Transportation Capital in the US: A Multimodal General Equilibrium Analysis

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ABSTRACT

This paper introduces a new general equilibrium approach to evaluate economic impact of public transportation capital stock in the US. By treating public transportation capital as separated factor accounts, the model enables us to assess the economic impact of public transportation stock for four modes: road, air, transit, and water transportation. The study provides a direct and easy way for policymaker and transportation planning practitioner to compare social and economic benefits of different modes of public transportation. Findings reveal that road stock has the highest contribution to the growth of GDP and levels of social welfare; public transit and other ground passenger transportation have the least impact on the US economy among the four modes.

Keywords: Transportation capital, Multimodal, General equilibrium analysis, Economic Impact

JEL classification: C23, R11, R42, R53

1. INTRODUCTION

To obtain a valid and credible understanding of the economic benefits of public transportation infrastructure has always been challenging for transportation planners and policymakers. Such an understanding helps to recognize merits of previous investment policy, and it also provides evidence and implication for developing future investment strategy. The need for this understanding becomes critical especially under the existing situation where public transportation funds are getting scarcer. The decline of public funds in transportation requires government to have a clearer and more precise understanding on the impacts of different transportation modes so that future funds can be allocated wisely and efficiently.

In the academic world, many studies have been conducted to investigate the linkages between transportation and economic outputs. Most of these studies were analyzed under a partial equilibrium assumption, in which the linkage between public capital and economic performance is measured only from the supply side (Aschauer, 1989; Munnell, 1990; 1994;Harmatuck, 1996; Nadiri & Mamuneas, 1996; Fernald, 1999; Bhatta & Drennan, 2003; Boarnet, 1997; Boarnet & Haughwout, 2000; Mattoon, 2002;Duffy-Deno & Eberts, 1991). A certain type of Cobb-Douglas production function is usually adopted as the theoretical foundation. Public capital or transportation capital is treated as an endowment together with labor and private capital. In these models, output elasticities of public capital or transportation capital are estimated through regression analysis either based on time-series data or panel data. These estimates are considered as impact indicators and often discussed in connection with levels of economic benefits.

The economic impact of transportation capital is also analyzed in spatial econometrics with considerations of spatial dimension. A spatial weighting matrix is first constructed based on either economic or geographic information. Then a certain type of spatial econometric model is applied to estimate output coefficients. One advantage of the spatial econometric approach is that economic impact can be analyzed separately from local effects and spillover effects (LeSage and Pace, 2009). But it should be noted that the analysis is still a partial equilibrium assessment as only determinants from the supply side of the economy are considered. However, partial equilibrium assessment cannot provide a comprehensive view of economic impact given the fact that economic benefits due to demand variation caused by input changes cannot be adequately and quantitatively assessed under such a framework.

As an alternative, the computable general equilibrium (CGE) assessment has gained mounting attention in infrastructure impact analysis. This approach considers determinants from both supply and demand sides of an economy by including different economic institutions such as consumer, producer, government, investment and savings and the rest of the world. The analysis calculates solutions for each institution under a general equilibrium. In order to assess impact of a policy, for instance, the change of a sales tax, a new economic equilibrium is calculated based on the revised policy input. The economic impact is then measured through the variations of economic outputs such as the levels of social welfare, gross product and household income, as compared to the relative values in the base equilibrium. CGE presents a more realistic impact assessment than the partial equilibrium approach.

The purpose of our study is to assess economic benefits of public transportation capital in the US using a general equilibrium assessment. This study differs from previous studies in the following ways:

First, a general equilibrium analysis with a focus on multimodal transportation capital will be established. The goal is to provide an analytical tool under general equilibrium to understand the relative economic importance of different modes of transportation. Specifically, six modes of transportation will be considered: road, rail, air, transit, water and pipeline. Each mode is treated as an individual sector together with other seven other non-transportation sectors.

Second, unlike existing transportation CGE models that only enable policy experiments through transport cost or total factor productivity, our general equilibrium model allows for a direct assessment of public transportation capital through the shock of the separated public capital accounts in the US social accounting matrix (SAM).This model offers more practical and instructive mechanism for decision-makers to evaluate the influences of different modes of public transportation capital.

