the extent of time delays, in turn increasing their productivity and lowering firms' costs.

Measures of Cost Effects and their Components

The goal for our exploration of own- and "neighboring"-state productive effects of transport network investments on state-level manufacturing industries is to measure the cost effects of these external factors, which can be represented as shadow values. For example, our scenario suggests that the cost-based shadow value of G, $Z_G = \partial VC/\partial G$, or its proportional equivalent in elasticity form, $\varepsilon_{VC,G} = \partial \ln VC/\partial \ln G$, will be (significantly) negative for large-hub states with strong interdependencies within the network. This represents decreased congestion (or increased reliability or other amenities) from airport expansions in linked hubs that enhance air traffic flows and thus the transport of business travelers and freight.

Analogous measures of the cost-effects or -savings arising from changes in external factors may be constructed for other arguments of the **r** vector. In particular, we may compute shadow values and cost-elasticities also for own-state airport infrastructure expenditures, $Z_I=\partial VC/\partial I$ and $\varepsilon_{VC,I} = \partial \ln VC/\partial \ln I$, and equivalently for highway infrastructure, B.[10] Although it is not directly a focus of our analysis, such shadow values or elasticities computed for K also provide implications about ultimate (long run) capital demand patterns. That is, $Z_K = \partial VC/\partial K$ and $\varepsilon_{VC,K} = \partial \ln VC/\partial \ln K$ represent the variable input cost savings of a change in the capital stock, which depends on G, I and B.

In addition, since optimal input demands are encompassed in the cost function, implied input-specific adaptations to changes in G, I, and B are embodied in their corresponding shadow value measures. For example, to determine the impacts of changes in the availability of linked-hub transport infrastructure, G, and its input-specific impact on NL demand, we can compute the elasticity $\varepsilon_{NL,G} = \partial \ln NL/\partial \ln G = (\partial NL/\partial G) \cdot G/NL = (\partial^2 VC/\partial p_{NL}\partial G) \cdot G/NL$, using Shephard's lemma (equation 2).

G (or other external) effects will involve technical change biases if not all input-specific impacts are equal, which is likely to be the case. In fact, the cost-saving impact on some input(s) could potentially be of an opposite sign to the overall cost effect. Thus, for this example, G investment would be absolutely NL-saving if $\varepsilon_{NL,G}$ is negative, and relatively

NL-saving if it is also larger (in absolute value) than $\varepsilon_{VC,G}$, similarly to technical change biases. This in turn would imply increased marginal productivity of NL, given output production levels. The impact of G changes may be significantly different for other inputs.

Note also that from Young's theorem (symmetry of 2^{nd} order derivatives), the $\varepsilon_{NL,G}$ measure will be equivalent to (but have a somewhat different interpretation than) the elasticity $\varepsilon_{ZG,pNL} = \partial \ln Z_G/\partial \ln p_{NL} = (\partial Z_G/\partial p_{NL}) \cdot p_{NL}/Z_G = (\partial^2 VC/\partial G \partial p_{NL}) \cdot p_{NL}/Z_G$. If $\varepsilon_{ZG,pNL}$ is negative, for example, the shadow value of G is greater at higher p_{NL} levels, implying larger cost-saving benefits from reducing NL. The impacts of G changes on the shadow value of K, implying long run incentives to expand the capital stock for efficient production, may similarly be computed as $\varepsilon_{ZK,G} = \partial \ln Z_K/\partial \ln G = \partial Z_K/\partial G \cdot G/Z_K = (\partial^2 VC/\partial K \partial G) \cdot G/Z_K$.

Finally, we may represent interactions among the external variables using second-order elasticities. That is, since the shadow values of the **r** vector components take the form of first derivatives, the cross-effect of, say, G and I, may be expressed as $\varepsilon_{ZG,I} = \partial \ln Z_G/\partial \ln I = \partial Z_G/\partial I \cdot I/Z_G = (\partial^2 VC/\partial G \partial I) \cdot I/Z_G$. Such a measure reflects the impact of an expanded hub in the own-state on the cost-savings associated with additional airport infrastructure investment in connected states.

Estimation Results

Airport Network Effects

The system of the $VC(\cdot)$ equation, three input demand equations, and output pricing equation, represented by (1), (2) and (3), was estimated by multivariate regression methods using PC-TSP for the Base and SAR stochastic specifications. The results for the parameter estimates for both models are presented in Appendix Table A1 (excluding the state dummies for ease of presentation). The "fits" for the equations, represented by the R^2s of 0.991 or higher for the cost equation and all three of the input demand equations, indicate a close characterization of the state-level manufacturing cost structure for our data sample. The individual parameter estimates are also largely statistically significant, although with this flexible functional form the parameter estimates are not intuitively very interpretable. The significance of the cost effects depends on that for the elasticity (shadow value) estimates, which are combinations of coefficients, each with their own standard error.

It is worth noting, however, that the parameter estimate for λ_Y is very small, but is highly significant in both the Base and SAR runs. This is also true for our highways-included model discussed in the next sub-section. Due to this clear significance, plus the impact on other elasticities' significance (implying joint significance) found when the imperfect competition adaptation was omitted, we included equation (3) in the estimating model even though it is not the focus of our analysis.

Note also that more of the parameters involving G and I are significant in the SAR than in the Base runs. In terms of elasticities, this ultimately implies that some second order shadow value elasticities (Z_I for large-hub and Z_G for non-hub states) are more robust in the SAR specification, although they are not substantive overall for either model. And the four spatial autocorrelation coefficients are individually significant. This also supports the SAR adaptation, although the implications emerging from elasticities for both models are quite consistent. The following discussion therefore focuses primarily on the SAR model, but comparisons of the two specifications will be made when differences arise.

The elasticities reported in Tables 1 and 2 for the Base and SAR specifications are averages (means) of the estimates computed for each observation within the sample under consideration. The associated t-statistics are based on evaluation of the elasticities at the mean values of the data. These measures document a wide variety of cost impacts and interactions associated with airport expansions.

First, for states with large hubs, the average own effect of airport infrastructure investment, $\varepsilon_{VC,I}$, is negative, significant, and nearly identical for both the Base and SAR models at about -0.10. This estimate implies that on average a 1 percent increase in airport infrastructure stocks corresponds to a 0.1 percent fall in manufacturing costs within the own-state. The implications about cost-effects of airport development in other (neighboring) hub-states vary somewhat more across specification. For both specifications we find that $\varepsilon_{VC,G}$ is significantly negative for states with large hubs, implying that manufacturing costs within such a state fall when other large-hub states expand their airports, although for the SAR model the $\varepsilon_{VC,G}$ estimate is about 20 percent smaller in magnitude at about -0.4.

