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Spatial Impact of Transportation Infrastructure: A Spatial Econometric CGE Approach

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Abstract

Transportation infrastructure plays an important role in regional economic development both in the stimulation of growth and as a response to output expansion. However, measuring these effects quantitatively has been a challenge due to the complicated impact mechanisms of transportation infrastructure. This complication is due to two reasons: first, regional impacts of transportation infrastructure are achieved through a mechanism that involves both a demand influence through the variation of transportation price and a supply influence implemented through the variation of transportation cost; second, impacts of transportation are usually evaluated in a regional context where the presence of unobserved local or regional variables may give rise to spatial autocorrelation. As a result, impact analysis may become biased and spurious. This study develops a new method called Spatial Econometric Computable General Equilibrium (SECGE) model, which integrates both spatial econometrics with equilibrium modeling techniques to improve the effectiveness of impact analysis on transportation infrastructure.

This study differs from previous studies in the following three aspects: First, through a spatial autocorrelation test, the presence of spatial dependence is observed and confirmed among the elasticities of factor substitution in the US. To deal with spatial dependence, spatial panel econometric techniques are introduced to estimate the elasticity of factor substitution of different sectors for the Constant Elasticity of Substitution (CES) production function with consideration of spatial direct and indirect effects.

Second, transportation impact analysis is conducted under different scenarios of general equilibrium frameworks. Unlike partial equilibrium analysis, general equilibrium analysis allows researchers to obtain much comprehensive understanding of transportation infrastructure's impacts given its consideration of interactions between the demand and the supply. The study validates the method by comparing traditional equilibrium simulation without controlling for spatial dependence and the new equilibrium simulation with consideration of spatial dependence. The comparison allows researchers to justify spatial impacts of transportation infrastructure.

Third, the study is conducted with a focus on multiple modes of transportation that includes road, rail, air, transit, pipeline and water transportation. Unlike a unimodal perspective, the perspective of multiple modes is essential to achieve a comprehensive understanding of the transportation infrastructure systems. It also enables us to compare impacts between different types of infrastructures and understand the relative importance of transportation investment by mode.

The study confirms that the US highway and streets plays a dominant role among all transportation infrastructure systems in economic development while public transit and passenger transportation only plays the least important role among the systems. The result general equilibrium analysis also shows a difference between using spatial econometric estimates

and traditional OLS estimates. Although the differences are relatively small in this aggregate case study, implications for more sensitive disaggregated regional models are clear.

Key words: Computable general equilibrium, Spatial econometrics, Spatial impact, Transportation infrastructure

JEL classification: C23, R11, R42, R53

1. Introduction

Transportation infrastructure plays an important role in regional economic development both in the stimulation of growth and as a response to output expansion. However, measuring these effects quantitatively has been a challenge due to the complicated impact mechanisms of transportation infrastructure. This complication is due to two reasons: first, regional impacts of transportation infrastructure are achieved through a mechanism that involves both a demand influence through the variation of transportation price and a supply influence implemented through the variation of transportation cost; second, impacts of transportation are usually evaluated in a regional context where the presence of unobserved local or regional variables may give rise to spatial autocorrelation. As a result, impact analysis may become biased and spurious. This study develops a new method called Spatial Econometric Computable General Equilibrium (SECGE) model, which integrates both spatial econometrics with equilibrium modeling techniques to improve the effectiveness of impact analysis on transportation infrastructure.

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The rest of this paper is organized as follow. Section 2 lays a theoretical foundation for the study from relevant literature. Section 3 discusses the CGE structure. The modeling procedure is discussed in section 4. Section 5 introduces the data and section 6 presents simulation results, which is followed by a conclusion in section 7.

2. Literature Review

The theories regarding economic impacts of transportation infrastructure can be reviewed from three fields based on the different analytical approaches: traditional econometric approach,

spatial perspective and general equilibrium approach. Meanwhile, the necessity for a multimodal investigation is also reviewed.

Traditional Theory

Since a series of papers by Aschauer (1989; 1990; 1994) argue that enhancing public infrastructure expenditure facilitate regions to achieve their economic potentials, a large number of studies on public infrastructure were conducted following a neo-classical approach using various forms of aggregate production functions (Gramlich, 1994; 2001; Harmatuck, 1996; Nadiri & Mamuneas, 1996; Fernald, 1999; Bhatta & Drennan, 2003; Boarnet, 1997; Boarnet & Haughwout, 2000; Mattoon, 2002; Duffy-Deno & Eberts, 1991). These studies have been subjected to a variety of criticisms (Gramlich, 1994).

Spatial Perspective

One of the criticisms is that these studies did not consider spatial interactions among units across geographic locations. Instead these studies normally assumed spatial independence among their research units. Spatial econometric theory indicates that estimation outcomes vary significantly if spatial dependence is considered in regional analysis (LeSage & Pace, 2009). This is because regional performance is influenced by a region's own as well as other regions' performance. Munnell (1992) indicated that the estimated impact of public capital becomes smaller as the geographic focus of study narrows. She believed that this is because of the effects of leakages from an infrastructure investment could not be captured at a small geographic area. Although this hypothesis may not be entirely accurate, as indicated by Boarnet (1998), it does suggest that the spatial dimension has influence on estimation and should not be neglected.

LeSage (1999) emphasized that traditional econometrics has largely ignored the spatial dimension of sample data. When data has geographic information, the issue of spatial dependence between observations violates the Gauss-Markov assumptions. Without considering this issue, estimation results may be statistically biased.