Third, the model is implemented based on a data base built from the Global Trade Analysis Project 8 (GTAP8) and the Bureau of Economic Analysis (BEA).This makes our model differ from other theoretical CGE models in having realistic, significant and practical implications.

Two research questions are answered in this study: what role does public transportation capital stock play on the US economy under a general equilibrium framework? How do the roles of public capital vary among different modes of transportation? The rest of the paper is organized as follow: Section 2 discusses the relevant theories and reviews some of the existing transportation CGE models. In section 3, data and modeling specifics are introduced. Section 4 illustrates simulation results under different policy scenarios. The final section summarizes conclusions and implications for future research endeavors.

2. LITERATURE REVIEW

Economic benefits of transportation capital are reviewed from the partial equilibrium theory and the general equilibrium theory perspective. Furthermore, the necessity for a multimodal investigation is assessed.

Partial Equilibrium Theory

The linkages between public capital or transportation capital and economic performance have been widely researched under the partial equilibrium framework (Gramlich, 1994; 2001; Harmatuck, 1996; Nadiri and Mamuneas, 1996; Fernald, 1999; Bhatta and Drennan, 2003; Boarnet, 1997; Boarnet and Haughwout, 2000; Mattoon, 2002; Duffy-Deno and Eberts, 1991). Given the nature of different model structures, time periods, measures of economic outcomes and control variables, findings are not consistent. Some argue that transportation capital such as the highway system had a positive and a large effect on productivity (Harmatuck, 1996; Fernald, 1999; Keeler & Ying, 2008); others suspect the magnitudes of such effects (Boarnet, 1997; Button, 1998).

Aschauer (1989) and Munnell and Cook (1990)analyzed the relationship between public capital and economic performance from 1970 to 1986 at the national and the state level respectively. The output elasticity of public capital stock was found to be 0.38 to 0.56 (Aschauer, 1989) and 0.15 (Munnell and Cook, 1990) respectively, with highway alone contributing 0.06 (Munnell and Cook, 1990). By focusing on nonmilitary public capital from 1949 to 1985, Harmatuck (1996) found the impact was positive and significant. Lau & Sin (1997) found a low value of public capital elasticity of around 0.1, much smaller than what Aschauer and Munnell had found.

These partial equilibrium studies have been subjected to a variety of criticisms. Gramlich (1994) summarized the defects in the following ways:

- Unclear causal relationship between infrastructure provision and economic performance;
- Vague definition of "infrastructure" making the quantitative analysis speculative.
- Poor use of policy variables that were not consistent in terms of level with relevant infrastructure variables.
- Lack of isolation of factors influencing macroeconomic performance: mixing transport with higher level variables and often leaving out issues in soft infrastructure including law, education, business services and defense.
- Different methodologies are applied to different types of datasets, resulting in implications that attribute an imprecise weight to quantitative estimates.

General Equilibrium Theory

Under a partial equilibrium framework, the association between economic output and infrastructure is evaluated only from the supply side of economy by assuming the demand of infrastructure is constant during the period of investigation. Under such an analytical framework, the outcome of economic impact is fractional since the impact caused by the variation of demand is not considered. For instance, the impact of transportation on travelers' welfare measured by utility level cannot be quantified in the partial equilibrium analysis. As a result, to achieve a comprehensive evaluation of transportation infrastructure's economic impact, a general equilibrium framework is more effective.

Computable general equilibrium (CGE) analysis was originally developed by Johansen (1960). It is basically an economic model that enables impact analysis with consideration of both demand and supply. The theoretical framework originates from neo-classical economic theory and relies on the Walras-Arrow-Debreu theory of general equilibrium, with modern modifications and extensions allowing for imperfect markets (Bröcker, 2004, p269). Because CGE contains linkage between the microeconomic structure and the macroeconomic environment, the model can be used to describe the interrelationship among multiple industrial sectors and markets and also assess direct and indirect effects from the change of public policy on any economic variable 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 by a production function or a constant equation substitution function (CES). Government plays dual roles in CGE. On 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) (Bröcker,2004).