Note also, from the SAR estimates in Table 3 that further divide the large hub-states,[11] that for hub states with more than 5 percent of all enplaned passengers $\varepsilon_{VC,I}$ is negative but very small (about -0.02) and insignificant, while $\varepsilon_{VC,G}$ remains negative and significant but is smaller than the average for all hub states (about -0.17). By contrast, the states with smaller large hubs (more than 1 but less than 5 percent of enplaned passengers) exhibit even greater impacts of both I and G on state manufacturing costs (average $\varepsilon_{VC,I} = -0.12$ and $\varepsilon_{VC,G} = -0.47$), although the neighboring hub effect is not quite significant at the 5 percent level. Thus, only the cost savings from diverted stopover traffic and reduced external bottlenecks seem consequential for the largest hub airports, and states with smaller large hubs appear more impacted overall by airport investment.

The much larger cross-hub effects, $\varepsilon_{VC,G}$, than own-state effects, $\varepsilon_{VC,I}$, for all the large hub states imply that airport expansions or improvements by other large-hub states have a greater effect on manufacturing costs in a particular state than own-state airport development. This may be because improvements in connected hub-states draw stopover traffic away from the own state, in addition to reducing time delays for own-state business travelers and freight flying through other states' airports. That is, development of airport infrastructure in other large hub states increases the traffic going through those hubs, thus reducing the congestion in the large hub airports in the own-state, as well as enhancing the flow of air traffic from the hub airports in the own-state to other locations. The relative importance of external (to the state) air network investment also implies an important public good component of airport expansion.[12] The flow of passengers and freight traveling from a given hub state is highly affected by the airports they may fly to, or – perhaps even more importantly – fly through. And the difference between $\varepsilon_{VC,I}$ and $\varepsilon_{VC,G}$ is particularly marked for the largest hubs, although both elasticities are significantly larger in size on average for the smaller large hubs. The magnitude of $\varepsilon_{VC,G}$ for the smaller large hub states thus most dramatically indicates the prevalence of free-riding behavior.

This evidence also suggests some form of complementarity between own- and linked-hub state airport expansion. This is consistent with the finding of Cohen (2001) that the average state increases its spending on airports between 50 and 60 cents when other states raise their airport spending by one dollar. It is also consistent with the positive values for $\varepsilon_{ZG,I}$ and $\varepsilon_{ZI,G}$ for the SAR model (although $\varepsilon_{ZI,G}$ is negative for the base case).[13] However, these cross-elasticities are also insignificant, implying no strong statistical impact on the shadow value of own-state airport infrastructure stocks from airport expansion elsewhere in the network. This could be a result of the counteracting influences, in terms of own-airport valuation, of reduced travel time and freight transport costs from and into a particular hub state, and lower own-state traffic flows from airport infrastructure investment in linked hubs. Also, since both I and G “inputs” are externalities, one might expect little direct connection of their impacts, as found in a somewhat different context by Cohen and Paul (2001b).

The interpretation of the cost-effects of G (and I) in terms of travel-time and transport reliability for business travelers and freight is supported by the large (average) negative value and significance of the mean $\varepsilon_{NL,G}$ elasticity for states with hub airports. This indicates that increased airport stocks in other hub states allows for non-production labor-saving (lowers non-production labor manufacturing industry demand) in the own state, which in turn implies an increased marginal product (greater “effective labor input) for these workers. $\varepsilon_{NL,I}$, like $\varepsilon_{VC,I}$, is the same sign as the G elasticity, but smaller as well as insignificant. It thus seems that benefits to firms from increased NL marginal productivity are driven more by the diversion of stopover traffic, and enhanced traffic flows in and out of the state, than by merely expanding own-state airports. The story for freight, represented by M, is reversed in terms of magnitudes, but the average input demand elasticities $\varepsilon_{M,G} = -0.03$ and $\varepsilon_{M,I} = -0.2$ are still negative and significant.[14] Although freight transport is facilitated by both own-state and connected hub expansion, it appears more affected by own-state investment.

Overall, these negative input demand elasticity estimates may thus be interpreted as increasing productivity of manufacturing (non-production) workers, who save traveling time, and materials, that are shipped with less disruption or more reliability, from both own- and neighboring-state airport improvements. An alternative perspective may also be attributed to these results, however, given the symmetry of elasticities such as $\varepsilon_{NL,G}$ and $\varepsilon_{ZG,pNL}$.[15] For example, for both the Base and SAR specifications, $\varepsilon_{ZG,pNL}$ is positive and significant in states with large hubs. Since $Z_G<0$, this implies that when the wages or costs of non-production workers increase, the value to own-state manufacturing firms of additional airport investment in other hub states increases.[16]

Other input-specific G- and I-effects vary more widely. For example, it appears that expansion of neighboring hubs reduces, and of own-state hubs augments, production worker requirements. This result may be linked with M demand. An increase in the marginal product of M (reducing effective demand), may decrease, in relative terms, the need for production workers – or be production-worker-saving. This could also be interpreted as a greater manufacturing production-worker component in states where transportation of production materials is facilitated by larger hubs. Also, the positive $\varepsilon_{ZK,G}$ and $\varepsilon_{ZK,I}$ elasticities suggest that the shadow value of private K rises with increases in public airport infrastructure, implying long run growth incentives that are consistent with overall lower production costs. The varying input demand impacts of I and G changes thus provide clear indications of input-composition biases from these public infrastructure shift factors.

In turn, for states with no major hubs, $\varepsilon_{VC,I}$ is on average significantly negative and $\varepsilon_{VC,G}$ insignificantly positive in both the Base and SAR specifications (Tables 1 and 2), and the cross-effects $\varepsilon_{ZG,I}$ and $\varepsilon_{ZI,G}$ are again positive but insignificant.[17] This evidence suggests that increasing airport investment in the own-state is cost-saving for these locations, but improvements in connected locations has a negligible effect. This may in turn imply that states without a major hub are not subject to the same kind of stopover traffic as hub states, so additional airport investment in other states does not have a congestion mitigating effect on own-state manufacturing workers' travel time costs. To the contrary, better airports in hub states might attract workers from non-hub states. This suggests some self-selection on the part of industries as well as workers in states with varying airport infrastructure support.

In terms of input-specific effects, in the SAR specification $\varepsilon_{NL,I}$ and $\varepsilon_{NL,G}$ are both on average negative but are insignificant for the non-hub states, indicating that a greater own- or connected-state airport stock is only weakly associated with non-production labor-saving and higher NL marginal productivity. The $\varepsilon_{NL,G}$ measure is also excessively large on average due to outliers, and for the Base specification it is positive, indicating a lack of robustness for this estimate. In addition, the own-state airport investment impact on NL, represented by $\varepsilon_{NL,I}$, is stronger in terms of both statistical significance and magnitude than for states with large hubs, although both are statistically insignificant. This could signify that improvements in own-state airports more directly lead to travel-time savings and thus productivity gains for business travelers than in large-hub states.