Thanks to the development of spatial econometric techniques by Paelinck & Klaassen (1979); Cliff & Ord (1981); Anselin (1988); LeSage & Pace (2009), Elhorst (2010) and many other spatial scientists, a number of empirical spatial analytical methods were developed. One of the dominant functions is to allow for measuring spatial spillover effect. This effect refers to the situation in which the input in one sector or region influences changes in neighboring local economies through trade linkages and market relationships (Bo *et al.*, 2010). Transportation infrastructure may have spillover effects on regional economic growth because the impacts generated from infrastructure are not confined to that specific region (Moreno & López-Bazo, 2007). To test the hypothesis empirically, different spatial models were adopted (Holtz-Eakin & Schwartz, 1995; Kelejian & Robinson, 1997; Cohen & Morrison, 2003a; 2004).

Reviews of the existing literature regarding the spatial impacts of transportation infrastructure (Boarnet, 1998; Holtz-Eakin & Schwartz, 1995; Kelejian & Robinson, 1997; Ozbay *et al.*, 2007; Moreno & López-Bazo, 2007; Cohen & Morrison, 2003; 2004; Cohen, 2007; Mohammad, 2009)

show that the conclusions are not consistent given the fact that different data, methods, regions and periods were used. Despite the development of spatial econometric techniques enabling scholars to investigate spillover effects of infrastructures, most studies only considered a certain types of spatial dependence alone as either spatial lag or spatial error. Without an adequate interpretation of the reasons that why a specific spatial model is used, it is likely that results of these studies may have estimation bias due to the neglect of any specific spatial dependence.

General Equilibrium

Most of the aforementioned impact analyses are conducted under the partial equilibrium framework. The relationships between economic output and infrastructure are normally evaluated from the supply side only by assuming a constant demand for infrastructure during the research period. As a matter of fact, the outcome of impact evaluation may be incomplete since impacts caused from the change in demand are not considered. For instance, transportation's impact on travelers' welfare measured by levels of utility cannot be measured under the partial equilibrium analysis. As a result, to obtain a comprehensive evaluation of infrastructure, a general equilibrium framework is required.

CGE model enables impact analysis with consideration of both demand and supply. The theoretical framework relies on the Walras-Arrow-Debreu theory of general equilibrium, with modern modifications and extensions allowing for imperfect markets (Bröcker, 2004). Because CGE provides a clear linkage between the microeconomic structure and the macroeconomic environment, the model can be used to describe the interrelationship among different industrial sectors and markets. More importantly, it can be used to assess both direct and indirect effects from the change of public policy on various economic variables such as output, employment, prices, income and welfare.

A CGE model usually consists of producer, consumer, government, and foreign economy. The fundamental assumptions on producers and consumers in CGE are that producers seek profit maximization while consumers seek utility maximization both within constraints of their resources. The process of production can be illustrated either by a Cobb-Douglas form or a CES form. Government plays dual roles in CGE. On the one hand as a policy maker, the relative policy variable is introduced in CGE as an exogenous factor impacting the economy. On the other hand as a consumer, government revenue that comes from tax and tariff is spent on a variety of public expenditure such as public affairs, intergovernmental transfers and subsidies. As far as international trade is concerned, the distributional process between the domestic market and exports is illustrated by a constant elasticity transformation (CET) while the process between the domestic market and imports is normally illustrated by an Armington function (Bröcker, 2004).

The applications of CGE in evaluating impacts of transportation infrastructure vary substantially. Impacts can be evaluated differently depending on specific research needs. Due to the fact that most transportation infrastructure achieves economic benefits through increasing accessibility and reducing transport costs, CGE analysis in transportation are usually constructed in a multi-

regional structure. Miyagi (2006) evaluated economic impact in relation to the accessibility change using a spatial CGE (SCGE). In his model, economic impact was measured through reduction of congestion due to the specialized infrastructure investment. The rate of return on transportation investment to reduce congestion was estimated from both traditional production function analysis and a so-called “free approach” using neural network analysis (Miyagi, 2006).

Haddad and Hewings (2005) assessed economic effects of changes in Brazilian road transportation policy by applying a multiregional CGE model. By introducing non-constant returns and non-iceberg transportation costs, their model found asymmetric impacts of transportation investment on a spatial economy in Brazil. *CGEurope* is another SCGE model developed by Bröcker (1998). The model is primarily used for spatial analysis on the distribution of welfare effects linked to changes in accessibility within and between regions (Bröcker *et al.*, 2001).

Pingo was another static CGE model used to forecast regional and interregional freight transportation (Ivanova, 2003). The model contains 19 regions with 10 economic sectors. Different to *Pingo*, *MONASH* model is widely used multiregional and multi-sectoral dynamic CGE model (Dixon and Rimmer, 2000). It allows for different choices in the level of sectoral and regional disaggregation. Transportation sectors in this model are treated as marginal sectors where the costs are imposed on the purchase price of goods and tradables.

Unlike the multiregional CGE model, *IFPRI* model is single regional CGE model which treats transportation cost as a type of transaction costs in trade (Löfgren, 2002). The model allows for assessing impacts through transaction cost variation. Generally speaking, transportation costs are treated as a part of trade in these CGE models. Some model transportation costs without an explicit representation of transportation sectors, such as *CGEurope*. In other models such as *Pingo*, *MONASH* and *IFPRI*, transportation costs are explicitly included to the price of final goods and services.

Unimodal vs. Multimodal

Another common feature of infrastructure impact studies is that many of them investigate transportation from a unimodal perspective. Some focus on public capital or transportation infrastructure in general (Duffy-Deno & Eberts, 1991; Berndt & Hansson, 1992; Kelejian and Robinson, 1997) while others only focus on a specific mode such as highways, airports or ports (Holtz-Eakin & Schwartz, 1995; Cohen & Morrison Paul, 2003; 2004; Cohen 2007; Ozbay *et al.*, 2007). Very few studies investigate the issue from a comparative and multimodal perspective (Addersson *et al.*, 1990; Blum, 1982; Cantos *et al.*, 2005). It should be noted that these multimodal assessments are conducted under partial equilibrium framework, none of them was conducted from a multimodal general equilibrium perspective.