The applications of CGE in evaluating the impact of transportation infrastructure vary substantially. Impact can be evaluated differently depending on the specific research needs. Due to the fact that most transportation infrastructure achieves economic benefits through increasing accessibility and reducing transport cost, 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 cost, 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).

The *Pingo* model was a static CGE model used to forecast regional and interregional freight transport (Ivanova, 2003). The model contains 19 regions with 10 economic sectors. The *MONASH* model is another widely used multi-regional, 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 in trade and service (Sundberg, 2005).

The single region *IFPRI* model is another type of CGE model which treats transportation cost as a type of transaction costs in trade (Lofgren, 2002). The model allows for assessing impacts through transaction cost variation. In general, transport costs are treated as part of trade in these CGE models. Some model transport cost without an explicit representation of the transport sector, like *CGEurope*. In other models such as *Pingo*, *MONASH* and *IFPRI*, transport costs are explicitly included to the price of final goods and services. It should be noted that transport costs are usually estimated externally through transport network models.

Unimodal vs. Multimodal

Another common feature of the 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, airport or ports (Holtz-Eakin and Schwartz, 1995; Cohen and Morrison Paul, 2003; 2004; Cohen 2007; Ozbay et al., 2007). Very few studies investigate the issue from a competitive multimodal perspective (Addersson et al., 1990; Blum, 1982; Cantos et al.; 2005).

It should be noted that even these multimodal assessments are conducted in partial equilibrium, very few studies enable infrastructure impact analysis from a multimodal general equilibrium perspective. Goce-Dakila and Mizokami (2007) constructed a multi-regional transportation CGE model with a focus on the Philippines. Land, air and sea transportation are treated as three sectors. By shocking technological improvement of different modes, they found that land transport had the highest impact on output (Goce-Dakila and Mizokami, 2007).

Summary

Despite a variety of transportation CGE models that have been established, none of these models have the capacity to evaluate economic benefits of transportation infrastructure capital explicitly. Most of these models evaluate the impact of transportation infrastructure by assuming input of transportation capital leads to a reduction of transport cost, which thus leads to an economic growth. Therefore, transport costs are treated as the fundamental input variables for CGE simulation. Transportation network models are used to obtain transport costs. Clearly, the linkage between transportation capital which is the real policy input and transport costs are not and cannot be captured.

In addition, there are very few CGE models that enable comparative analysis of transportation infrastructure by modes. The only multimodal CGE model is the case of Philippine which had experiments on productivity of infrastructure through technological improvements by assuming the positive relationship between transportation investment and technological improvement. These models make sense in theory, but they lack practical capacity as no direct linkage between public transportation capital and economic activities is modeled explicitly in the general equilibrium framework.

3. MODELING THE PUBLIC TRANSPORT CAPITAL

In this study, we intend to fill the gap by conducting a general equilibrium investigation with a multimodal focus. This analysis enables us to differentiate the relative importance of transportation infrastructure by mode through comparing their social and economic impacts. In this section, the construction process of the US national social accounting matrix (SAM) is explained and the major modeling structures of each institution are discussed.

Structure of the US Economy (13X9)

In order to assess and compare impacts of transportation capital by mode, one of the approaches is to treat the different transportation modes as individual sector and add them to the SAM. In this study, the GTAP 8 data base is adopted as the starting point for creating the US national SAM. The GTAP 8 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 six industrial sectors, including agriculture, manufacture, utility and construction, trade, information, and service. Transportation sectors are originally divided into three commodity types in GTAP: water transport (WTP), air transport (ATP) and other transport (OTP). Because the 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.

Because 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 investment[1], 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.

[1]Public 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 rateδ, capital stock is naturally primarily influenced by the investment level.

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) in 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 capitals 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 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.

Modeling Structure

The modeling structure of the study adopts the 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 codes are implemented in GAMS using the PATH solvers. 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 using the Armington assumption (Armington, 1969) under 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.

[2] Because 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.

