REGIONAL IMPACT OF PUBLIC TRANSPORTATION INFRASTRUCTURE IN THE U.S. NORTHEAST MEGAREGION: A SPATIAL ECONOMETRIC COMPUTABLE GENERAL EQUILIBRIUM ASSESSMENT

by

Zhenhua Chen
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Submitted to the
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Dedication

This is dedicated to my loving wife Jiahua (Alice).

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Any remaining errors and judgmental mistakes belong to myself.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Amtrak	National Railroad Passenger Corporation
ATP	Air Transportation
BEA	Bureau of Economic Analysis
BTS	Bureau of Transportation Statistics
CADF	Cross-sectional Augmented Dickey Fuller
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGE	Computable General Equilibrium
CUE	City-University Energysaver
DTAX	Income Tax Revenue from Non-Government Institutions
EG	Government Expenditure
ETAX	Export Tax Revenue
EV	Equivalent Variation
FAA	Federal Aviation Administration
FDI	Foreign Direct Investment
FHWA	Federal Highway Administration
GAMS	General Algebraic Modeling System
GDP	Gross Domestic Product
GMM	Generalized Method of Moments
GMP	Gross Metropolitan Product
GTAP	Global Trade Analysis Project
HSR	High Speed Rail
IADJ	Investment Scaling Factor
IFPRI	International Food Policy Research Institute
IID	Independent and Identically Distributed
IMPLAN	IMpact analysis for PLANning
INVES	Total Investment Expenditure
IV	Instrumental Variable
ITAX	Indirect Tax Revenue
KAPGOV	Government Savings
KAPWOR	Current Account Balance
LEO	Leontief
LM	Lagrange Multiplier
LR	Likelihood Ratio
MAP-21	Moving Ahead for Progress in the 21st Century
MERCOSUR	Mercado Común del Sur (Southern Common Market)

MicroMSA	Micropolitan Statistical Area
MSA	Metropolitan Statistical Area
MTAX	Tariff Revenue
NAICS	North American Industry Classification System
NEC	Northeast Corridor
OLS	Ordinary Least Square
OTP	Other Transportation
PIM	Perpetual Inventory Method
ROW	Rest of World
SAM	Social Accounting Matrix
SAR	Spatial Autoregressive Model
SCGE	Spatial Computable General Equilibrium
SDM	Spatial Durbin Model
SECGE	Spatial Econometric Computable General Equilibrium
SEM	Spatial Error Model
STAX	Sales Tax Revenue
TERM	The Enormous Regional Model
TOTSAV	Total Savings
TTSPC	Total Transportation Stock per Capita
QGD	Government Commodity Consumption
QGDADJ	Government Consumption Demand Scaling Factor
QQ	Supply of Composite Commodity
WTP	Water Transportation
YG	Government Income

Abstract

REGIONAL IMPACT OF PUBLIC TRANSPORTATION INFRASTRUCTURE IN THE U.S. NORTHEAST MEGAREGION: A SPATIAL ECONOMETRIC COMPUTABLE GENERAL EQUILIBRIUM ASSESSMENT

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Transportation investment is a major public policy issue at the federal, state and local levels of government in the U.S. This dissertation develops, demonstrates and applies a new extension to computable general equilibrium analysis to assist policy makers in assessing the impact of public investments on economic output at different geographic scales (national, state and metropolitan) with an emphasis on the U.S. northeast megaregion.

The dissertation confirms that public transportation infrastructure plays a vital role in stimulating and facilitating regional economic growth even in a mature transportation systems region. The positive effects of public transportation infrastructure are found under both the partial equilibrium assessment and the general equilibrium assessment. In terms of the modal comparison, highway infrastructure is found to play a dominant role in economic growth at the national level, the state level and the metropolitan level.

Nationally, airports are the next most important public investment. The impact of public airport infrastructure was found much larger at the national level rather than at the northeast state level or the northeast metropolitan level. The regional impact of public passenger rail and transit varies among different geographic scales and locations. A higher impact from public passenger rail and transit investment was found at both the state and the metropolitan levels. After considering spatial spillover effects, the dissertation confirms that public passenger rail and transit infrastructure in the northeast megaregion make a substantial contribution to regional economic growth. Such impacts were much stronger than public airports' but significantly smaller than highways'.

Chapter 1 Introduction

Transportation infrastructure plays an important role in regional economic development both in stimulation of growth and as a response to output expansion. However, to measure these effects quantitatively has been a challenge. Due to the complexity of benefits of transportation infrastructure, they are difficult to measure accurately. Some benefits, such as job creation, can be measured at the micro level, while other benefits such as social welfare and wealth accumulation are often measured at the macro level. Since each investigation has to be implemented based on information for a specific region, period, infrastructure type or scale of analysis, findings are often not consistent. Consequently, conclusions and policy implications of each investigation are very specific, and not easily generalized or applied to other cases.

In recent years, there has been an increasing debate about how to fund U.S. transportation infrastructure effectively. Some favor a traditional approach such as investing in the existing highway systems. Others support a novel approach, such as investing in high speed intercity passenger rail. With the recent passage of *Federal Aviation Administration (FAA) Modernization and Reform Act of 2012* and *Moving Ahead for Progress in the 21st Century (MAP-21)*, the national transportation infrastructure systems were provided with additional financial resources for the year 2013-2014. How to allocate these funds or future funds more wisely and efficiently so that a higher level of social and economic returns could be generated becomes a critical challenge for decision makers. The interplay between existing supply and the increase of future demand is obviously a complex consideration for policy making and an understanding of the regional impacts of the existing systems is fundamental.

1.1 Research Highlights

To achieve the latter goal, this study is conducted to add a piece of new evidence to the existing literature. The study differs from previous studies in the following respects.

First, the focus of the study is on four mature public transportation infrastructure modes in the northeast megaregion in the United States: airports, highways, public railways, and public transit. The focus contains three levels of special consideration: a mature system, a multimodal perspective, and a focus on the northeast megaregion.

A large number of studies with a U.S. context have analyzed impacts of transportation infrastructure from a unimodal perspective. The U.S. highway system is most widely studied (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). This is understandable, as the highway system is the most dominant transportation mode in the U.S. in terms of usage. Obviously, the unimodal perspective can only provide information on one mode. Without considering the other modes such as airports, rail and transit, the impact analysis of public transportation infrastructure is partial at best. The issue becomes more apparent for regions like the northeastern megaregion where passenger rail services and public transit are heavily used. Therefore, a multimodal perspective is essential to achieve a comprehensive understanding of the public transportation infrastructure system.

Second, this study considers a mature public transportation system. A mature system differs from an evolving system. A mature transportation system refers to the system that has been completed and is currently at an evolved stage rather than at a developing stage. At the developing stage, economic impacts of public transportation infrastructure are not derived from the network effects such as a better connectivity and accessibility. Instead, impacts are usually from construction related activities, such as demand for raw materials, job creation and change in access. At an evolved stage, transportation networks are completed, but impacts from added transportation infrastructure can further be achieved through network effects as well as the effects from maintenance, operation and continuous technology upgrading activities. Clearly, because of the different effects, the impacts of transportation infrastructure are different at different stages and not even consistent across similar stages.