Summary

Literature review indicates that although spatial econometrics and CGE have been well established, there is no study that integrates the two methods together to improve the validity of

transportation impact analysis, not to mention allowing for transportation modal comparative analysis under such an integrated framework. The lack of a multimodal perspective limits our understandings on spatial impacts of transportation infrastructure, particularly in counties like the US where multiple modes of infrastructure are comprehensively, competitively and maturely established. To fill the gaps in the literature, this study is conducted to answer the following questions:

- Question 1: how does public transportation infrastructure contribute to economic outputs in the US?
- Question 2: how do such impacts vary among different modes of transportation?
- Question 3: does the impact differ when comparing the estimation with and without consideration of spatial dependence in CGE?

3. CGE Structure

The modeling structure of the study adopts an edited version of a single country CGE model in the tradition of the *IFPRI* standard model, or the Dervis-DeMelo-Robinson tradition developed by McDonald (2005). The model is an open economy including 13 commodities, 13 activities, 9 factors, 1 household and 1 rest of world account (ROW). Trade is modeled under the Armington assumption (Armington, 1969) and the assumption of imperfect substitution between domestically produced and imported goods, represented by a one level CES function. In addition, exports are assumed to be imperfect substitutes for domestically produced goods and this is represented by a one level CET function. The small country assumption is relaxed with the export demand function. The model allows for non-traded, non-produced and non-consumed domestic goods. The main model structures are discussed in details from different institutional blocks as described below.

Consumer

Consumer maximizes utility in a Cobb-Douglas form with constant returns to scale subject to a budget constraint. The household commodity consumption can be represented as:

$$PQD_i \cdot QCD_i = \sum_{k=1}^h Comhav_{i,k} \cdot HEXP_k \quad (1)$$

where

PQD_i : The purchase price of composite commodity i ;

QCD_i : Household consumption by commodity i ;

$Comhav_{i,k}$: Household consumption shares of commodity i in household k ;

$HEXP_h$: Household consumption expenditure in household h .

Household income and household expenditure are denoted respectively as:

$$YH_h = \sum_{k=1}^f hvash_{h,k} \cdot YF_k + hwor_h \cdot ER \quad (2)$$

$$HEXP_h = YH_h \cdot (1 - tyh_h) \cdot (1 - SAdj \cdot kaphsh_h) \quad (3)$$

where

YH_h : Household income of household h ;

$h\text{vash}_{h,f}$: Share of income from factor f to household h ;

YF_k : Income to factor f ;

$hwor_h$: Transfers to household from ROW (constant in foreign currency);

ER: Exchange rate (domestic currency per world unit);

tyh_h : Direct tax rate on household h ;

SADJ: Savings rate scaling factor. The value assumes 1 in this study;

$kaphsh_h$: Shares of household income saved after taxes of household h .

Producer

There are 13 firms that produce one commodity each, maximize their profits and face a nested production function, with capital, labor and inter-industry flows as factors of production. A two-stage production structure applies for producers in all sectors (See Figure 1). The top level assumes Leontief technology with value added and intermediate inputs as factors of production while the second level assumes value added CES technology with capital, labor and other endowments as factors of production, and intermediate inputs a Leontief technology with the commodities of all firms as factors of production. The CES multi-factor production function for activity is represented as:

$$QX_a = adx_a \cdot \left(\sum_{k=1}^f \text{deltax}_{k,a} \cdot FD_{k,a}^{-\text{rhox}_a} \right)^{-\frac{1}{\text{rhox}_a}} \quad (4)$$

Where

QX_a : Domestic production by activity a ;

adx_a : Shift parameter for CES production functions for QX ;

$\text{deltax}_{f,a}$: Share parameters for CES production functions for QX ;

$FD_{f,a}$: Demand for factor f by activity a ;

rhox_a : Elasticity parameter for CES production functions for QX .

The Intermediate input demand by commodity function and the domestic commodity production can be denoted respectively as:

$$QINTD_c = \sum_{k=1}^a ioqx_{c,k} \cdot QX_k \quad (5)$$

$$COMOUT_c = \sum_{k=1}^a ioqxcq_{c,k} \cdot QX_k \quad (6)$$

Where

$QINTD_c$: Demand for intermediate inputs by commodity;

COMOUT_c: Domestic commodity production;

ioqx_{c,k}: Use matrix coefficients;

ioxcqx_{a,c}: Share of commodity c in output by activity a.

Transportation services provided by transportation sectors are treated as intermediates in non-transportation sectors through the Leontief technology function. The value is added to the final product together with inputs from the CES production function. In transportation sectors of truck, air, transit and water, the factor inputs of the CES production function includes labor, private and public capital. The public transportation capital accounts are set to zero for the non-transportation sectors and the two private transportation sectors rail and pipeline. The elasticities of factor substitution are assumed consistent for all factors substitution. It is exogenously estimated through both ordinary least squares (OLS) regression models and spatial econometric models.