Consumer

In this model, consumer maximizes a constant return to scale Cobb-Douglas utility function subject to a budget constraint. The household commodity consumption can be represented as:

$$\mathrm{PQD_i} \cdot \mathrm{QCD_i} = \sum_{k=1}^{h} \mathrm{Comhav_{i,k}} \cdot \mathrm{HEXP_k} \tag{1}$$

Where:

$\mathrm{PQD_i}$: The purchase price of composite commodity i;

$\mathrm{QCD_i}$: Household consumption by commodity i;

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

$\mathrm{HEXP_h}$: Household consumption expenditure in household h.

Household income and household expenditure are denoted respectively as:

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

$$\mathrm{HEXP_h} = \mathrm{YH_h} \cdot (1 - \mathrm{tyh_h}) \cdot (1 - \mathrm{SADJ} \cdot \mathrm{kaphsh_h}) \tag{3}$$

Where:

$\mathrm{YH_h}$: Household income of household h;

$\mathrm{hvash_{h,f}}$: Share of income from factor f to household h;

$\mathrm{YF_k}$: Income to factor f;

$\mathrm{hwor_h}$: Transfers to household from ROW (constant in foreign currency);

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

$\mathrm{tyh_h}$: Direct tax rate on household h;

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

$\mathrm{kaphsh_h}$: 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 technologies with value added and intermediate inputs as factors of production while the second level assumes value added CES technology with capital and labor 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 can be represented as:

$$\mathrm{QX_a} = \mathrm{adx_a} \cdot \left(\sum_{k=1}^{f} \mathrm{deltax_{k,a}} \cdot \mathrm{FD_{k,a}}^{-\mathrm{rhox_a}}\right)^{-\frac{1}{\mathrm{rhox_a}}} \tag{4}$$

Where

QX_a: Domestic production by activity a;

adx_a: Shift parameter for CES production functions for QX;

$deltax_{f,a}$: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:

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

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

Where

$QINTD_c$: Demand for intermediate inputs by commodity;

$COMOUT_c$: Domestic commodity production;

$ioqx_{c,k}$: Use matrix coefficients;

ioqxcqx:$_{a,c}$: Share of commodity c in output by activity a.

Transportation service provided by transportation sectors is treated as intermediates in non-transport 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.

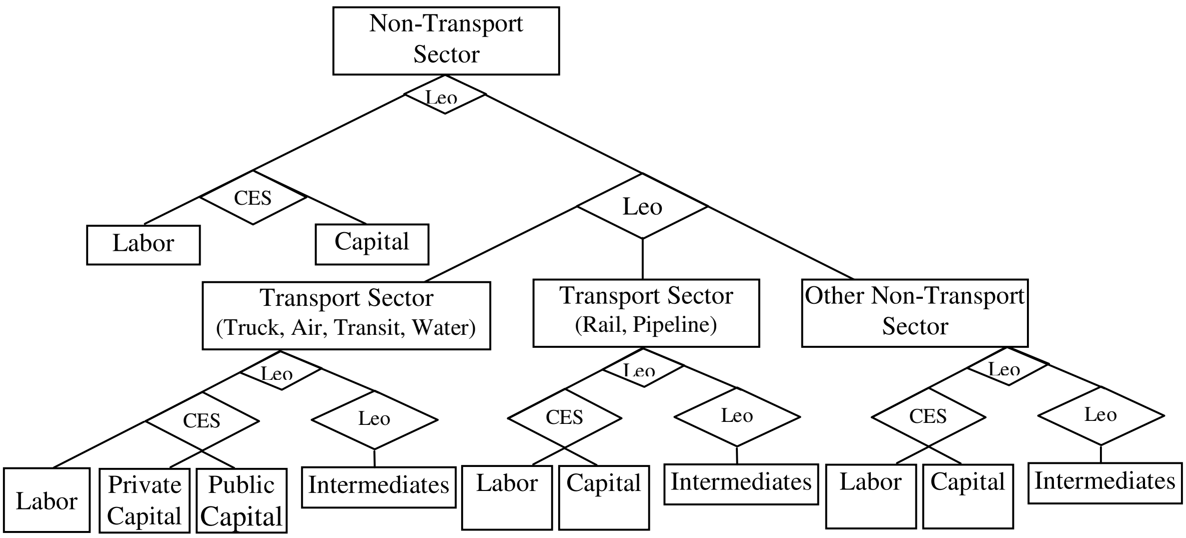

Figure 1. Nested Production Structure

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:

$$\mathrm{MTAX} = \sum_{k=1}^{c} \mathrm{tm}_k \cdot \mathrm{pwm}_k \cdot \mathrm{ER} \cdot \mathrm{QM}_k \tag{7}$$

$$\mathrm{ETAX} = \sum_{k=1}^{c} \mathrm{te}_k \cdot \mathrm{PWE}_k \cdot \mathrm{ER} \cdot \mathrm{QE}_k \tag{8}$$

$$\mathrm{STAX} = \sum_{k=1}^{c} \mathrm{ts}_k \cdot \mathrm{PQS}_k \cdot (\mathrm{QINTD}_k + \mathrm{QCD}_k + \mathrm{QGD}_k + \mathrm{QINVD}_k) \tag{9}$$

$$\mathrm{ITAX} = \sum_{k=1}^{a} \mathrm{tx}_k \cdot \mathrm{PX}_k \cdot \mathrm{QX}_k \tag{10}$$

$$\mathrm{DTAX} = \sum_{k=1}^{h} \mathrm{tyh}_k \cdot \mathrm{YH}_k \tag{11}$$

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:

$$\mathrm{YG} = \mathrm{MTAX} + \mathrm{ETAX} + \mathrm{STAX} + \mathrm{ITAX} + \mathrm{DTAX} + (\mathrm{govwor} \cdot \mathrm{ER}) \tag{12}$$

$$\mathrm{QGD}_c = \mathrm{QGDADJ} \cdot \mathrm{qgdconst}_c \tag{13}$$

$$\mathrm{EG} = \sum_{k=1}^{c} \mathrm{QGD}_k \cdot \mathrm{PQD}_k \tag{14}$$

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;

$\mathrm{qgdconst}_c$: Government demand volume of commodity c;

Investment and saving

Investment and saving block includes the following three equations:

$$\mathrm{TOTSAV} = \sum_{k=1}^{h} \mathrm{YH}_k \cdot (1 - \mathrm{tyh}_k) \cdot \mathrm{SADJ} \cdot \mathrm{kaphsh}_k + \mathrm{KAPGOV} + (\mathrm{KAPWOR} \cdot \mathrm{ER}) \quad (15)$$

$$\mathrm{QINVD}_c = \mathrm{IADJ} \cdot \mathrm{qinvdconst}_c \quad (16)$$

$$\mathrm{INVEST} = \sum_{k=1}^{c} \mathrm{PQD}_k \cdot \mathrm{QINVD}_k \quad (17)$$

Where

TOTSAV: Total savings;

KAPGOV: Government Savings;

KAPWOR: Current account balance;

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

$\mathrm{qinvdconst}_c$: Investment demand volume.

Market clearing condition

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:

$$\mathrm{FS}_f = \sum_{k=1}^{a} \mathrm{FD}_{f,k} \quad (18)$$

$$\mathrm{QQ}_c = \mathrm{QINTD}_c + \mathrm{QCD}_c + \mathrm{QGD}_c + \mathrm{QINVD}_c \quad (19)$$

$$\mathrm{KAPGOV} = \mathrm{YG} - \mathrm{EG} \quad (20)$$

$$\mathrm{KAPWOR} = \sum_{k=1}^{cm} \mathrm{PWM}_k \cdot \mathrm{QM}_{cm} + \frac{\sum_{j=1}^{f} \mathrm{YFWOR}_j}{\mathrm{ER}} - \sum_{i=1}^{ce} \mathrm{PWE}_i \cdot \mathrm{QE}_i - \sum_{l=1}^{h} \mathrm{hwor}_l - \mathrm{govwor} - \sum_{m=1}^{f} \mathrm{factwor}_m \quad (21)$$

$$\mathrm{TOTSAV} = \mathrm{INVEST} + \mathrm{WALRAS} \quad (22)$$

Where

FS_f: Supply of factor f;

QQ_c: Supply of composite commodity c;

YFWOR_f: Foreign factor income;

$\mathrm{factwor}_m$: Factor payments from ROW (constant in foreign currency);

INVEST: Total investment expenditure;

WALRAS: Slack variable for Walras's Law.