Mamuneas and Nadiri (2006) show the different effects of highway infrastructure at different stages. Based on the highway capital stock data from 1949 to 2000, they found that the elasticity of highway capital has been declining as the system has been completed. In an earlier period (1949 to 1959), the impact elasticity was 0.55, but it then fell to 0.48 during the decade from 1960 to 1969. During 1990 and 2000, it finally reached to 0.14, which was close to the long-term interest rate. Fernald (1999) had a similar finding showing declining effects as the U.S. highway system evolves. He found that the rate of return of highway investment was 0.14 per year before 1973 and 0.04 per year after 1973. One of the explanations for this decline is due to highway congestion, which has a negative impact on national productivity (Shatzet al., 2011)

Recognizing the different stage of transportation infrastructure is important especially when doing project comparison or modal comparison analysis, as it helps to avoid the mistake of "comparing apples and oranges". Meanwhile, such a consideration helps to improve understanding of economic impact of critical infrastructure under different conditions.

In the United States, the evolving stage of public transportation infrastructure varies by mode. The interstate highway system was constructed from 1956 to 1991. After the deregulation of aviation industry in the 1970s, public airports in the U.S. experienced dramatic developments. The key parts of airport infrastructure such as runways, terminals and control towers have been completed before 1990s.

The American railroad networks were completed even earlier, starting in the 1830s and continuing through the 1920s when the total railway mileage reached its highest level. Because of the bankruptcy of railroads during the 1950s and 1970s and major railroad policy reforms during 1970s, most of the current public rail services are operated on rail networks that belong to private railways. The exception is the main rail networks in the U.S. northeast megaregion which are publicly owned after the establishment of the National Passenger Railway Corporation (Amtrak) in 1971.

As regards public transit, most of the new transit network systems were built after 1960s in major U.S. cities (Kain, 1999). However, major transit systems in the northeast metropolitan cities, such as the subways in New York City, commuter rail in the Philadelphia metro areas, light rail system in Boston were all built much earlier.

Third, to provide context, a U.S. national level analysis is conducted even though the main focus of this study is on the U.S. northeast megaregion. This region is also referred to variously as Megalopolis (Gottmann, 1961), BOSWASH region (Kahn *et al.*, 1967), the northeast megaregion (Regional Plan Association, 2006; 2007) and northeast corridor (NEC) (USDOT, 1978). The term *megalopolis*, raised by Gottmann (1961), refers to the concept that “ the various cities contained in the region such as Washington, D.C., Baltimore, Philadelphia, New York City and Boston are despite discrete and independent, uniquely tied to each other through the intermeshing of their suburban zones, acting in some ways as a unified super-city.”

The transportation infrastructure in the northeast is unique in the U.S. Although highways and air transportation play dominant roles in terms of usage (Borthwick, 2001), intercity passenger rail and public transit are also heavily used. As indicated by Business Alliance for Northeast Mobility (2012), there are 750,000 passengers use intercity and commuter rail services between homes and work places in this region every day. According to Amtrak’s statistics, “the northeast corridor is the busiest passenger rail corridor in North America. More than three quarters of a million riders use the NEC on every weekday, generating more than 4.9 million daily passenger miles” (Amtrak, 2012).

Hence, public rail infrastructure is an important component in the northeast U.S. transportation system and is included in this assessment. The empirical multimodal investigation helps us to understand the nature of the public transportation infrastructure in this region.

Another reason why public rail is included in this assessment comes from the debates of high speed rail development in the U.S. Since the inauguration of President Obama in 2008, the national high speed rail plan has been elevated to a new stage. While the California high speed rail (HSR) project has received the most federal support so far, the proposal of adding a dedicated HSR line in the northeast megaregion has gained much attention as well. Amtrak (2010) reported that the new proposed HSR would reduce travel time from the existing 3 hours 45 minutes to 96 minutes between Washington D.C. and New York City, and from the existing 3 hours 37 minutes to 2 hours between New York City and Boston. Although some studies suggest that the northeast megaregion is the most suitable place to have HSR service in the U.S., it is a theoretical argument based on population density and geographic distance between major cities (Hagler & Todorovich, 2009; 2011). There is still a lack of empirical evidence showing the regional impact of public passenger rail services or the potential HSR services. Given the fact that Amtrak has a high speed rail service, named "Acela Express", that has been serving this megaregion for more than a decade (since 2000), it is valuable to assess the regional impact of such a system from an *ex post* standpoint.

Fourth, the linkage between public transportation infrastructure and regional economic output is assessed with three different methodologies, which not only includes the classical methods such as spatial econometric panel assessment and computable general equilibrium (CGE) assessment, but also a new quantitative approach called spatial econometric computable general equilibrium model (SECGE). As an integration of both spatial econometric analysis and CGE estimation, SECGE contributes new ideas for infrastructure impact analysis by controlling for spatial dependence under a general equilibrium framework.

The estimation procedure for SECGE modeling has five characteristics: 1) elasticity of factor substitution for constant elasticity of substitution (CES) production function for different sectors is estimated respectively based on financial data measured in real monetary terms; 2) spatial dependence is dealt through spatial econometric estimation; 3) regional impacts are measured in terms of output, household income and welfare in the response to transportation under a general equilibrium framework; and 4) impacts are measured at the micro level through the influences on final demand due to changes in transportation costs caused by infrastructure stock improvements, and 5) the efficiency of infrastructure investment is assessed at the macro level through the spatial econometric estimations of spillover effects. The outcome of SECGE is expected to be robust since the parameters of factor substitution elasticity are exogenously estimated and the issue of spatial dependence has been adequately controlled for. Thus results of CGE simulation are expected to be much closer to reality than traditional methods.

1.2 Analytical Structure

The analytical structure of this dissertation is illustrated in Figure 1. The rest of the study is organized as follows. Chapter 2 introduces the public transportation infrastructure from a contextual perspective. Chapter 3 lays a theoretical foundation for the study from the existing literature. Both advantages and disadvantages of relevant studies are discussed. Research questions and hypothesis are addressed in Chapter 4. The spatial econometric panel assessment is discussed in Chapter 5, followed by the national level CGE analysis in Chapter 6. Chapter 7 addresses the SECGE assessment at the northeast state level. Chapter 8 assesses using SECGE at the northeast metropolitan level. Chapter 9 summarizes and concludes.