The average $\varepsilon_{M,I}$ elasticity remains negative and significant, though small, for these states, implying that the cost saving effects from greater I investment involve lower M costs for a given amount of output . By contrast, $\varepsilon_{M,G}$ is large and positive but statistically insignificant, as is $\varepsilon_{PL,G}$, for the non-hub states. Thus the M and PL impacts seem to drive the positive cost effect of G expansion, although these impacts are not very robust or significant, and thus definitive. And the implications from the K shadow value elasticities are quite similar to those for hub states; investment incentives appear to be enhanced by both I and G investment, although the I-impact is smaller than for the hub states.

Highways and Airports

In many states that have undertaken or plan to undertake airport expansions, the issue of highway and access road congestion resulting from airport improvements has been raised, since major highways typically lead up to or surround airport hubs. That is, development or expansion of "large hub" airports without corresponding highway investment may cause other transport system congestion and delays for business travelers. This has been observed recently in large-hub states throughout the country, including Massachusetts and Illinois, as noted by Cohen (1997). It is also suggested by the evidence for large-hub states of relatively small cost-benefits of own-state airport infrastructure expansion documented in the previous sub-section. Thus, if the constraints associated with the existing highway network in a particular state are directly recognized, we could find that "intermodal" time delay congestion counteracts the positive productivity (cost-saving) benefits of improved airports.

We can address this in our model by including the state level highway capital stock, B, as an additional external factor in the **r** vector. This allows not only for estimation of the separate cost effect from additional B, but also for the representation of cross-effects between each of the other (external and internal) factors and highways, which are embedded in the estimates without B included due to the omitted variable. We can thus use the differences in the estimated shadow value elasticities, and these interaction measures, to disentangle the independent value of airport infrastructure to manufacturing firms from the combined effect that is implied if highway stock constraints are not explicitly recognized.

In Table 4 we present the primary elasticity estimates from our SAR specification including B effects (with the underlying parameter estimates reported in Appendix Table A1).[18] First, note that these estimates indicate somewhat more significance of the G elasticities, but less of the I elasticities, than is evident from the airport-only specifications. This implies that some counteracting B effects are imbedded in the airport-only models. In addition, for non-hub states $\varepsilon_{VC,G}$ is now negative, although it is still insignificant, and for the large hub states it is both larger (in absolute value) and somewhat more significant than before. $\varepsilon_{VC,B}$ is also negative and significant for both hub-states and non-hub-states. These results indicate cost savings from own-state highway investment, and connected-state airport infrastructure investment. However, $\varepsilon_{VC,I}$ becomes positive although not quite significant at the 5 percent level for states with large hubs, and very small and insignificant for states without hubs. Having larger own-state airports thus seems to increase manufacturing costs in a particular state, or at least does not generate cost-savings benefits, if highway infrastructure stocks are correspondingly increased to accommodate the resulting congestion.

That is, when constraints associated with existing highways are accounted for, $\varepsilon_{VC,I}$ changes sign, particularly for hub-states; the estimated average $\varepsilon_{VC,I}$ is 0.06 whereas it was -0.1 without B. But the average $\varepsilon_{VC,B}$ is -0.22, so the combined impact of I and B investment still is cost-saving – and in fact more so than is implied by the airports-only model. This evidence of the linkage between I and B, and thus $\varepsilon_{VC,I}$ and $\varepsilon_{VC,B}$, suggests that increased spending on own state hub airports only results in cost-savings benefits for manufacturing firms if expenditures are also targeted to augment public highway infrastructure. Otherwise, congestion costs in the overall transport network appear actually to rise rather than fall.

When we split out the largest hubs states, as also reported in Table 4, average $\varepsilon_{VC,I}$ remains positive for both subcategories but is slightly larger – 0.07 – and significant at the 5 percent level, for the large-hub states with less than 5 (but more than 1) percent of enplaned passengers. The estimate of $\varepsilon_{VC,I}$ for the 5 largest hub states with more than 5 percent of passengers is instead .025 and insignificant, implying that on average, intermodal highway congestion resulting from own-state infrastructure improvements is not as major a concern for the largest hub states as for the smaller hub states.

Given the panel nature of the data, this may also be interpreted as evidence that many states with large airport hubs, but limited highway networks, have higher manufacturing costs. This implication that increased highway congestion counteracts the cost-savings benefits of airport expansion is consistent with Morrison's (2001) variation of a well-known line from the movie "Field of Dreams": "If you build it, he will come and come and come."

Note also that the $\varepsilon_{NL,I}$ elasticity is still negative and significant in this specification for both large- and no-hub states. It is the (positive and significant) M elasticity, $\varepsilon_{M,I}$, that drives this cost-effect, although it is much smaller for the non-hub states. In reverse, $\varepsilon_{NL,B}$ is significantly positive, but is outweighed by a strongly negative $\varepsilon_{M,B}$. This indicates that freight transport is more heavily affected by highway networks, and worker transport by air networks, which is consistent with the traditional focus on materials in the highway infrastructure literature, and labor in the airport literature.

The patterns for the G elasticities are less affected by the inclusion of B. Both $\varepsilon_{NL,G}$ and $\varepsilon_{M,G}$ are negative, although $\varepsilon_{NL,G}$ is much larger and significant than $\varepsilon_{M,G}$. And for the non-hub states this is a sign reversal for $\varepsilon_{M,G}$, although it is still not significant. These patterns thus support the notion that airport improvements in other states reduce the costs of transporting materials, as well as travel disruptions for business travelers. But the latter effect is far stronger, which again is consistent with a greater impact of airport investment on NL, and of highway investment on M.

Concluding Remarks

In this study we have used a generalized Leontief cost function model, combined with input demand and output pricing equations, to compute a range of elasticities representing the web of interactions among U.S. transport network components and manufacturing industry costs. Our results from incorporating measures of public transport infrastructure stocks in a cost model document substantive impacts of both airport and highway infrastructure investment on manufacturing industry costs and productivity. And that these "free inputs" not only have individual cost impacts, but are even more important in combination, due to spillovers within the air transport network across states, and from the supporting highway system within states. In addition, accounting for spatial autocorrelation resulting from interdependencies in states' airport investment, through our spatial econometrics adjustment, increases the robustness of the overall story emerging from our estimating models and elasticity measures. It also suggests slightly more overall statistical significance for many parameters and elasticities, including significance of the spatial autregressive parameter estimates.

We find that manufacturing costs are lower in hub-states with greater own-state airport infrastructure stocks, implying cost-saving benefits from airport improvements, although on average the cost-savings are negligible for the states with the largest hubs. These savings are due to lower costs of both non-production workers and materials, or increased "effectiveness" (marginal products) of these inputs, from the enhanced traffic flow and reliability of the transport network. Airport expansion in linked hubs appears to have an even greater manufacturing-cost-impact than own-state airport investment, potentially due to reduced bottlenecks and stopover traffic. This is also driven by non-production worker and materials savings arising from increased input effectiveness, and implies an important externality present with transport networks that should be taken into account in developing policy measures to boost the overall efficiency of the air traffic system. For states without hubs, own-state airport investment is also cost-saving, primarily due to enhanced business travel for non-production workers, although its impact is smaller, and there is virtually no impact of investment in linked hub-states.