4. POLICY SIMULATION

Policy simulation is conducted in two directions. First, the exogenous public capitals of different modes are shocked sequentially at the same level of percentage change, *ceteris paribus*. For instance at the 10% increase of exogenous factor supply scenario, public road capital, public air transport capital, public transit capital and public water transport capital and the total transport capital which includes all public capitals of the four modes are shocked respectively. The variations of welfare, value added GDP, domestic production and consumption are estimated and compared. The second direction of simulation is to shock different levels of percentage changes of the exogenous public capital supply. The result allows comparing different magnitudes of impacts due to the different levels of public transport capital inputs. Meanwhile, the result helps to identify how sensitive the estimation relates to the values of inputs. In total, 30 groups of policy simulations are implemented during the CGE experiments.

The impact on value added GDP are summarized in Table 1. When the initial exogenous public capital in truck transportation sector increases 10 percent, in other words, the initial highway and street capital increases 10 percent, the value added GDP in the US in 2007 is likely to increase 0.02 percent, *ceteris paribus*. Assuming the exogenous public capital in air transportation sector increases 10 percent, the value added GDP is likely to increase a 0.012 percent, *ceteris paribus*. Compared to truck and air sectors, the economic impact of public capital in transit and water transportation sectors are much smaller. A 10 percent increase of the initial public capital inputs in transit and water transportation sectors are associated with only a 0.002 and a 0.005 percent increase in value added GDP respectively, *ceteris paribus*. Apparently, public capital in highway and streets has the biggest impact on contributing GDP growth among these four modes.

Table 1 Percentage Change of Value added GDP

Percentage Change	Road	Air	Transit	Water	All Transport
-30%	-0.063	-0.038	-0.006	-0.015	-0.123
-20%	-0.042	-0.025	-0.004	-0.010	-0.082
-10%	-0.021	-0.013	-0.002	-0.005	-0.041
0	0.000	0.000	0.000	0.000	0.000
10%	0.021	0.012	0.002	0.005	0.040
20%	0.041	0.025	0.004	0.010	0.080
30%	0.061	0.037	0.006	0.015	0.119

Source: Authors' calculation.

The economic impact comparison of different modes can be viewed through the different levels of public capital change. Assuming the initial public capital input changes of different transportation modes vary consistently from a negative 30 percent to a positive 30 percent, the percentage changes of value added GDP simulated in our CGE reveal that the public capital in highway and streets still plays the most dominant role in affecting the variations of economic output. A 30 percent increase in public capital in truck sectors is associated with a 0.061 percent increase in value added GDP, confirming the existence of constant returns to scale. Public air transport capital plays the second largest role in economic growth in the US as its output elasticity is approximately half that of highways and streets. Public water transport capital plays the third largest role as its output elasticity is around one fourth of the roads'. Public capital of transit and other ground passenger transport plays the smallest impact on promoting national economic growth as the output elasticity is around one tenth of roads'.

The results of welfare variations due to the changes of different modes of public capital inputs are illustrated in Table 2.Welfare effect is measured by Equivalent Variation (EV), which measures "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. The results reveal that the increase of public capital in highways and streets generates the highest welfare gain. Public capital of air transport still plays the second in generating welfare. A 10 percent increase in public capital inputs in air transport is likely to lead to a 994 unit increase of EV. Public capital in water transport and transit sectors still rank third and fourth, respectively.

Table2 Percentage Change of Equivalent Variation Welfare Measure

Percentage Change	Truck	Air	Transit	Water	All Transport
-30%	-5038	-3047	-496	-1195	-9782
-20%	-3335	-2017	-328	-790	-6476
-10%	-1656	-1002	-162	-392	-3216
0	0	0	0	0	0
10%	1640	994	163	391	3183
20%	3261	1977	323	776	6330
30%	4865	2950	480	1157	9446

Source: Authors' calculation.

In terms of the different magnitude of public transportation capital input, the simulation result confirms the same sequence of importance as the previous result. Apparently, a sharp decrease of public capital input in highways and streets (30 percent) is likely to cause a more severe social welfare loss than the loss caused by the same percentage decrease of public transit capital input.