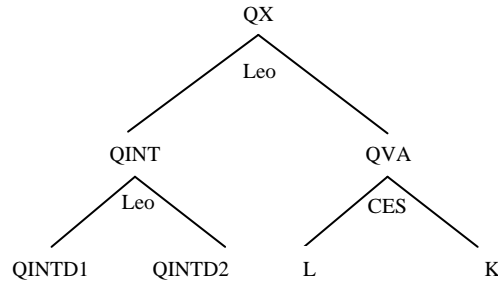


Figure 1 Nested Production Structure

Government

Government block includes functions representing government taxes and government income and expenditure. Five types of taxes are included in the model: tariff, export tax, sales tax, indirect tax and income tax from non-government institutions. The functions of different taxes revenue are denoted respectively as below:

$$MTAX = \sum_{k=1}^c tm_k \cdot pwm_k \cdot ER \cdot QM_k \quad (7)$$

$$ETAX = \sum_{k=1}^c te_k \cdot PWE_k \cdot ER \cdot QE_k \quad (8)$$

$$STAX = \sum_{k=1}^c ts_k \cdot PQS_k \cdot (QINTD_k + QCD_k + QGD_k + QINVD_k) \quad (9)$$

$$ITAX = \sum_{k=1}^a tx_k \cdot PX_k \cdot QX_k \quad (10)$$

$$DTAX = \sum_{k=1}^h tyh_k \cdot YH_k \quad (11)$$

Where

MTAX: Tariff revenue;

ETAX: Export tax revenue;

STAX: Sales tax revenue;

ITAX: Indirect tax revenue;

DTAX: Income tax revenue from non-government institutions;

tm_c : Tariff rates on commodity c ;

te_c : Export tax rate by commodity c ;

pwm_c : World price of imports in dollars on commodity c ;

PWE_c : World price of exports in dollars;

QM_c : Imports of commodity c ;

QE_c : Domestic output exported by commodity c ;

ts_c : Sales tax rates;

PQS_c : Supply price of composite commodity c ;

QGD_c : Government consumption demand by commodity c ;

The functions of government income, consumption and expenditure are denoted as the following equations respectively:

$$YG = MTAX + ETAX + STAX + ITAX + DTAX + (govwor \cdot ER) \quad (12)$$

$$QGD_c = QGDADJ \cdot qgdconst_c \quad (13)$$

$$EG = \sum_{k=1}^c QGD_k \cdot PQD_k \quad (14)$$

where

YG, QGD and EG denote government income, government commodity consumption and government expenditure respectively;

govwor: Transfers to government from world (constant in foreign currency);

QGDADJ: Government consumption demand scaling factor. The value assumes 1 in this study;

$qgdconst_c$: Government demand volume of commodity c ;

Investment and saving

Investment and saving block includes the following three equations:

$$TOTSAV = \sum_{k=1}^h YH_k \cdot (1 - tyh_k) \cdot SADJ \cdot kaphsh_k + KAPGOV + (KAPWOR \cdot ER) \quad (15)$$

$$QINVD_c = IADJ \cdot qinvdconst_c \quad (16)$$

$$INVEST = \sum_{k=1}^c PQD_k \cdot QINVD_k \quad (17)$$

where

TOTSAV: Total savings;

KAPGOV: Government Savings;

KAPWOR: Current account balance;

IADJ: Investment scaling factor. The value assumes 1 in this study;

qinvdconst_c: Investment demand volume.

Market clearing conditions

Market clearing conditions include equilibriums in factor market, commodity market, government, foreign trade, and savings and investment. These conditions can be represented in the following equations:

$$FS_f = \sum_{k=1}^a FD_{f,k} \quad (18)$$

$$QQ_c = QINTD_c + QCD_c + QGD_c + QINVD_c \quad (19)$$

$$KAPGOV = YG - EG \quad (20)$$

$$KAPWOR = \sum_{k=1}^{cm} PWM_k \cdot QM_{cm} + \frac{\sum_{j=1}^f YFWOR_j}{ER} - \sum_{i=1}^{ce} PWE_i \cdot QE_i - \sum_{l=1}^h hwor_l - govwor - \sum_{m=1}^f factwor_m \quad (21)$$

$$TOTSAV = INVEST + WALRAS \quad (22)$$

where

FS_f: Supply of factor f;

QQ_c: Supply of composite commodity c;

YFWOR_f: Foreign factor income;

factwor_m: Factor payments from ROW (constant in foreign currency);

INVEST: Total investment expenditure;

WALRAS: Slack variable for Walras's Law.

4. Estimation Procedure

The estimation procedure of the study is carried out sequentially in the following four steps.

Step 1 Spatial Autocorrelation Test

The first step is to diagnose spatial autocorrelation. The spatial autocorrelation, which is measured by values of Moran's I, is tested for the capital-labor ratio variable and wage-rental ratio variable using *GeoDa*, developed by the Spatial Analysis Laboratory at the University of Illinois at Urbana-Champaign (Anselin *et al.*, 2006). The universal global Moran's I is defined as (Moran, 1950; Cliff and Ord, 1981):

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n w_{ij}} \cdot \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^n w_{ij} (x_i - \bar{x})^2} \quad (23)$$

where n is the number of states, which in this case equals to 49 for most sectors except the sectors of pipeline and water transportation, which only contain 48 regions and 36 regions

respectively. x and \bar{x} denote the specific state and the mean of x respectively. w_{ij} is the spatial weight matrix, representing the spatial relationship between region i and j . The spatial relationship in this study is defined as being contiguous to each other. Thus the spatial weight matrix is generated using the Queen Contiguity method.

Table 1 Moran's I Value of the Selected Years

Sector	1997		2004		2011		Obs
	Ln(KL)	Ln(wr)	Ln(KL)	Ln(wr)	Ln(KL)	Ln(wr)	
Agriculture	0.14*	0.45***	0.20*	0.33**	0.25**	0.36***	49
Manufacture	0.40***	0.42***	0.31**	0.34***	0.23**	0.25**	49
Utility&Construction	0.43**	0.38***	0.35***	0.36***	0.29**	0.36***	49
Trade	0.21*	0.24**	0.22**	0.26**	0.07	0.12	49
Truck	0.48***	0.46***	0.58***	0.49***	0.22**	0.01	49
Rail	0.59***	0.59***	0.26**	0.27***	-0.51***	-0.50***	49
Air	0.01	0.01	0.07	0.07	0.10	0.10	49
Transit	-0.10	0.06	0.19**	0.17*	0.20**	0.14*	49
Water	0.13	0.07	-0.12	-0.06	-0.05	-0.07	36
Pipeline	-0.06	0.07	-0.12	-0.16*	-0.09	0.00	48
Warehouse	0.36***	0.37***	0.33***	0.32**	0.29***	0.31***	49
Information	0.23***	0.25**	0.21**	0.26**	0.28**	0.21**	49
Service	0.44***	0.46***	0.44***	0.47***	0.52***	0.53***	49

Note: ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.