The implied disruption- and time-savings for business travelers and freight from both own- and linked hub-state airport investment may result from various improvements in transport efficiency and traffic flows, including reduced congestion, increased reliability, and better security. In particular, in the wake of disruptions in air traffic from terrorist activity, expenses incurred to augment the reliability and safety of air travel may be expected to generate benefits in terms of increased consumer (and producer) confidence. This will facilitate resumed normal business activity through the air transport network, which is fundamental to effective productivity and growth in our modern economy.

Also, when we account for the presence of highway investment in addition to airport investment, to recognize the broader transport network, it becomes apparent that the benefits of own-state airport infrastructure expansion are only attained when combined with highway infrastructure investment, especially for the smaller large hubs. Manufacturing costs in states with large hubs actually seem to rise when airport infrastructure increases, if the highway stock is not also expanded. This seems attributable to increased congestion around the improved airports, which affects the transport of materials (freight shipments) more than business travelers; own-state airport investment is still associated with decreased non-production worker costs, but increased materials costs if highway infrastructure does not keep up. This suggests that although policy makers should recognize both the direct and indirect benefits of expanding airport infrastructure, constraints associated with existing highway infrastructure should also be a key factor taken into account by airport planners when deciding whether and how to expand hub airports.

Table 1 - Base Elasticities

	States with large hubs			***States with no large hubs***	
	Mean	*t-statistics*		*Mean*	*t-statistics*
$\varepsilon_{VC,I}$	**-0.1032**	*-2.339*	$\varepsilon_{VC,I}$	**-0.0710**	*-2.412*
$\varepsilon_{VC,G}$	**-0.4958**	*-2.628*	$\varepsilon_{VC,G}$	**0.1179**	*-0.104*
$\varepsilon_{VC,K}$	**-0.3823**	*-21.221*	$\varepsilon_{VC,K}$	**-0.5173**	*-24.122*
$\varepsilon_{VC,Y}$	**1.1512**	*152.821*	$\varepsilon_{VC,Y}$	**1.2569**	*237.742*
$\varepsilon_{VC,T}$	**-0.0116**	*-12.376*	$\varepsilon_{VC,T}$	**-0.0151**	*-6.472*
$\varepsilon_{VC,pNL}$	**0.1383**	*29.913*	$\varepsilon_{VC,NL}$	**0.0828**	*14.819*
$\varepsilon_{VC,pPL}$	**0.1386**	*26.879*	$\varepsilon_{VC,PL}$	**0.1164**	*19.686*
$\varepsilon_{VC,pM}$	**0.7390**	*141.253*	$\varepsilon_{VC,M}$	**0.7681**	*102.271*
$\varepsilon_{ZG.I}$	**0.2374**	*1.081*	$\varepsilon_{ZG.I}$	**-1.1027**	*0.103*
$\varepsilon_{ZK,I}$	**0.2063**	*4.076*	$\varepsilon_{ZK,I}$	**0.0170**	*4.243*
$\varepsilon_{NL,I}$	**-0.0310**	*-0.975*	$\varepsilon_{NL,I}$	**-0.1845**	*-1.488*
$\varepsilon_{PL,I}$	**0.3299**	*1.427*	$\varepsilon_{PL,I}$	**0.0189**	*0.040*
$\varepsilon_{M,I}$	**-0.2105**	*-2.875*	$\varepsilon_{M,I}$	**-0.0752**	*-3.107*
$\varepsilon_{ZI,G}$	**-0.4193**	*0.937*	$\varepsilon_{ZI,G}$	**0.9542**	*1.483*
$\varepsilon_{ZK,G}$	**0.2898**	*2.914*	$\varepsilon_{ZK,G}$	**0.3133**	*3.130*
$\varepsilon_{NL,G}$	**-1.0478**	*-2.630*	$\varepsilon_{NL,G}$	**0.7131**	*0.129*
$\varepsilon_{PL,G}$	**-0.1309**	*-1.201*	$\varepsilon_{PL,G}$	**4.7753**	*2.479*
$\varepsilon_{M,G}$	**-0.4720**	*-2.077*	$\varepsilon_{M,G}$	**-0.6400**	*-0.893*
$\varepsilon_{ZI,K}$	**-0.3136**	*2.253*	$\varepsilon_{ZI,K}$	**0.1604**	*1.904*
$\varepsilon_{ZI,pNL}$	**0.5668**	*1.081*	$\varepsilon_{ZI,NL}$	**0.1807**	*2.227*
$\varepsilon_{ZI,pPL}$	**0.9975**	*-1.008*	$\varepsilon_{ZI,PL}$	**-0.0366**	*-0.039*
$\varepsilon_{ZI,pM}$	**-0.5643**	*4.003*	$\varepsilon_{ZI,M}$	**0.8559**	*3.937*
$\varepsilon_{ZI,T}$	**-0.0099**	*0.713*	$\varepsilon_{ZI,T}$	**0.0054**	*0.787*
$\varepsilon_{ZG,K}$	**0.4040**	*2.045*	$\varepsilon_{ZG,K}$	**-3.7262**	*0.104*
$\varepsilon_{ZG,pNL}$	**0.2856**	*3.252*	$\varepsilon_{ZG,NL}$	**0.4881**	*-0.073*
$\varepsilon_{ZG,pPL}$	**0.0569**	*1.618*	$\varepsilon_{ZG,PL}$	**2.3231**	*-0.103*
$\varepsilon_{ZG,pM}$	**0.6575**	*3.544*	$\varepsilon_{ZG,M}$	**-1.8111**	*0.115*
$\varepsilon_{ZG,T}$	**0.0087**	*1.433*	$\varepsilon_{ZG,T}$	**-0.0608**	*0.102*