The sectoral impacts of different modes of public transportation capital show some different patterns compared to aforementioned aggregated level impacts. Table 3 summarizes the domestic production variations by sectors after a 10 percent shock of transportation capital by modes. The increase of public highway and streets has the widest sectoral influences on domestic production. A 10 percent increase would lead to a 0.092 percent increase in truck transportation production and around 0.025 to 0.028 percent increase of production in agriculture, manufacture, utility and construction, rail transportation, pipeline and warehouse and storage sectors. Sectors such as trade, air transportation, transit, water transportation, information and service also experience an increase of domestic production ranging from 0.016 to 0.023 because of the expansion of public road capital.

Table 3 Domestic Production Variations by Sectors
(10% increase of different transportation capital)

Sector	Road	Air	Transit	Water	All Transport
Agriculture	0.025	0.004	0.002	0.004	0.035
Manufacture	0.026	0.005	0.002	0.004	0.037
Utility and Construction	0.028	0.015	0.003	0.006	0.051
Trade	0.022	0.011	0.002	0.005	0.040
Truck transportation	0.092	0.008	0.002	0.004	0.106
Rail transportation	0.027	0.006	0.002	0.004	0.040
Air transportation	0.022	0.492	0.002	-0.002	0.514
Transit	0.019	0.006	0.116	0.003	0.145
Water transportation	0.023	-0.006	0.002	0.419	0.438
Pipeline	0.026	0.014	0.002	0.006	0.049
Warehouse and Storage	0.028	0.049	0.002	0.007	0.085
Information	0.019	0.011	0.002	0.004	0.037
Service	0.016	0.009	0.002	0.003	0.030

Source: Authors' calculation.

Public transportation capitals in air, transit and water demonstrate relatively concentrated sectoral influences of domestic production. Unlike the wide sectoral impact of highway and street capital, a 10 percent increase in public air capital leads to a relatively high increase of domestic production in the air transportation sector but a relatively low increase in other sectors. Generally, the average domestic production variation caused by a public air capital shock is much smaller than a highway and street capital shock. There is even a negative production increase in water transportation sector, which implies the competitive nature of air freight and water freight transport service. Similarly, a 10 percent increase in public transit capital leads to a 0.116 percent increase of domestic transit production, but only leads to around 0.002 percent increase of other sectoral production. A 10 percent increase in public water transport capital leads to a 0.419 percent increase of domestic transit production, but only leads to a much small number increase of other sectoral production.

Household consumption variations by sectors after a 10 percent shock of transportation capital by modes are summarized in Table 4. Again, public highway and streets demonstrate the widest sectoral influences on demand change. A 10 percent increase of public highway and street capital under the general equilibrium would lead to a 0.118 percent increase in truck service consumption and around a 0.02 percent consumption increase in the rest of the sectors.

Public transportation capital in air, transit and water demonstrate has relatively concentrated sectoral influences on household consumption as well. A 10 percent increase in public air capital leads to a 0.177 percent increase of air transport service consumption but an approximately 0.01

percent increase in other sectors. Similarly, a 10 percent increase in public transit capital also leads to a 0.177 percent increase of transit consumption but only around 0.002 percent consumption increase in other sectors. Likewise, a 10 percent increase in public water transport capital leads to a 0.256 percent consumption increase of water transport service, but an average 0.004 percent increase in other sectors.

Table 4 Household Consumption Variations by Sector (10% increase of different transportation capitals)

Sector	Road	Air	Transit	Water	All Transport
Agriculture	0.020	0.014	0.002	0.005	0.041
Manufacture	0.021	0.013	0.002	0.005	0.041
Utility and Construction	0.021	0.012	0.002	0.004	0.039
Trade	0.020	0.012	0.002	0.004	0.037
Truck transportation	0.118	0.012	0.002	0.004	0.136
Rail transportation	0.020	0.012	0.002	0.004	0.038
Air transportation	0.020	0.177	0.002	0.004	0.202
Transit	0.020	0.013	0.177	0.005	0.215
Water transportation	0.020	0.006	0.002	0.256	0.284
Pipeline	0.020	0.012	0.002	0.005	0.038
Warehouse and Storage	0.020	0.013	0.002	0.005	0.040
Information	0.019	0.012	0.002	0.004	0.038
Service	0.019	0.011	0.002	0.004	0.037

Source: Authors' calculation.