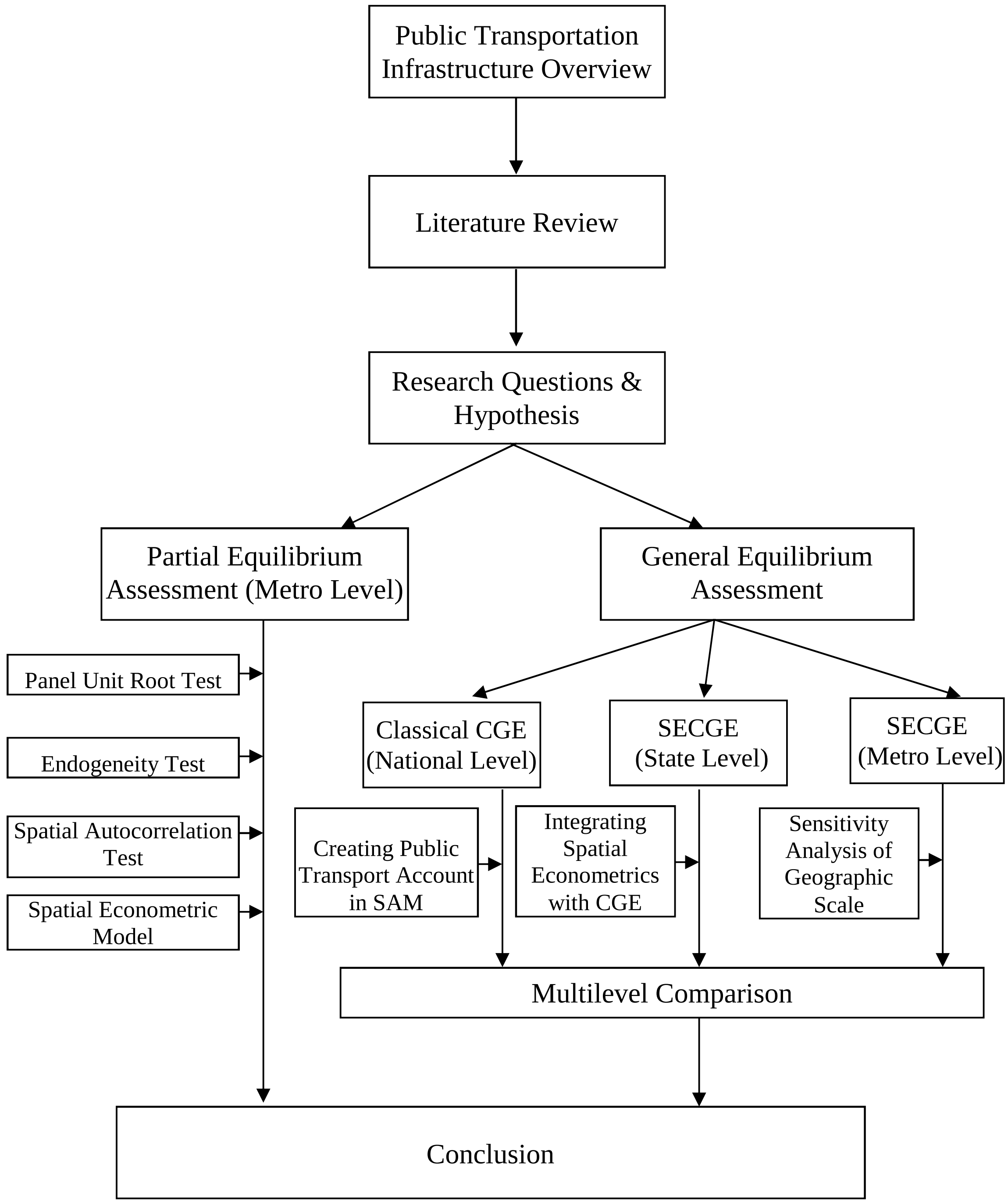


Figure 1 Analytical Structure

Chapter 2 Public Transportation Infrastructure in the Northeast Megaregion

According to the definition from America2050, megaregion is a new scale of geography which was formed by the interconnecting of metropolitan regions throughout the second half of the twentieth century. This new geographic scale has highly interlocking economic systems, shared natural resources and ecosystems, and an integrated transportation system that link various population centers together (Regional Plan Association, 2006). There are 11 meagregions in the United States, each of which covers thousands of square miles and is connected by large networks of metropolitan areas. The northeast megaregion is regarded as one of the largest agglomeration of people, economic activity and urbanized land (Regional Plan Association, 2007). The public transportation infrastructure in the northeast megaregion is unique in the United States because there are no other regions where all modes of transportation are heavily utilized. The overall transportation plays vital role in stimulating regional economic activities, facilitating social communication as well as knowledge exchanges. This chapter covers a brief overview of the development, current status and challenges of the public transportation infrastructure in the northeast megaregion.

2.1 An Overview

Public transportation infrastructure has a long history of development in the United States. Because the northeast megaregion contains the original location of

European settlements in the early eighteenth century, the first transportation infrastructure such as road, railway and transit were all built in the northeast states. Each mode of transportation experienced different evolution paths to reach its current status. Today, the northeast megaregion possesses a comprehensive transportation infrastructure system that includes highway, airport, railway, transit, pipeline and waterway.

One of the big concerns about the northeastern existing transportation infrastructure is that the system is aging rapidly and operating over its capacity due to a rapid population growth and economic development during the last two decades. In addition, the lack of sustainable public financial support results a shortage of funds for transportation infrastructure improvement. Side-effects such as roadway congestion, air and train travel delay has become severe social issues that cause negative impacts on regional economic growth.

During the period between 1991 and 2009, public transportation infrastructure capital stock in the northeast megaregion experienced various growth patterns both temporally and spatially across different metropolitan areas. Figure 2 illustrates the temporal and spatial variation of the overall transportation infrastructure capital stock that includes highway, public airport, public rail and transit. It shows that five metropolitan areas including Washington, D.C., Baltimore, Philadelphia, New York and Boston own the dominant transportation capital stock in the northeast megaregion. Among these five areas, New York metropolitan area possesses the highest value of public transportation infrastructure capital.

A similar growth pattern is found when comparing the temporal and spatial variation of the capital stock at the per capita level. As illustrated in Figure 3, the total transportation capital stock per capita in most metro areas experienced a modest growth during the last two decades. New York metropolitan area has a relative higher growth rate of transportation capital per capita between 1991 and 2009. In terms of spatial distribution, public transportation infrastructure capital stock varies substantially across different areas in the northeast megaregion. The central urbanized metropolitan areas such as Washington, D.C., Baltimore, Philadelphia, New York and Boston have a higher level of public transportation infrastructure per capita than the periphery metro areas on average. The disparity of public transportation infrastructure reveals the relative importance of different growth centers in the northeast megaregion.

The average annual growth rate of public transportation capital stock is illustrated in Figure 4. The northeast megaregion experienced a 3 percent annual growth rate of public transportation capital stock and a 2 percent annual growth rate of public transportation capital stock per capita on average during the period 1991-2009. Some metropolitan areas such as Providence-New Bedford-Fall River in Rhode Island and Massachusetts, Barnstable Town, and Springfield in Massachusetts, and the New York-Northern New Jersey-Long Island in states of New York, New Jersey and Pennsylvania have a higher average growth rate (above 4 percent) while other metro areas such as Manchester-Nashua in New Hampshire, Baltimore-Towson in Maryland, Bridgeport-Stamford-Norwalk and New Haven-Milford in Connecticut have lower growth rate (below 2 percent) of both public transportation capital stock in total and in per capita.