Table 2 - SAR Elasticities

States with large hubs			*States with no large hubs*		
	Mean	*t-statistics*		*Mean*	*t-statistics*
$\varepsilon_{VC,I}$	**-0.0997**	*-2.143*	$\varepsilon_{VC,I}$	**-0.0599**	*-2.087*
$\varepsilon_{VC,G}$	**-0.3979**	*-2.104*	$\varepsilon_{VC,G}$	**0.3605**	*0.342*
$\varepsilon_{VC,K}$	**-0.3775**	*-21.461*	$\varepsilon_{VC,K}$	**-0.5002**	*-23.556*
$\varepsilon_{VC,Y}$	**1.1673**	*166.072*	$\varepsilon_{VC,Y}$	**1.2579**	*246.906*
$\varepsilon_{VC,T}$	**-0.0122**	*-12.142*	$\varepsilon_{VC,T}$	**-0.0145**	*-5.622*
$\varepsilon_{VC,pNL}$	**0.1386**	*31.065*	$\varepsilon_{VC,NL}$	**0.0819**	*14.256*
$\varepsilon_{VC,pPL}$	**0.1390**	*27.964*	$\varepsilon_{VC,PL}$	**0.1155**	*19.137*
$\varepsilon_{VC,pM}$	**0.7366**	*143.334*	$\varepsilon_{VC,M}$	**0.7588**	*96.016*
$\varepsilon_{ZG.I}$	**0.1276**	*0.487*	$\varepsilon_{ZG.I}$	**-0.0409**	*-0.297*
$\varepsilon_{ZK,I}$	**0.1551**	*3.555*	$\varepsilon_{ZK,I}$	**0.0145**	*3.668*
$\varepsilon_{NL,I}$	**-0.0296**	*-0.769*	$\varepsilon_{NL,I}$	**-0.1433**	*-1.151*
$\varepsilon_{PL,I}$	**0.3165**	*1.487*	$\varepsilon_{PL,I}$	**0.0400**	*0.318*
$\varepsilon_{M,I}$	**-0.2021**	*-2.664*	$\varepsilon_{M,I}$	**-0.0685**	*-2.806*
$\varepsilon_{ZI,G}$	**0.4884**	*0.457*	$\varepsilon_{ZI,G}$	**0.4728**	*0.573*
$\varepsilon_{ZK,G}$	**0.2509**	*2.792*	$\varepsilon_{ZK,G}$	**0.2866**	*2.980*
$\varepsilon_{NL,G}$	**-1.7978**	*-3.473*	$\varepsilon_{NL,G}$	**-4.6237**	*-1.505*
$\varepsilon_{PL,G}$	**-0.9295**	*-2.212*	$\varepsilon_{PL,G}$	**0.9135**	*0.401*
$\varepsilon_{M,G}$	**-0.0324**	*-0.481*	$\varepsilon_{M,G}$	**0.6646**	*0.694*
$\varepsilon_{ZI,K}$	**1.1125**	*2.041*	$\varepsilon_{ZI,K}$	**0.1561**	*1.648*
$\varepsilon_{ZI,pNL}$	**0.0912**	*0.834*	$\varepsilon_{ZI,NL}$	**0.1700**	*1.626*
$\varepsilon_{ZI,pPL}$	**-0.2953**	*-1.012*	$\varepsilon_{ZI,PL}$	**-0.0609**	*-0.283*
$\varepsilon_{ZI,pM}$	**1.2041**	*3.626*	$\varepsilon_{ZI,M}$	**0.8910**	*3.337*
$\varepsilon_{ZI,T}$	**0.0176**	*1.116*	$\varepsilon_{ZI,T}$	**0.0113**	*1.266*
$\varepsilon_{ZG,K}$	**0.4343**	*1.776*	$\varepsilon_{ZG,K}$	**-0.1641**	*-0.338*
$\varepsilon_{ZG,pNL}$	**0.5993**	*2.775*	$\varepsilon_{ZG,NL}$	**-0.0082**	*-0.315*
$\varepsilon_{ZG,pPL}$	**0.3380**	*2.791*	$\varepsilon_{ZG,PL}$	**0.3399**	*0.329*
$\varepsilon_{ZG,pM}$	**0.0628**	*0.581*	$\varepsilon_{ZG,M}$	**0.6684**	*0.526*
$\varepsilon_{ZG,T}$	**0.0126**	*1.531*	$\varepsilon_{ZG,T}$	**-0.0143**	*-0.348*

Table 3 - Selected SAR Elasticities, Large Hubs

Airports Only

Large hubs with > 5% of passengers			***Large hubs with < 5% of passengers***		
	Mean	*t-statistics*		*Mean*	*t-statistics*
$\varepsilon_{VC,I}$	**-0.0245**	*-0.788*	$\varepsilon_{VC,I}$	**-0.1232**	*-2.506*
$\varepsilon_{VC,G}$	**-0.1731**	*-2.630*	$\varepsilon_{VC,G}$	**-0.4681**	*-1.739*
$\varepsilon_{VC,K}$	**-0.3014**	*-18.125*	$\varepsilon_{VC,K}$	**-0.4012**	*-21.465*
$\varepsilon_{VC,Y}$	**1.0098**	*107.065*	$\varepsilon_{VC,Y}$	**1.2166**	*182.812*
$\varepsilon_{VC,T}$	**-0.0118**	*-14.047*	$\varepsilon_{VC,T}$	**-0.0123**	*-10.427*
$\varepsilon_{VC,pNL}$	**0.1264**	*38.486*	$\varepsilon_{VC,NL}$	**0.1424**	*73.799*
$\varepsilon_{VC,pPL}$	**0.1219**	*30.906*	$\varepsilon_{VC,PL}$	**0.1443**	*71.284*
$\varepsilon_{VC,pM}$	**0.7540**	*176.319*	$\varepsilon_{VC,M}$	**0.7311**	*244.372*
$\varepsilon_{NL,I}$	**0.0770**	*0.066*	$\varepsilon_{NL,I}$	**-0.0629**	*-1.089*
$\varepsilon_{PL,I}$	**0.3939**	*1.422*	$\varepsilon_{PL,I}$	**0.2923**	*1.261*
$\varepsilon_{M,I}$	**-0.1174**	*-2.097*	$\varepsilon_{M,I}$	**-0.2285**	*-2.780*
$\varepsilon_{NL,G}$	**-0.6607**	*-3.610*	$\varepsilon_{NL,G}$	**-2.1532**	*-3.192*
$\varepsilon_{PL,G}$	**-0.4972**	*-2.702*	$\varepsilon_{PL,G}$	**-1.0646**	*-1.838*
$\varepsilon_{M,G}$	**-0.0497**	*-1.103*	$\varepsilon_{M,G}$	**-0.0270**	*-0.256*

Table 4 - Primary SAR Elasticities, Airports and Highways

States with large hubs

	Mean	*t-statistics*
$\varepsilon_{VC,I}$	**0.0585**	*1.829*
$\varepsilon_{VC,B}$	**-0.2176**	*-7.141*
$\varepsilon_{VC,G}$	**-0.6629**	*-2.455*
$\varepsilon_{VC,K}$	**-0.3326**	*-17.214*
$\varepsilon_{VC,Y}$	**1.1790**	*163.234*
$\varepsilon_{VC,T}$	**-0.0101**	*-10.730*
$\varepsilon_{VC,pNL}$	**0.1390**	*25.281*
$\varepsilon_{VC,pPL}$	**0.1396**	*22.862*
$\varepsilon_{VC,pM}$	**0.7266**	*122.462*
$\varepsilon_{NL,I}$	**-0.7991**	*-4.496*
$\varepsilon_{M,I}$	**0.3680**	*4.734*
$\varepsilon_{NL,B}$	**0.4205**	*5.114*
$\varepsilon_{M,B}$	**-0.4965**	*-15.935*
$\varepsilon_{NL,G}$	**-2.1482**	*-3.447*
$\varepsilon_{M,G}$	**-0.2731**	*-1.110*