Source: Author's calculation.

Because Moran's I can only be tested on a yearly basis, Moran's I of each year from 1997 to 2011 is calculated. The results are similar for each variable in each year. Due to the space and page limits, Table 1 only shows the global Moran's I of capital-labor ratio (KL) and wage-rental ratio (wr) in the three selected years covering the beginning, the middle and the end of the investigation period. The Moran's I values of capital-labor ratio of several sectors in most years are significant, which indicates spatial autocorrelation of capital-labor ratio exists across different regions and years. Most of the values are positive indicating a tendency toward clustering, although some values such as the ratios of rail sectors in 2011 are negative, which indicates a tendency toward dispersion. The existence of spatial dependence among both the dependent variable and independent variable implies the complicated spatial autocorrelation is an issue for this analysis.

Step 2 Non-Spatial Assessment

The second step is to obtain the basic values of elasticity of factor substitution for CGE analysis. The study follows the classical CES production function to estimate the elasticity of factor substitution. The basic equation can be written as:

$$Q = \left[\alpha_{kl} K^{\frac{\sigma_{kl}-1}{\sigma_{kl}}} + (1 - \alpha_{kl}) L^{\frac{\sigma_{kl}-1}{\sigma_{kl}}} \right]^{\frac{\sigma_{kl}}{\sigma_{kl}-1}} \quad (24)$$

$$\ln\left(\frac{K}{L}\right) = \sigma_{kl} \ln\left(\frac{1-\alpha_{kl}}{\alpha_{kl}}\right) + \sigma_{kl} \ln\left(\frac{w}{r}\right) \quad (25)$$

Where Q is the composite goods of capital and labor, w and r represent wage and rental rates, respectively. σ_{kl} and α_{kl} are the substitution elasticity and distribution parameter of K and L . The equation can also be simplified as a linear regression equation:

$$\ln y = \beta_0 + \beta_1 \ln x + \varepsilon \quad (26)$$

where y is the capital-labor ratio, x is the wage-rental ratio, and ε is the independent and identically distributed (iid) error. The elasticity of substitution between capital and labor is represented by β_1 .

A panel data includes the 48 states and the District of Columbia for 15 years from 1997 to 2011 are constructed following Balistreri *et al* (2003)'s approach, which collected similar data from Bureau of Economic Analysis (BEA) but used it only at an aggregate level of analysis. Four data series are collected to operationalize equation 26: employment, total compensation of employee, private fixed asset and property type income. In the non-spatial assessment, the elasticity of factor substitution for different sectors is estimated using OLS regression. Panel regressions including both fixed effects and random effects estimations are also implemented. However, since some substitution elasticities have negative estimates that have no economic meanings, the estimates of panel regressions are not adopted for CGE integration.

Step 3 Spatial Econometric Analysis

The third step is to estimate the elasticity of factor substitution for different sectors using spatial econometric estimation to control for spatial dependence. Given the potential complexity of this issue, a generalized spatial model named "Spatial Durbin Model" (SDM) is adopted as the initial model for the assessment. The general form of substitution elasticity under SDM is written as:

$$\left(\frac{K}{L}\right)_{i,t} = \rho W \left(\frac{K}{L}\right)_{i,t} + \beta \left(\frac{w}{r}\right)_{i,t} + \theta W \left(\frac{w}{r}\right)_{i,t} + \varepsilon_{i,t} \quad (27)$$

$$\varepsilon_{i,t} \sim N(0, \sigma_{i,t}^2 I_n)$$

where $\frac{K}{L}$ and $\frac{w}{r}$ denote capital-labor ratio variable and wage-rental ratio variable, respectively.

$W \left(\frac{K}{L}\right)_{i,t}$ and $W \left(\frac{w}{r}\right)_{i,t}$ denote the spatial lag terms of capital-labor ratio variable and wage-rental ratio variable, respectively. i and t represent different regions and time periods. ρ , β and θ denote coefficients that needs estimation. The analysis is conducted based on the same panel data as used in step 2.

A key function of spatial analysis is to investigate the spatial effects of factor substitution among different states. Because the spatial information of neighboring regions is added in the form of a

spatial weight matrix, SDM is endowed with the capacity to separate spatial effects from total effects (LeSage & Pace, 2009). As a result, three types of impacts can be estimated through the spatial model: average direct impact, average total impact to an observation and average total impact from an observation (LeSage & Pace, 2009). The first impact measures the influences of the explanatory variables that come from the same geographic unit as the dependent variable. The second impact, which is also called “indirect effect” measures influences of explanatory variables that come from different geographic units. The third impact, which is also named “total impact”, consists of both the direct impacts and indirect impacts.

Step 4 SECGE

During the step 4, a CGE model with an integration of spatial econometric estimates is established. The structure of CGE model has been discussed in Section 3. The elasticity of factor substitution which estimated under both non-spatial and spatial econometric models in step 2 and 3 are utilized respectively for CES production function in the CGE. The spatial econometric CGE (SECGE) is the second type of integration. Given the fact that the elasticity of factor substitution is not assumed or calibrated in this equilibrium model, the estimates based on historical data under the spatial econometric approach is expected to be more realistic for policy simulation. In addition, compared to the non-spatial econometric estimation, the spillover effects of factor substitution elasticity can be adequately estimated under the spatial econometric estimation.