The Washington-Arlington-Alexandria metropolitan area has a growth rate of public transportation capital stock at 3 percent on average. However, the growth rate drops to only 1 percent annually after weighted by population change. The Concord metro area in New Hampshire had a negative annual growth rate of public transportation capital stock per capita during the period 1991-2009.

In the following sections, the temporal and spatial variation of public transportation infrastructure is discussed in details by mode. Challenges of infrastructure improvement of each mode are addressed as well.

2.2 Highway

Highway is the most dominant transportation infrastructure mode in the northeast megaregion and in the United States as a whole. Interstate 95 serves as the main artery, linking the five big metropolitan cities together and to regions outside the northeast U.S.. Due to the increasing traffic demand and usage, most of the Northeast's highways have reached their maximum capacities. The issues caused by highway congestion such as increase of travel time, energy consumption and air pollution become much severe than decades ago. Urgent repairs and upgrading are needed in many road sections just to maintain existing levels of capacity and solve gridlock.

The temporal and spatial distribution of highway capital stock and capital stock per capita are illustrated in Figure 5 and 6, respectively. Most highway capital stock locate in the five major metropolitan areas along the northeast I-95 corridor. The New

York metropolitan area owns the largest amount of highway capital. However, the spatial distributional pattern changes when the highway capital is measured at per capita level. After controlling for the variation of population, Baltimore-Towson in Maryland becomes the metro area with the highest value of highway capital stock per capita on average.

The temporal changes of highway capital stock differ across the metro areas. As illustrated in Figure 7, metro areas such as New York-Northern New Jersey-Long Island, Springfield and Barnstable Town in Massachusetts and Boston-Cambridge-Quincy in Massachusetts and New Hampshire, have a higher annual growth rate (above 4 percent) of highway capital stock on average, even after controlling for the population change, while other metro areas such as Manchester-Nashua and Concord in New Hampshire, the growth rate of both the highway capital stock in total and in capital terms are negative, which suggests highway infrastructure intensity in these areas are declining.

Overall, the average annual growth rate of highway capital is 3 percent and the average annual growth rate of highway capital stock per capita is 2 percent for the northeast megaregion during the period 1991-2009.

2.3 Public Airport

Public Airports are another critical infrastructure in the northeast megaregion. In this study, the public airport is defined as airport that is publicly owned and funded by the federal, state and local government. The study includes commercial airports such as

Dulles International Airport, John F. Kennedy International Airport, and the Baltimore–Washington International Airport. Regional and local airports such as Manassas Regional Airport in Northern Virginia and Beverly Municipal Airport in Massachusetts are also included. In total, 65 public airports are considered in this analysis (A list of public airports is included in appendix IV).

The temporal and spatial distribution of public airport capital stock and capital stock per capitaare illustrated in Figure 5 and 6, respectively. Similar to highways, the five major metropolitan areas including Washington, D.C., Baltimore, Philadelphia, New York and Boston hold the dominant public airport capital both in total and in per capita terms.

The growth rates of public airport capital stock and capital stock per capita vary across the northeastern metro areas. As illustrated in Figure 8, several metro areas experienced rapid annual growth rates (above 10 percent) of public airports both in total and in per capita levels. These areas include small metro areas such as Barnstable Town in Massachusetts, York-Hanover in Pennsylvania, Manchester-Nashua in New Hampshire, and Hartford-West Hartford-East Hartford in Connecticut. Large metro areas such as Providence-New Bedford-Fall River in Rhode Island and Massachusetts, and Washington-Arlington-Alexandria in Washington D.C. Virginia, Maryland and a part of West Virginia are also included. On the other hand, many metro areas experienced negative growth rates of both public airport capital stock and capital stock per capita. Metro areas such as Dover in Delaware, Concord in New Hampshire, Willimantic in

Connecticut, Lebanon and Harrisburg-Carlisle in Pennsylvania, Lewiston-Auburn in Maine, and Poughkeepsie-Newburgh-Middletown in New York, all have a negative 4 percent growth rate of public airport capital stock per capita.

2.4 Public Rail

Public rail in this study is defined as railway infrastructure that is publicly owned. The infrastructure is constructed, maintained and operated using public funds. Specifically, it refers to the National Passenger Rail Corporation (Amtrak), who provides intercity passenger rail services along the northeast corridor and owns most of the infrastructure. Commuter rail is also run on some shared facilities, but they are counted as public transit in accordance with the classification of the U.S. Federal Transit Administration. Private railroad companies such as CSX, Norfolk Southern and Pan Am Railway Lines also invest in railway infrastructure in this corridor. However, they are excluded in this investigation given the focus is only on "public" infrastructure.

The spatial distribution of public rail capital stock and capital stock per capita in Figure 5 and Figure 6 suggests that most public rail infrastructure stock locates along the five major metropolitan areas. During the period 1991-2009, public rail in the northeast experienced relatively faster growth than other modes. The average growth rate of public rail capital was 6 percent while the average growth rate of public rail capital per capita was about 5 percent. Figure 9 illustrates the differences of average growth rate of public rail capital both in total and in per capita across all metro areas in the northeast megaregion. There are five metropolitan areas whose average annual growth rates of public rail capital was over 20 percent, most of which happens in the upper New England states. Concord metro area in New Hampshire is one of them. The increase of public rail capital against a backdrop of a decline of capital stock of other modes suggests public transportation infrastructure in Concord, New Hampshire is shifting from highway and airport to public rail.

Although the ownership base of public rail infrastructure is large at metropolitan areas such as Boston, New York, Philadelphia, Baltimore and Washington, D.C., their average annual growth rates are relatively modest. Among all the metro areas who owns public rail infrastructure, only Dover in Delaware experienced both a negative growth rate for public rail capital and a negative rate for public rail capital per capita. This raises the question on whether public rail infrastructure is gradually substituted for other modes of transportation.

2.5 Public Transit

The definition of public transit is defined through the Federal Transit Act, which notes that it as "transportation by a conveyance that provides regular and continuing general or special transportation to the public, but does not include school bus, or intercity bus transportation or intercity passenger rail transportation (Amtrak)". This dissertation includes both major transit authorities such as Washington Metropolitan Area Transit Authority, Massachusetts Bay Transportation Authority, Metropolitan Transportation Authority, and small transit agencies such as City of Fairfax CUE Bus, York County Transportation Authority, and Manchester Transit Authority. In total the study covers 162 transit agencies (see appendix V for detailed information of transit agencies), including buses, metro rails, commuter rails and light rails.

Spatial and Temporal Variation of Public Transit Stock in total and in per capita level are illustrated in Figure 5 and 6 respectively. Similar to the distribution of other modes, the five major metropolitan areas account for the dominant public transit capital stock.