States with no large hubs

	Mean	*t-statistics*
$\varepsilon_{VC,I}$	**0.0009**	*0.201*
$\varepsilon_{VC,B}$	**-0.2658**	*-5.281*
$\varepsilon_{VC,G}$	**-0.9664**	*-1.418*
$\varepsilon_{VC,K}$	**-0.4316**	*-18.305*
$\varepsilon_{VC,Y}$	**1.2531**	*242.916*
$\varepsilon_{VC,T}$	**-0.0110**	*-5.180*
$\varepsilon_{VC,NL}$	**0.0812**	*7.285*
$\varepsilon_{VC,PL}$	**0.1157**	*11.265*
$\varepsilon_{VC,M}$	**0.7380**	*71.076*
$\varepsilon_{NL,I}$	**-0.6500**	*-3.401*
$\varepsilon_{M,I}$	**0.1030**	*3.639*
$\varepsilon_{NL,B}$	**1.4784**	*5.380*
$\varepsilon_{M,B}$	**-0.6188**	*-14.929*
$\varepsilon_{NL,G}$	**-9.4722**	*-2.900*
$\varepsilon_{M,G}$	**-0.2484**	*-0.350*

Large hubs with > 5% of passengers

	Mean	*t-statistics*
$\varepsilon_{VC,I}$	**0.0254**	*0.920*
$\varepsilon_{VC,B}$	**-0.1696**	*-6.427*
$\varepsilon_{VC,G}$	**-0.1969**	*-2.335*
$\varepsilon_{VC,K}$	**-0.2469**	*-14.579*
$\varepsilon_{VC,Y}$	**1.0425**	*105.468*
$\varepsilon_{VC,T}$	**-0.0121**	*-10.758*
$\varepsilon_{VC,pNL}$	**0.1271**	*31.819*
$\varepsilon_{VC,pPL}$	**0.1223**	*25.679*
$\varepsilon_{VC,pM}$	**0.7593**	*153.578*
$\varepsilon_{NL,I}$	**-0.6399**	*-2.800*
$\varepsilon_{M,I}$	**0.2478**	*4.098*
$\varepsilon_{NL,B}$	**0.3578**	*4.952*
$\varepsilon_{M,B}$	**-0.3765**	*-15.376*
$\varepsilon_{NL,G}$	**-0.6580**	*-2.949*
$\varepsilon_{M,G}$	**-0.0824**	*-1.470*

Large hubs with < 5% of passengers

	Mean	*t-statistics*
$\varepsilon_{VC,I}$	**0.0688**	*1.998*
$\varepsilon_{VC,B}$	**-0.2326**	*-7.136*
$\varepsilon_{VC,G}$	**-0.8085**	*-2.325*
$\varepsilon_{VC,K}$	**-0.3594**	*-17.198*
$\varepsilon_{VC,Y}$	**1.2216**	*179.595*
$\varepsilon_{VC,T}$	**-0.0094**	*-9.928*
$\varepsilon_{VC,NL}$	**0.1428**	*41.197*
$\varepsilon_{VC,PL}$	**0.1450**	*40.715*
$\varepsilon_{VC,M}$	**0.7164**	*178.044*
$\varepsilon_{NL,I}$	**-0.8488**	*-4.598*
$\varepsilon_{M,I}$	**0.4056**	*4.796*
$\varepsilon_{NL,B}$	**0.4402**	*4.982*
$\varepsilon_{M,B}$	**-0.5341**	*-15.971*
$\varepsilon_{NL,G}$	**-2.6139**	*-3.427*
$\varepsilon_{M,G}$	**-0.3327**	*-0.938*

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Data Appendix

Labor quantities: The number of workers engaged in production (PL) at operating manufacturing establishments and the number of full-time and part-time employees (TOTAL) on the payrolls of operating manufacturing establishments are from the U.S. Census Bureau's *Annual Survey of Manufactures* (ASM), *Geographic Area Statistics*. Total number of non-production workers (NL) are obtained as the difference between TOTAL and PL.

Wage bills: The ASM reports wages paid to production workers and gross earnings of all employees on the payroll of operating manufacturing establishments. Wage bill for NL is obtained by subtracting the wages paid to PL from the gross earnings of all employees. Non-production wage is obtained by dividing the non-production wage bill by NL. Production wage is obtained by dividing the production wage bill by PL.

Airports capital stock: The perpetual inventory method was applied to data on state level expenditures on air transportation (airports) from the Census Bureau's "Government Finances" (various years),with the initial capital stock (1982) values for each state taken as the average of the first three years of spending data for that state times the inverse of the depreciation rate. The annual depreciation rate of .0152 was taken from the Bureau of Economic Analysis' publication "Fixed Reproducible Tangible Wealth, 1925-94" and is their depreciation rate for "Government nonresidnetial structures, Federal, State, Local nonbuildings, other." The investment deflator was from the 2000 Economic Report of the President, Table B-7, for "Government consumption expenditures and gross investment, state and local."

Highway capital stock: The perpetual inventory technique was applied to state-level public infrastructure investment data to generate highway capital stock estimates. Following Eberts, Park and Dalenberg (1986), discards were assumed to follow a truncated normal distribution, with the truncation occurring at one half the average life and one and one half times the average life. The Federal Highway Administration's composite price index was used to deflate the capital and maintenance outlay series.

Private capital stock: the private capital stock data were constructed for each state using the perpetual inventory method on state level new capital expenditures data from the ASM, with the initial capital stock (1982) values taken from Morrison and Schwartz (1996). Depreciation rates for capital equipment are from the Bureau of Labor Statistics, Office of Productivity and Technology. The investment deflator was obtained from the Bureau of Labor Statistics and is their input price deflator for total manufacturing (SIC 20-39) capital services. The price of capital is obtained as $(i_t + d_t)q_{K,t}[1/(1\text{-}taxrate_t)]$, where d_t is the depreciation rate, i_t is the Moody's Baa corporate bond rate (obtained from the Economic Report of the President), $q_{K,t}$ is the investment deflator, and $taxrate_t$ is the corporate tax rate (obtained from the Office of Multifactor Productivity, Bureau of Labor Statistics).

Materials: The ASM reports direct charges actually paid or payable for items consumed or put into production during the year. The quantity of materials is obtained by deflating these charges by the ratio of nominal Gross Domestic Product to real Gross Domestic Product as reported on the Bureau of Economic Analysis website. This deflator is also used as the price of materials.