5. Data

Data used for this analysis includes two fractions: the first is a panel data including quantity and price of capital and labor for the 13 economic sectors covering the 48 contiguous states in the US and the District of Columbia for the period from 1997 to 2011. The data is used to estimate elasticities of factor substitution for the 13 sectors. The second data is a US national social accounting matrix (SAM), which is constructed from the GTAP 8 data base.

The GTAP8 data base is developed by the Center of Global Trade Analysis at Purdue University. The latest version of GTAP data contains dual reference years of 2004 and 2007 as well as 129 world countries and regions for all 57 commodity types. Since our research interest is on multiple modes of transportation, non-transportation sectors are grouped into seven industrial sectors including agriculture, manufacture, utility and construction, trade, information, warehouse and service. Transportation sectors are originally divided into three commodity types in GTAP: water transport (WTP), air transport (ATP) and other transport (OTP). Surface modes of transportation such as road, rail, pipelines and auxiliary transport activities are all combined in the sector of OTP. For this analysis it becomes necessary to separate them.

Since 2007 is the latest reference year for the input-output tables and macroeconomic data in GTAP 8 (Narayanan *et al.*, 2012), we use the BEA 2007 annual I-O table after redefinition as the complement information to further disaggregate the combined surface transportation sectors. Truck, rail, transit and other ground transportation, pipeline and warehousing and storage and

others are separated out of the OTP based on their industrial shares in both make and use tables. The rest of OTP which includes auxiliary transport activities and travel agencies are combined with the service sector. Ultimately, six modes of transportation sectors and seven non-transportation sectors are established.

Another challenge of the study is to add public transportation capital accounts in the US national SAM. Public transportation capital stock has important relationships to public transportation investment. The variation of public transportation capital is primarily influenced by level of investment¹, thus a shock of public transportation capital in the CGE drives the social and economic variations that result from level of transportation investment by mode.

Another important note is that public transportation investment in the US is highly modal biased. Highway and streets receive the most public investment while airport, transit and water transportation receives relatively less public investment. The pipeline and rail sectors in the US are primarily privately owned. So these massive infrastructure investments rely on the private sector. Public investment in pipeline and freight rail sectors is primarily used for safety and regulation related purposes and the amount is negligible compared to other modes of investment. Given this background, it is understandable that public transportation capital accounts can be added only for the road, air, transit and water related sectors.

In our CGE model, the four transportation sectors are considered differently to other sectors. The factor endowments consumed by truck, air, transit and water include not only labor and private capital, but also public capital. The ratios of public capital for road, air, transit and water are calculated based on the information of the national fixed assets from BEA.² Since the original capital account in GTAP 8 Data Base includes the entire capital stock (both public and private) of the economy, values of public capital for road, air, transit and water can be calculated using the public capital ratio times the total capital stock for each specific transportation sector.

To separate the public capital accounts from the original capital accounts for the four transportation sectors, two assumptions need to be made: The first is that non-transportation sectors do not have transportation capital. They solely depend on transportation sectors for transport services. The second is that the original capital account for truck transportation includes not only public capital in truck sectors, but also highway and street public capital. Similarly the original capital accounts of air transportation, transit and water transportation include not only public capital in each sector, but also includes public capital of all the relevant infrastructures of each respective mode.

The assumptions are made based on the unique characteristics of transportation sectors. Capital inputs for truck transportation include not only privately owned vehicles, trailers and relevant

¹Public capital stock is normally estimated through the Perpetual Inventory Method based on the level of depreciation rate and level of investment. The linkage can be written as $K_t = (1 - \delta)K_{t-1} + I_t$. Given the predetermined ratio of depreciation rate δ , capital stock is naturally primarily influenced by the investment level.

²Because there is no specific information of public transportation capital by mode except the highway and streets, the public capital shares for air, transit and water transportation have to be estimated based on the activity share.

facilities, it also demands public capital such as the road networks to produce a road transport service. Air and water transportation sectors are similar. Capital stocks such as aircrafts and watercrafts are primarily privately owned while airports, air traffic control, ports and seaport terminals are mostly publicly owned. In other words, public transportation stocks are treated as factors for these transportation sectors to produce transportation services.

6. Results

Policy simulations are conducted under two scenarios of general equilibrium. The first scenario adopts CES elasticity of factor substitution from OLS estimation while the second scenario adopts estimates from spatial econometric models. The results of CES elasticity of factor substitution from the two estimations are displayed in Table 2.

Table 2 CES Elasticity of Substitution for Capital and Labor

Sector	OLS	SE	Direct	Indirect	W*lwr	W*dep
Agriculture	0.62***	0.62***	0.63***	-0.01	0.00	-0.01
Manufacture	0.53***	0.61***	0.49***	0.12***	0.13***	-0.01
Utility&Construction	0.55***	0.60***	0.54***	0.05***	0.05	0.01
Trade	0.84***	0.84***	0.84***	0.00	0.01	-0.01
Truck	0.61***	0.69***	0.62***	0.07***	0.08**	-0.01
Rail	0.33***	0.33***	0.29***	0.05	0.03	0.06*
Air	0.77***	0.79***	0.75***	0.03	0.05*	-0.02
Transit	0.72***	0.81***	0.71***	0.10***	0.06	0.06*
Water	0.70***	0.69***	0.70***	-0.01	-0.01	0.00
Pipeline	0.51***	0.70***	0.47***	0.23***	0.16**	0.10***
Warehouse	0.93***	0.94***	0.93***	0.01	0.01	-0.01
Information	1.03***	1.04***	1.03***	0.01	0.01	0.00
Service	0.91***	0.91***	0.91***	0.00	0.01	-0.01

Note: 1. ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.