In terms of the temporal variation of public transit capital stock, the average annual growth rate of public transit capital is 5 percent. After controlling for the change of population, the average annual growth rate of public transit capital per capita is 4 percent. Both growth rates are higher than highway and airport, but lower than public rail. The detailed growth rate of public transit capital stock is illustrated in Figure 10. During the period 1991-2009, five metro areas including Springfield in Massachusetts, Norwich-New London in Connecticut, Lebanon in Pennsylvania and Kingston in New York had both annual growth rates of public transit capital in total and in per capita of over 10 percent on average. The public transit in major metropolitan areas such New York, Philadelphia, Boston and Baltimore had average annual growth rates ranging from 1 percent to 6 percent. Other metro areas such as Trenton-Ewing in New Jersey and Lewiston-Auburn in Maine had negative growth rates of public transit capital stock.

The public transit capital stock in Washington D.C. metropolitan area has a positive average annual growth rate at about 0.3 percent. However, after controlling for the population growth, the growth rate of public transit capital stock per capita becomes negative 1.1 percent, which suggests the public transit infrastructure input has not kept up with the pace of population growth.

2.6 Summary

Chapter 2 discusses the development of public transportation capital stock during the period 1991-2009. The descriptive statistics suggest that public transportation infrastructure distribution is unevenly both temporally and spatially. Although most public transportation infrastructure concentrates along the main corridor of the northeast megaregion in Boston, New York, Philadelphia, Baltimore and Washington, D.C., the distributional pattern varies after controlling for the change of population.

In addition, from the observation of average annual growth rates, public transportation infrastructure experienced quite different development patterns. These evidences suggest that advanced methodologies that considered for spatial characteristics of this distribution is needed to capture a full understanding of the regional impacts of public transportation infrastructure.

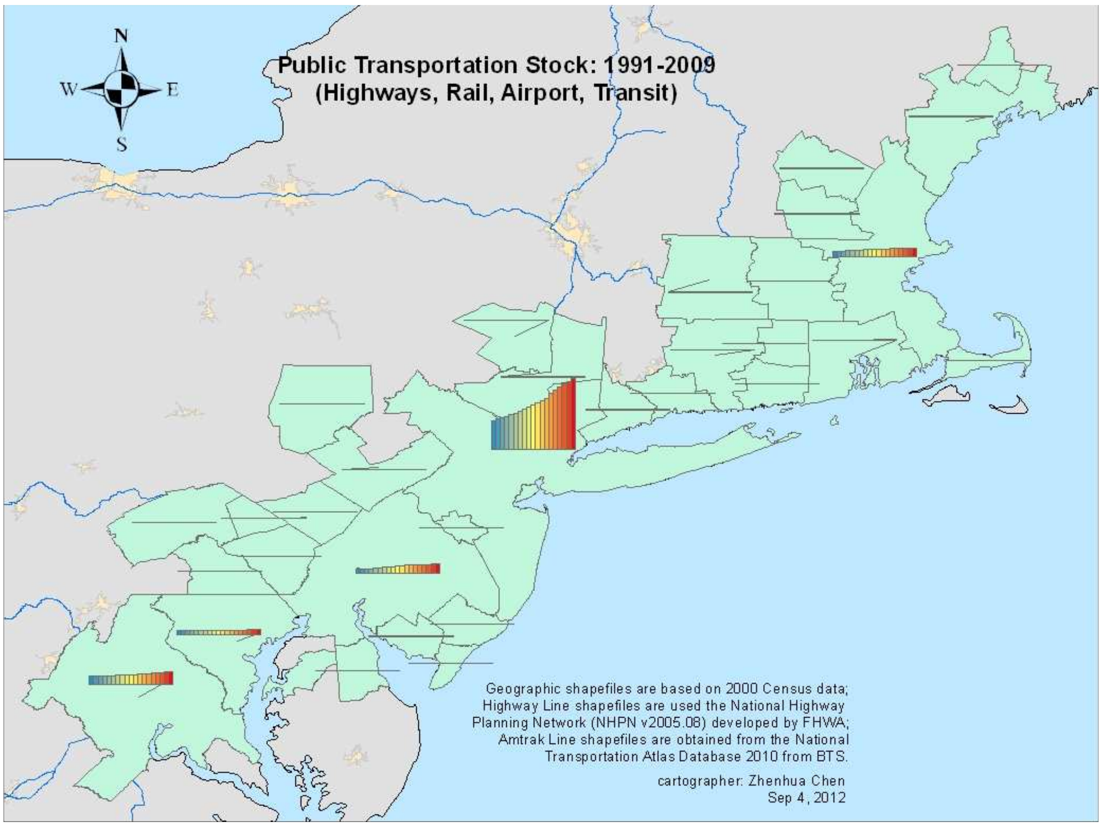


Figure 2 Temporal and Spatial Variation of Public Transportation Infrastructure Capital Stock in the Northeast Megaregion

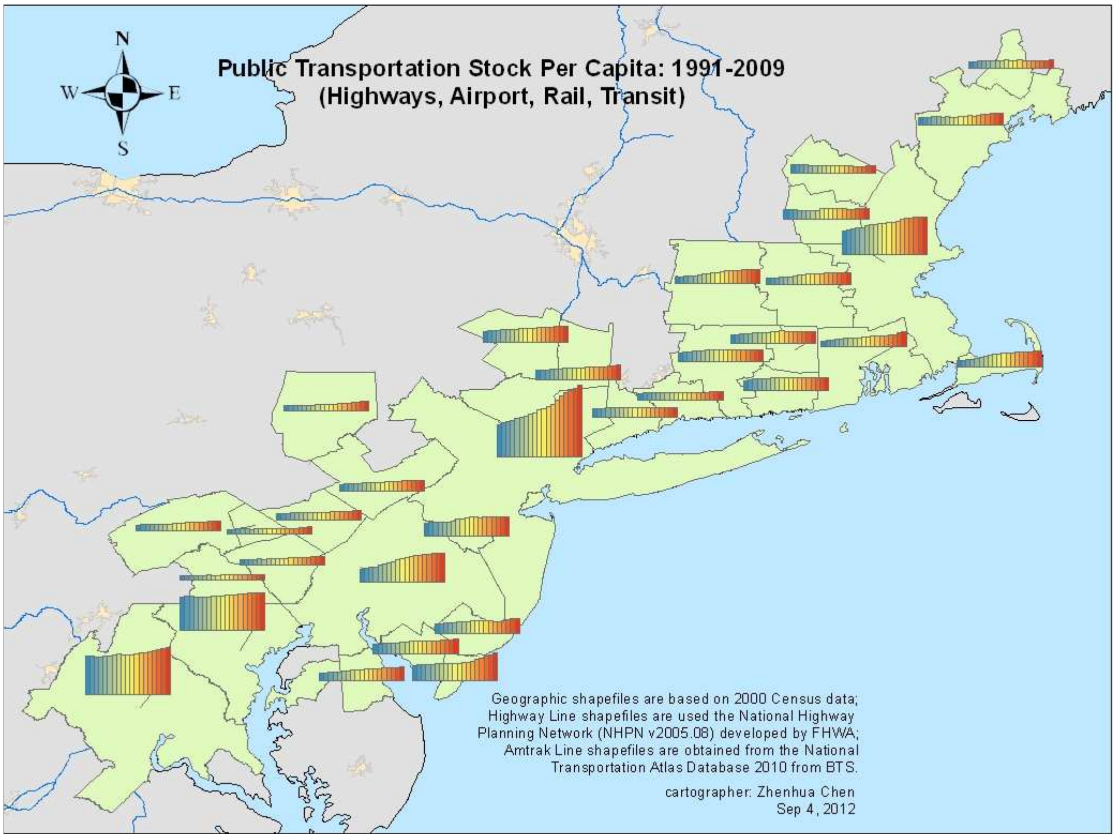


Figure 3 Temporal and Spatial Variation of Public Transportation Infrastructure Capital Stock per Capita in the Northeast Megaregion