Output: Value of shipments reported in the ASM were deflated by manufacturing Gross State Product deflators for each state (provided by Jennifer Fuller and Rachel Crampton of DRI).

Spatial weights: These were calculated by giving weight to all states classified as having at least one "large air traffic hub" as defined by the Federal Aviation Administration's Statistical Handbook of Aviation, and zero weight to all other states that are not classified as having at least one "large air traffic hub". The relative importance of each state with a large hub on each of the 48 continental states was determined by the share of person trips originating in the particular state and terminating in the state with a large hub airport. Data on interstate person trips by air were provided by the Bureau of Transportation Statistics, and were generated from the 1995 American Travel Survey.

Footnotes

[1] Since airports are congestable, they cannot be considered pure public goods.

[1] The FAA considers an airport a "large hub" if it has at least 1 percent of the country's enplanements of passengers. We define a "large hub state" as a state that has at least one large hub located within its borders.

[1] Such disruptions were highlighted in a *Wall Street Journal* Article from September 13, 2001, "Flight Ban Disrupts U.S. Economy Reliant on Last-Minute Shipping" (Thurm, Brooks and Ball).

[1] We carry out our analysis at the state level at least in part due to the availability of production data at the state level. Although it is possible to consider a more disaggregated sample of airports, since expenditure data are available for individual airports, it is not possible to consistently partition the production data. In addition, our data on person-trips are at the state level – from state of origin to state of destination.

[1] They find a positive effect on own-states' choices of "neighboring" states expenditure patterns, including those for highways

[1] See the data appendix for more details about the data used for estimation of the model.

[1] Note, however, that we could potentially represent long run behavior by solving for the implied level of K associated with the steady state equilibrium condition $p_K=-\partial VC/\partial K$, where p_K is the market price of K and = $-\partial VC/\partial K = Z_K K$ is the shadow value of K.

[1] This is consistent with a linear demand curve.

[1] This adaptation also accommodates to some extent any endogeneity in the output price that may arise from the level of aggregation of the data.

[1] In our discussion of results below we will emphasize the proportional elasticity measures, both because their interpretation is more clear (like any other elasticity they are unit-less), and because their sign and statistical equivalence is equivalent to those for the shadow value.

[1] To separately identify patterns for the largest "large hubs", we split the large hub states sample into two subsamples, representing large hub states with greater (>) or less (<) than 5 percent of enplaned passengers. This breakdown allows us to explore whether smaller hub states such as MA have different elasticities than a state such as TX, which could distort the standard errors and t-statistics for the subsample). Since there are only 5 states that are in the >5% category (for 1996 these were CA, FL, GA, IL and TX), and 14 in the <5% category, the overall averages are more similar to those for the latter category.

[1] See footnote 1.

[1] All the Z_I elasticities for the Base case are quite volatile (high standard errors), however, as well as being of perverse signs compared not only to the SAR case but also to their symmetric elasticities (such as $\varepsilon_{ZG,I}$ and $\varepsilon_{ZI,G}$, which should provide similar information, but may not if the fitted shadow values are not robust). This suggests that this specification does not appropriately represent horizontal linkages in the stochastic specification. It also may simply imply that there is less robustness, and thus more outliers, in the Base case, since the perverse $\varepsilon_{ZI,G}$ estimate for this case is driven by several large outlier observations, most of which are for the state of Florida, that pull the average into the negative range.

[1] For the Base specification the pattern for these estimates is more like that for NL, and the $\varepsilon_{ZG,M}$ estimate is also much larger. These differences imply that the recognition of horizontal linkages, via the SAR adaptation, is particularly important for the representation of freight costs.

[1] The symmetry of the second order derivatives does not mean that the elasticities are necessarily equivalent in magnitude or significance ($\varepsilon_{NL,I}$ is insignificant but $\varepsilon_{I,NL}$ is significant), because the shadow value elasticities are evaluated at the fitted shadow values, and thus depend on coefficients and standard errors embodied in these estimates as well as the derivatives themselves.

[1] As alluded to above, the Z_I elasticities are very different than the demand elasticities with respect to I on average for large hubs and the Base specification, even given the expectation of symmetry. This results from the greater volatility of these estimates, which is due to the less

robust estimates of I as compared to G effects in this model. The Z_I elasticities are therefore less definitive for the Base case for large hubs than are the Z_G elasticities. The reverse is true for the Z_G elasticities for non-hub states and the Base specification; they are more volatile and thus less definitive. This provides one indication that the SAR specification is preferable, even though most primary results do not differ substantively.

[1] The reversed signs for the estimates and t-statistics for the Base run $\varepsilon_{VC,G}$ and $\varepsilon_{ZG,I}$ measures again result from the lack of robustness of this specification; evaluated at the mean of the data these estimates are the reversed in sign from the mean of the estimated elasticities across the sample. However, their very low significance levels indicate that the deviation of these measures from zero is simply not well defined.

[1] We focus exclusively on this model, and on the primary cost and input demand elasticities, due to the evidence of the desirability of the SAR adaptation and of the lack of robustness of the shadow value measures, from our airport-only specifications.