2. W*dep and W*lwr represent spatial weighted dependent variable and spatial weighted independent variable.

3. OLS indicates result is estimated through OLS analysis while SE indicates result is estimated through spatial econometric analysis.

Source: Author's calculation.

The results show that the elasticities of factor substitution vary significantly across different sectors. Rail sector has the lowest value of substitution elasticity while information sector has the highest. The comparison of OLS estimation and spatial panel estimation indicates differences of substitution elasticities exist among different sectors. For instance, the values for sectors of manufacture, utility and construction, truck, air, transit, water, pipeline, warehouse and information from the spatial econometric estimation are relatively higher than OLS estimation, which may possibly imply the existence of positive spillover effects of factor substitution.

The spatial interactions of substitution elasticities are observed in the direct effects and indirect effects (See table 2). Significant and positive indirect effects are found in sectors of manufacture, utility and construction, truck, transit and pipeline, which indicate that wage-rental ratios from

adjacent regions have positive impacts on the local region itself. The results further confirm the existence of spatial dependence among these sectors.

To understand the total impacts of public transportation infrastructure as well as the impacts of each mode, public capital of different modes are shocked sequentially and respectively at the same level of 10 percent change, *ceteris paribus*. The impacts on welfare, value added GDP, domestic production of each sector are simulated and compared.

Table 3 Spatial Impact of Transportation Infrastructure by Mode

	Truck		Air		Water		Transit		All modes	
	OLS	SE	OLS	SE	OLS	SE	OLS	SE	OLS	SE
Agriculture	0.0194	0.0187	-0.0439	-0.0449	-0.0071	-0.0070	0.0006	0.0004	-0.0309	-0.0326
Manufacture	0.0239	0.0236	-0.0439	-0.0449	-0.0053	-0.0052	0.0016	0.0014	-0.0235	-0.0248
Utility&Cons	0.0244	0.0239	0.0053	0.0051	0.0040	0.0040	0.0020	0.0019	0.0359	0.0351
Trade	0.0179	0.0171	0.0014	0.0012	0.0017	0.0017	0.0014	0.0013	0.0223	0.0213
Truck	0.4112	0.4602	-0.0219	-0.0224	-0.0013	-0.0012	0.0012	0.0010	0.3891	0.4375
Rail	0.0352	0.0364	-0.0316	-0.0324	-0.0036	-0.0035	0.0021	0.0021	0.0022	0.0027
Air	-0.0153	-0.0208	2.7084	2.7530	-0.0330	-0.0324	-0.0024	-0.0030	2.6552	2.6942
Transit	0.0114	0.0102	-0.0202	-0.0205	-0.0027	-0.0026	0.7363	0.8193	0.7247	0.8061
Water	0.0037	0.0009	-0.0883	-0.0903	2.2666	2.2431	-0.0007	-0.0010	2.1762	2.1473
Pipeline	0.0243	0.0239	0.0042	0.0040	0.0064	0.0064	0.0014	0.0013	0.0364	0.0357
Warehouse	0.0509	0.0545	0.2137	0.2170	0.0150	0.0149	0.0011	0.0009	0.2804	0.2869
Information	0.0126	0.0117	0.0090	0.0090	0.0010	0.0010	0.0023	0.0024	0.0248	0.0240
Service	0.0105	0.0097	0.0035	0.0034	0.0010	0.0010	0.0014	0.0014	0.0164	0.0155
Household	0.0201	0.0201	0.0143	0.0143	0.0052	0.0052	0.0020	0.0020	0.0416	0.0416
GDPVA	0.0204	0.0203	0.0143	0.0143	0.0053	0.0053	0.0020	0.0020	0.0419	0.0419
Welfare	1603	1598	1137	1140	414	414	164	164	3311	3309

Note: 1. Numbers indicate percentage change. Each column represents a CGE simulation result due to a 10 percent increase of the corresponding transportation capital.

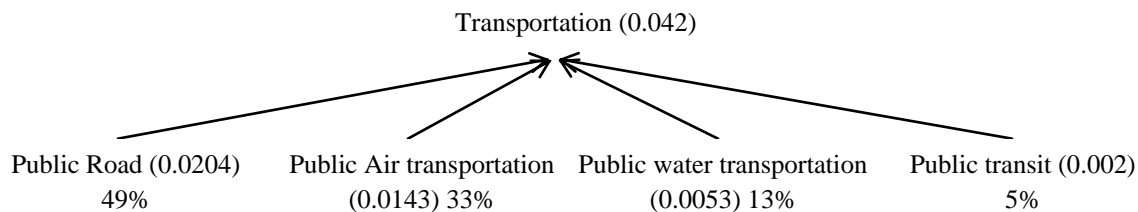
2. OLS indicates is simulated using OLS estimates while SE indicates result is simulated using spatial econometric estimates.

Source: Author's calculation.

The spatial impacts of different transportation modes are summarized in Table 3. The result shows that a 10 percent increase shock of total public transportation capital is associated with a 0.04 percent increase in both value added GDP and household income. In terms of the modal influences, the economic impacts vary significantly by modes. For instance, a 10 percent increase of public capital in truck sector, in other words, a 10 percent increase of highway and street capital is associated with a 0.02 percent increase in both the US value added GDP and household income in 2007, *ceteris paribus*. Assuming a 10 percent increase of public capital in air transportation sector, the US value added GDP and household income are likely to increase by 0.014 percent, *ceteris paribus*. Compared to truck and air sectors, the economic impacts of public capital in transit and water transportation sectors are much smaller. A 10 percent increase of public capital in transit and water transportation sectors are associated with only a 0.002 and a

0.005 percent increase in value added GDP and household income respectively, *ceteris paribus*. The comparison clearly indicates that public capital in highway and streets has the overwhelming impact on growths of GDP and household income among the four public transportation modes. The relative economic contributions among the four modes of public transportation are illustrated in Figure 2.