Figure 4 Average Annual Growth Rate of Public Transportation Capital Stock

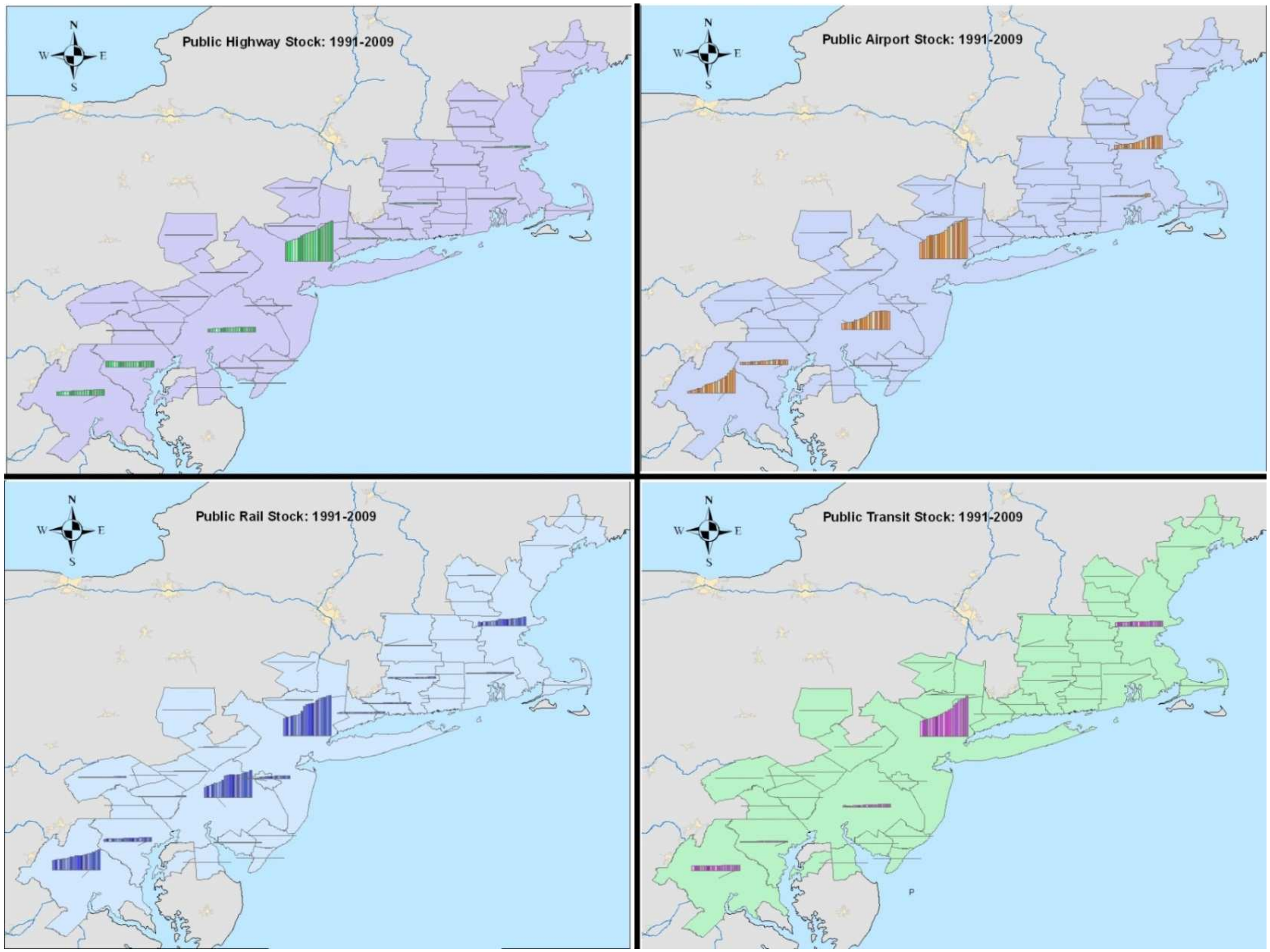


Figure 5 Spatial and Temporal Variation of Public Transportation Stock by Mode in the Northeast Megaregion