Appendix Table A1 - Parameters and t-statistics

Base, Airports Only			*SAR, Airports Only*			*SAR, Airports and Highways*		
Paramete	Estimate	t-statistic	Paramete	Estimate	t-statistic	Paramete	Estimate	t-statistic
$\alpha_{NL,PL}$	**-2.36E+03**	*-3.542*	$\alpha_{NL,PL}$	**-1.99E+03**	*-2.875*	$\alpha_{NL,PL}$	**-3.11E+03**	*-4.933*
$\alpha_{PL,M}$	**4.70E+03**	*3.962*	$\alpha_{PL,M}$	**3.75E+03**	*3.002*	$\alpha_{PL,M}$	**5.20E+03**	*4.429*
$\alpha_{PL,M}$	**9.68E+03**	*8.162*	$\alpha_{PL,M}$	**9.33E+03**	*7.489*	$\alpha_{PL,M}$	**1.14E+04**	*10.375*
$\delta_{NL,Y}$	**1.75E-01**	*29.708*	$\delta_{NL,Y}$	**1.79E-01**	*40.632*	$\delta_{NL,B}$	**7.88E-02**	*1.202*
$\delta_{PL,Y}$	**2.12E-01**	*37.256*	$\delta_{PL,Y}$	**2.16E-01**	*53.195*	$\delta_{PL,B}$	**1.18E-01**	*1.813*
$\delta_{M,Y}$	**7.59E-01**	*86.720*	$\delta_{M,Y}$	**7.68E-01**	*98.379*	$\delta_{M,B}$	**-9.41E-01**	*-11.601*
$\delta_{NL,T}$	**7.34E+01**	*1.603*	$\delta_{NL,T}$	**8.10E+01**	*1.817*	$\delta_{NL,Y}$	**1.68E-01**	*36.182*
$\delta_{PL,T}$	**4.40E+01**	*0.969*	$\delta_{PL,T}$	**6.90E+01**	*1.570*	$\delta_{PL,Y}$	**2.06E-01**	*50.724*
$\delta_{M,T}$	**5.78E+00**	*0.087*	$\delta_{M,T}$	**7.92E+00**	*0.113*	$\delta_{M,Y}$	**7.83E-01**	*103.907*
$\delta_{NL,I}$	**1.12E-04**	*0.716*	$\delta_{NL,I}$	**1.01E-05**	*0.066*	$\delta_{NL,T}$	**9.92E+01**	*2.366*
$\delta_{PL,I}$	**2.74E-04**	*1.756*	$\delta_{PL,I}$	**1.62E-04**	*1.070*	$\delta_{PL,T}$	**8.68E+01**	*2.115*
$\delta_{M,I}$	**-3.36E-04**	*-1.449*	$\delta_{M,I}$	**-4.21E-04**	*-1.814*	$\delta_{M,T}$	**6.41E+01**	*1.014*
$\delta_{NL,G}$	**-5.81E-04**	*-1.410*	$\delta_{NL,G}$	**-8.66E-04**	*-2.142*	$\delta_{NL,I}$	**-1.27E-04**	*-0.620*
$\delta_{PL,G}$	**-3.25E-04**	*-0.794*	$\delta_{PL,G}$	**-6.25E-04**	*-1.559*	$\delta_{PL,I}$	**-2.85E-05**	*-0.141*
$\delta_{M,G}$	**-9.11E-04**	*-1.704*	$\delta_{M,G}$	**-4.14E-04**	*-0.764*	$\delta_{M,I}$	**1.06E-03**	*3.962*
$\delta_{NL,K}$	**8.57E-02**	*1.885*	$\delta_{NL,K}$	**1.04E-01**	*2.446*	$\delta_{NL,G}$	**-7.82E-04**	*-2.080*
$\delta_{PL,K}$	**-4.18E-02**	*-0.925*	$\delta_{PL,K}$	**-3.13E-02**	*-0.736*	$\delta_{PL,G}$	**-5.31E-04**	*-1.434*
$\delta_{M,K}$	**-1.04E+00**	*-18.025*	$\delta_{M,K}$	**-1.04E+00**	*-19.022*	$\delta_{M,G}$	**-5.52E-04**	*-1.125*
$\delta_{Y,Y}$	**-3.98E-07**	*-11.466*	$\delta_{Y,Y}$	**-3.72E-07**	*-11.314*	$\delta_{NL,K}$	**1.95E-02**	*0.409*
$\delta_{I,I}$	**2.24E-12**	*0.988*	$\delta_{I,I}$	**3.34E-12**	*1.535*	$\delta_{PL,K}$	**-1.34E-01**	*-2.839*
$\delta_{K,K}$	**1.64E-06**	*4.021*	$\delta_{K,K}$	**1.45E-06**	*3.687*	$\delta_{M,K}$	**-8.54E-01**	*-14.771*
$\delta_{G,G}$	**1.69E-11**	*1.708*	$\delta_{G,G}$	**1.84E-11**	*1.973*	$\delta_{B,B}$	**5.73E-06**	*5.218*
$\delta_{Y,G}$	**3.68E-10**	*1.604*	$\delta_{Y,G}$	**3.17E-11**	*0.992*	$\delta_{Y,Y}$	**-3.34E-07**	*-9.636*

Appendix Table A1(Continued) - Parameters and t-statistics

Base, Airports Only

Paramete	Estimate	t-statistic
$\delta_{Y,K}$	**4.26E-07**	*2.118*
$\delta_{G,K}$	**-6.66E-09**	*-3.044*
$\delta_{Y,I}$	**5.79E-10**	*3.963*
$\delta_{G,I}$	**-1.18E-11**	*-1.111*
$\delta_{K,I}$	**-3.88E-09**	*-4.247*
$\delta_{Y,T}$	**-2.84E-03**	*-13.205*
$\delta_{G,T}$	**-2.95E-06**	*-1.344*
$\delta_{I,T}$	**-1.28E-06**	*-0.843*
$\delta_{K,T}$	**-1.02E-04**	*-0.122*
λ_{Y}	**-1.66E-06**	*-32.018*

SAR, Airports Only

Paramete	Estimate	t-statistic
$\delta_{Y,K}$	**3.80E-07**	*1.979*
$\delta_{G,K}$	**-5.89E-09**	*-2.898*
$\delta_{Y,I}$	**4.79E-10**	*3.523*
$\delta_{G,I}$	**-4.96E-12**	*-0.488*
$\delta_{K,I}$	**-3.23E-09**	*-3.675*
$\delta_{Y,T}$	**-2.79E-03**	*-12.811*
$\delta_{G,T}$	**-3.27E-06**	*-1.582*
$\delta_{I,T}$	**-2.40E-06**	*-1.626*
$\delta_{K,T}$	**-6.85E-04**	*-0.815*
ρ	**2.72E-01**	*9.364*
ρ_{NL}	**2.73E-01**	*7.924*
ρ_{PL}	**2.36E-01**	*6.608*
ρ_{M}	**2.60E-01**	*8.703*
λ_{Y}	**-1.56E-06**	*-30.503*

SAR, Airports and Highways

Paramete	Estimate	t-statistic
$\delta_{I,I}$	**-5.72E-12**	*-1.934*
$\delta_{K,K}$	**2.22E-06**	*5.016*
$\delta_{G,G}$	**1.11E-11**	*1.280*
$\delta_{B,Y}$	**-7.80E-07**	*-3.747*
$\delta_{B,G}$	**5.82E-09**	*1.983*
$\delta_{B,K}$	**-4.93E-06**	*-4.464*
$\delta_{Y,G}$	**-3.16E-11**	*-0.310*
$\delta_{Y,K}$	**5.18E-07**	*2.700*
$\delta_{G,K}$	**-3.10E-09**	*-1.328*
$\delta_{B,I}$	**2.77E-10**	*0.244*
$\delta_{Y,I}$	**1.23E-09**	*6.140*
$\delta_{G,I}$	**-1.51E-11**	*-1.080*
$\delta_{K,I}$	**3.77E-10**	*0.343*
$\delta_{B,T}$	**-7.08E-03**	*-5.697*
$\delta_{Y,T}$	**-2.31E-03**	*-10.715*
$\delta_{G,T}$	**-2.80E-06**	*-1.410*
$\delta_{I,T}$	**7.78E-10**	*0.000*
$\delta_{K,T}$	**1.06E-03**	*1.125*
ρ	**2.73E-01**	*10.706*
ρ_{NL}	**2.82E-01**	*8.744*
ρ_{PL}	**2.59E-01**	*7.803*
ρ_{M}	**2.63E-01**	*9.868*
λ_{Y}	**-1.50E-06**	*-29.112*