Figure 2 Economic Contributions of Transportation Infrastructure by Mode in the US



Note: The values are obtained from separate simulations based on the condition that each mode of transportation capital increases by 10 percent. The percentage indicates the share of contribution from the individual mode. Economic outputs are measured by the variations of value added GDP or household income.

The results of welfare impact of public transportation infrastructure are similar to its economic impacts. Welfare effect in the study is measured by equivalent variation (EV), which is defined as “the income change at current prices that would be equivalent to the proposed change in the new equilibrium in terms of its impact on utility” (Varian, 1992, 161). A positive value of the EV indicates a welfare gain and vice versa. Table 3 indicates that the increase of public capital in highways and streets generates the highest welfare gain. Public capital of air transportation has the second largest impact on welfare generation. Public water transportation and public transit still rank the third and the fourth in terms of their impacts on welfare, respectively.

Table 4 Estimation Ratio of SECGE and traditional CGE

	Truck	Air	Water	Transit	All modes
Agriculture	-4%	2%	-2%	-34%	6%
Manufacture	-1%	2%	-2%	-7%	6%
Utility&Construction	-2%	-4%	1%	-4%	-2%
Trade	-4%	-16%	2%	-8%	-5%
Truck	12%	2%	-6%	-12%	12%
Rail	3%	2%	-3%	-2%	23%
Air	35%	2%	-2%	25%	1%
Transit	-11%	2%	-4%	11%	11%
Water	-75%	2%	-1%	57%	-1%
Pipeline	-2%	-5%	0%	-10%	-2%
Warehouse	7%	2%	-1%	-13%	2%
Information	-7%	0%	4%	2%	-3%
Service	-8%	-3%	3%	-2%	-5%
GDPVA	0%	0%	0%	0%	0%
Household	0%	0%	0%	0%	0%
Welfare	0%	0%	0%	0%	0%

Source: Authors' calculation.

To assess whether the issue of spatial dependence has influence on the result of impact analysis is another task of the study. To achieve this goal, CGE simulation results of the two scenarios that adopt substitution elasticities from OLS and spatial econometric estimations are compared. Table 4 displays the estimation ratios of SECGE and traditional CGE. The ratio is calculated using the difference of CGE results based on the spatial econometric estimations and OLS estimation divided by the result of corresponding OLS estimation. The ratio indicates the magnitude of difference between traditional CGE and SECGE. For instance, a ratio of zero indicates there is no difference of simulation results; a positive value indicates that SECGE provides higher values of simulation than traditional CGE that based on OLS estimation of substitution elasticities. Despite the two estimation routines do not show any differences among the aggregate economic outputs, the ratio does reveal that the results vary among different sectors and by different modes.

7. Conclusion

This study develops a new method with integration of both spatial econometrics and equilibrium modeling techniques to improve the effectiveness of impact analysis on transportation infrastructure. Findings of the study have three implications:

First, the economic impacts of public transportation infrastructure in the US are confirmed to be positive under the general equilibrium framework. However, the magnitude of impact is much smaller than that have been found in many previous studies (Boarnet, 1998; Holtz-Eakin & Schwartz, 1995; Kelejian & Robinson, 1997; Ozbay *et al.*, 2007; Cohen & Morrison, 2003; 2004; Cohen, 2007). There are two causes of this. First of all, the study differs from previous studies in that the evaluation focuses on the most recent period. Since the massive construction and expansions of transportation infrastructure in the US have mostly completed, it is reasonable to believe that the general impacts of the matured US transportation infrastructures are no longer as significant as they used to have during their evolving stages. Second, general equilibrium analysis may find a smaller effects than partial equilibrium analysis because of its consideration of the whole economy.

Second, the study identifies the relative importance of spatial impacts of different transportation modes in the US from a multimodal and comparative perspective. Under the same percentage of increase of public transportation capital, contribution from highways and streets takes about 49 percent of total impacts of transportation, while the modes of air, water and transit only take 33 percent, 13 percent and 5 percent, respectively (See Figure 2). The assessment confirms that the US highway and streets plays a dominant role among all transportation infrastructure systems in economic development while public transit and passenger transportation only plays the least important role among the systems.

Third, the study develops a SECGE model for transportation impact analysis. The method integrates spatial econometric estimation with general equilibrium analysis, which enables researchers to control for the issue of spatial dependence under equilibrium. This integration is important as spatial dependence has been observed among some economic sectors through

spatial autocorrelation test. Without considering this issue, the elasticity of factor substitution will be biased in traditional OLS estimation, which thus may impair validity of CGE simulation. This has been confirmed in the comparative analysis using both OLS estimation and spatial econometric estimation.

However, the differences are only found to exist among the sectoral productions especially among those sectors where spatial dependence is explicitly identified, but not among the aggregate economic outputs. The impacts of domestic production of different sectors become relative high when the substitution elasticities estimated from spatial econometric models. In particular, a higher percentage increase of outputs is observed among transportation sectors including truck, air, transit and water when a 10 percent increase of overall transportation capital being implemented. The increase of output could possibly be explained by the inclusion of spillover effects of transportation infrastructure under SECGE, which could not be measured in traditional CGE models.

Given the fact that the study focuses on the national level, the spatial impacts do not vary significantly as spatial dependence may not be a serious issue at such a high aggregate level of analysis. Although the differences are relatively small in this aggregate case study, implications for more sensitive disaggregated regional models are clear, and will be further investigated in the future.

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