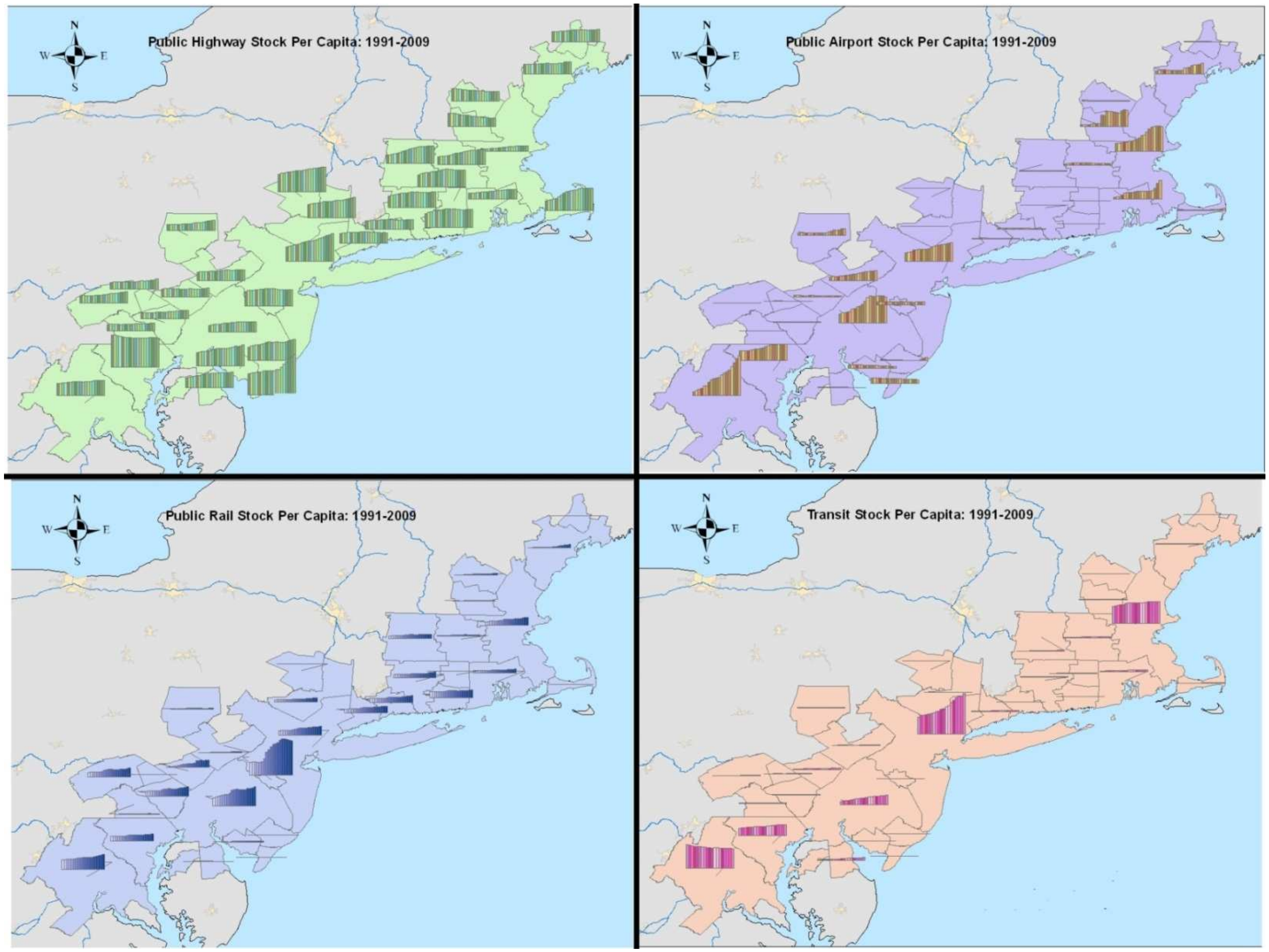


Figure 6 Spatial and Temporal Variation of Public Transportation Stock per Capita by Mode in the Northeast Megaregion