5. CONCLUSIONS

Unlike previous transportation CGE studies, we build a new general equilibrium framework to evaluate economic impact of public transportation capital. In our analysis, a single country CGE model is applied to the US national SAM with separated public transportation capital accounts for truck, air, transit and water sectors. Public transportation capital is treated as endowments in addition to labor and private capital for the four sectors and their economic influences are simulated and compared. Our results confirm that public transportation capital in general does have a positive impact on both economic growth and social welfare. However, the elasticity of value added GDP is only 0.004, which indicates a one percent increase in public transportation capital input leads to a 0.004 percent increase in value added GDP. The value is relatively smaller than what has been found in partial equilibrium literature, which may be possibly explained by the following two reasons:

First, under the general equilibrium analysis, the output elasticity represents the influences of transportation capital on value added GDP. Given the fact that the value added GDP is the difference between the value of the gross output and the value of all intermediate consumption, the elasticity of value added GDP should be smaller than the gross output elasticities found in most partial equilibrium literature (Munnell and Cook, 1990; Moonmaw, Mullen and Martin 1994; Fernald, 1999), because the value added GDP does not include the value of intermediate consumption.

Second, the economic impact of transportation infrastructure has been found to vary during different economic periods and transportation construction periods. For instance based on the highway capital stock data from 1949 to 2000, Mamuneas and Nadiri (2006) found that the elasticity of highway capital has been declining as the system has been completed under a partial equilibrium analytical framework. In the earlier period from 1949 to 1959, the value is 0.55, but it then falls to 0.48 during the decade 1960 to 1969. In the decade 1990 to 2000, it finally ends at 0.14. Since this analysis is based on the economic information of 2004 and 2007, during this time period, most of public transportation infrastructures in the US have already been built. It is thus understandable that the economic benefits of public transportation capitals should not be expected to be as high as that during the earlier construction period.

This study improves on our understanding of the relative importance of public investment on different transportation modes. It shows that public capital in road transportation sectors has the highest level of impact on both economic growth and social welfare. The change of highway and street capital causes the widest sectoral impact, indicating the dominant effect of road transportation infrastructure. Public capital in air transportation is the second most important mode in stimulating economic growth and creating welfare. Public capital in water transportation and transit and other passenger transportation rank the third and fourth, respectively. Since infrastructures of rail transportation and pipeline in the US are primarily funded by private sectors, the impacts of public capital in these two modes are not considered in this study.

Future research will be conducted in two directions. One is to expand the analysis from the national level to the regional level. A multi-regional CGE model with a multimodal focus will be developed to investigate regional impacts of public transportation capital through both local effect and spillover effect. The other direction is to improve the simulation algorithms by introducing more realistic parameters representing factor substitution rates. Given the issues of spatial autocorrelation and heterogeneity in regional transportation capital distribution, it will be interesting to consider the integration of spatial econometric models with CGE to improve the validity of regional general equilibrium analysis in an attempt to provide a truly "spatial" CGE.

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AppendixI

Conceptual Structure of the US SAM

Receipts	Activities	Commodities	Private factors	Public transport capital	Households	Government	Savings-Investment	Rest of the World	Total
Activities		Marketed outputs							Gross Output
Commodities	Intermediate inputs				Household consumption	Government consumption	Investment	Export	Demand
Private factors	Value added								Factor income
Public transport capital	Value added								Public transport capital
Households			Factor income to household	capital income to household					Household income
Government	Producer taxes, value added tax	Sales taxes, tariffs, export taxes			Transfers to government, direct				Government income
Savings-Investment					Household savings			Foreign savings	Savings
Rest of the World		Imports							Foreign exchange outflow
Total	Activity	Supply expenditures	Factor expenditures	Public transport capital expenditures	Household expenditures	Government expenditures	Investment	Foreign exchange inflow	