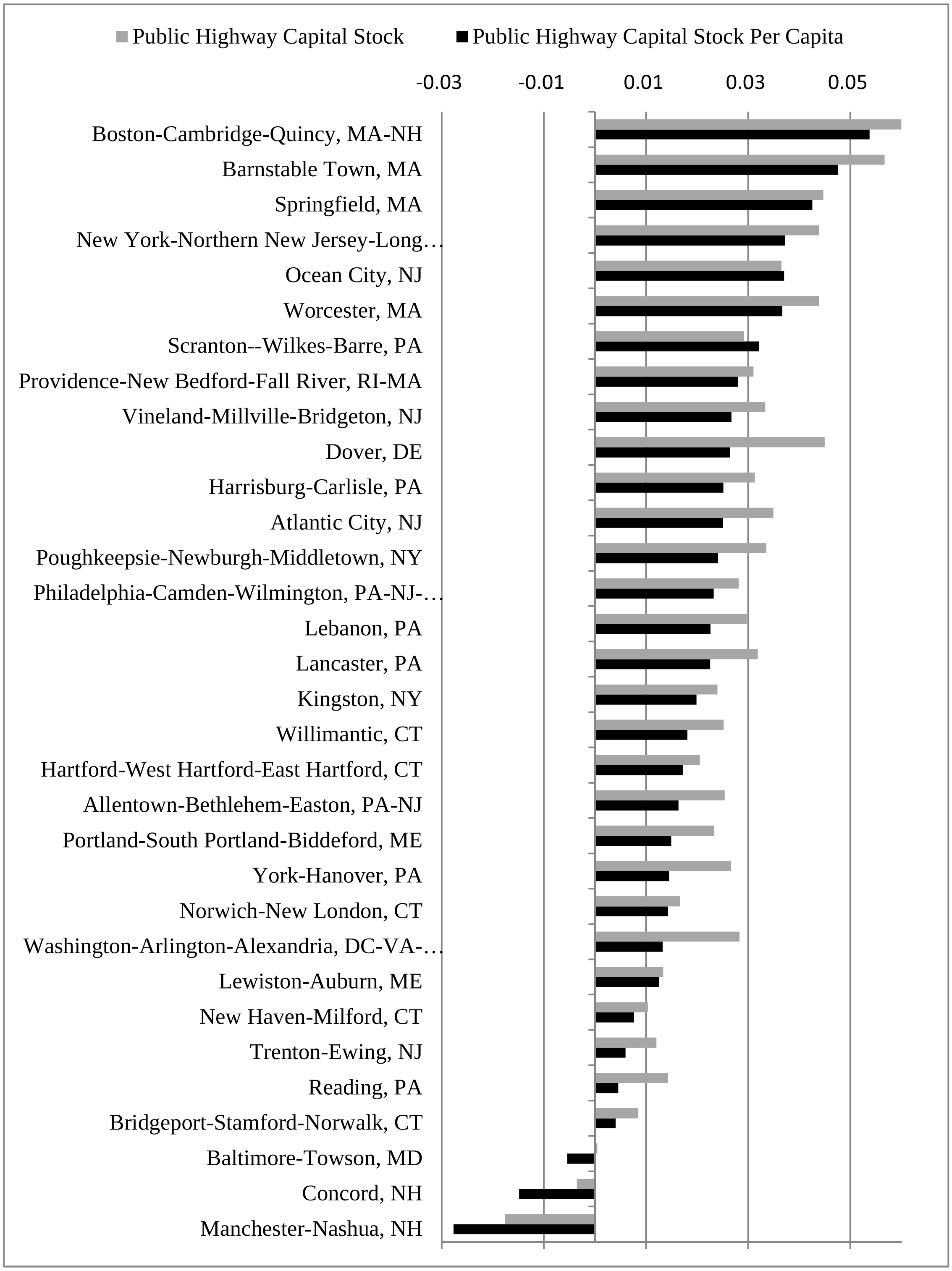


Figure 7 Average Annual Growth Rate of Public Highway Capital Stock

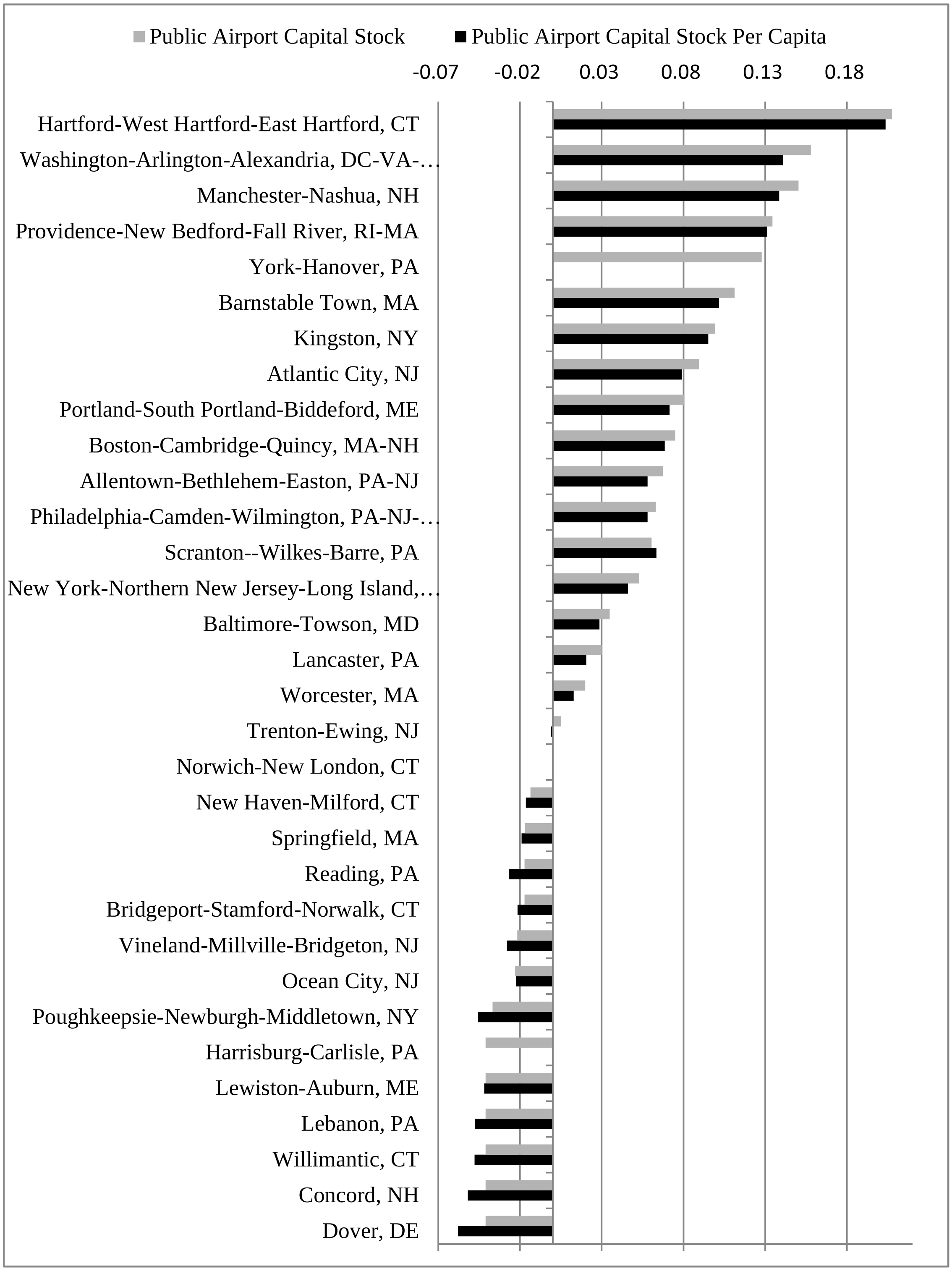


Figure 8 Average Annual Growth Rate of Public Airport Capital Stock

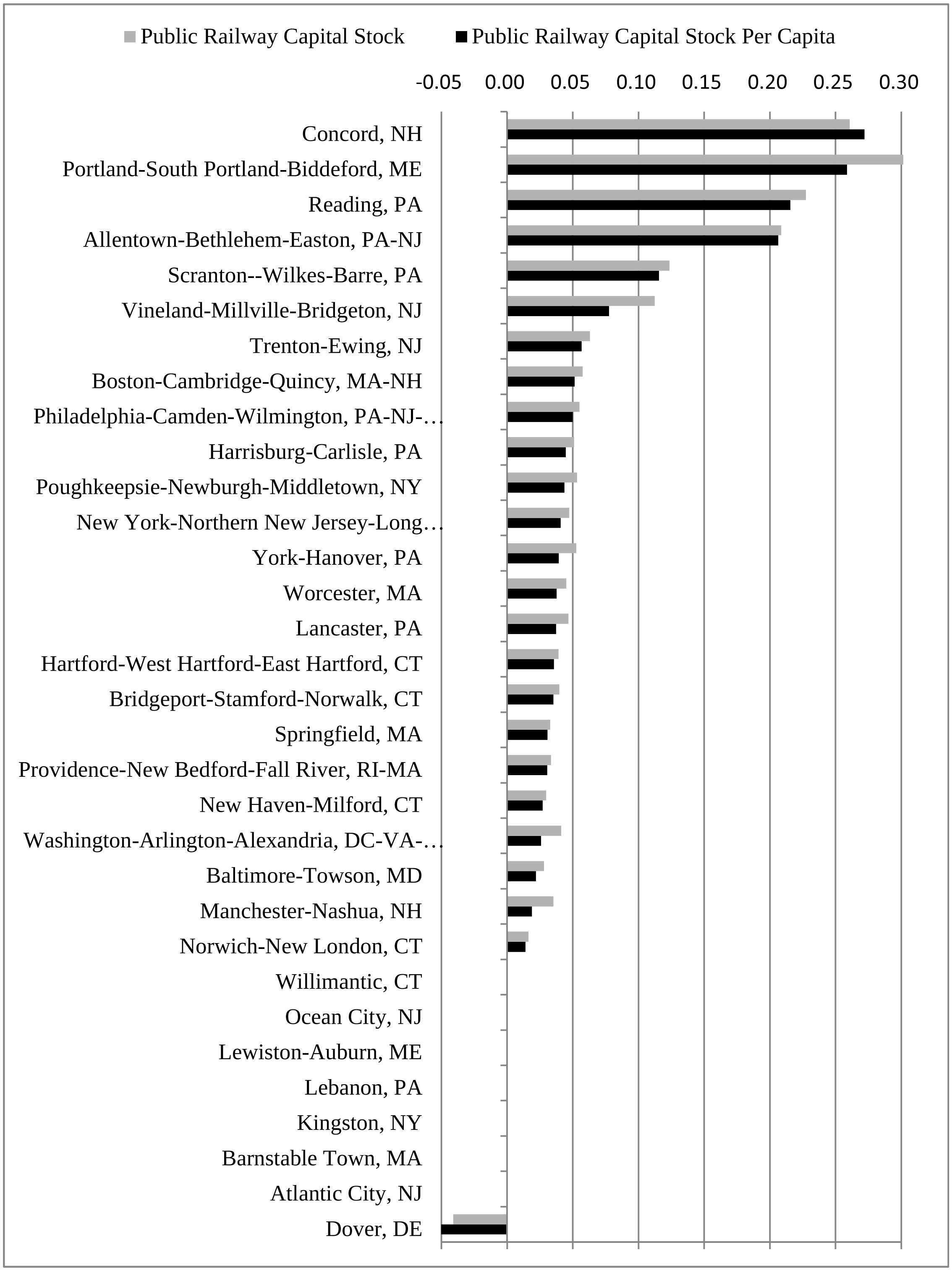


Figure 9 Average Annual Growth Rate of Public Railway Capital Stock

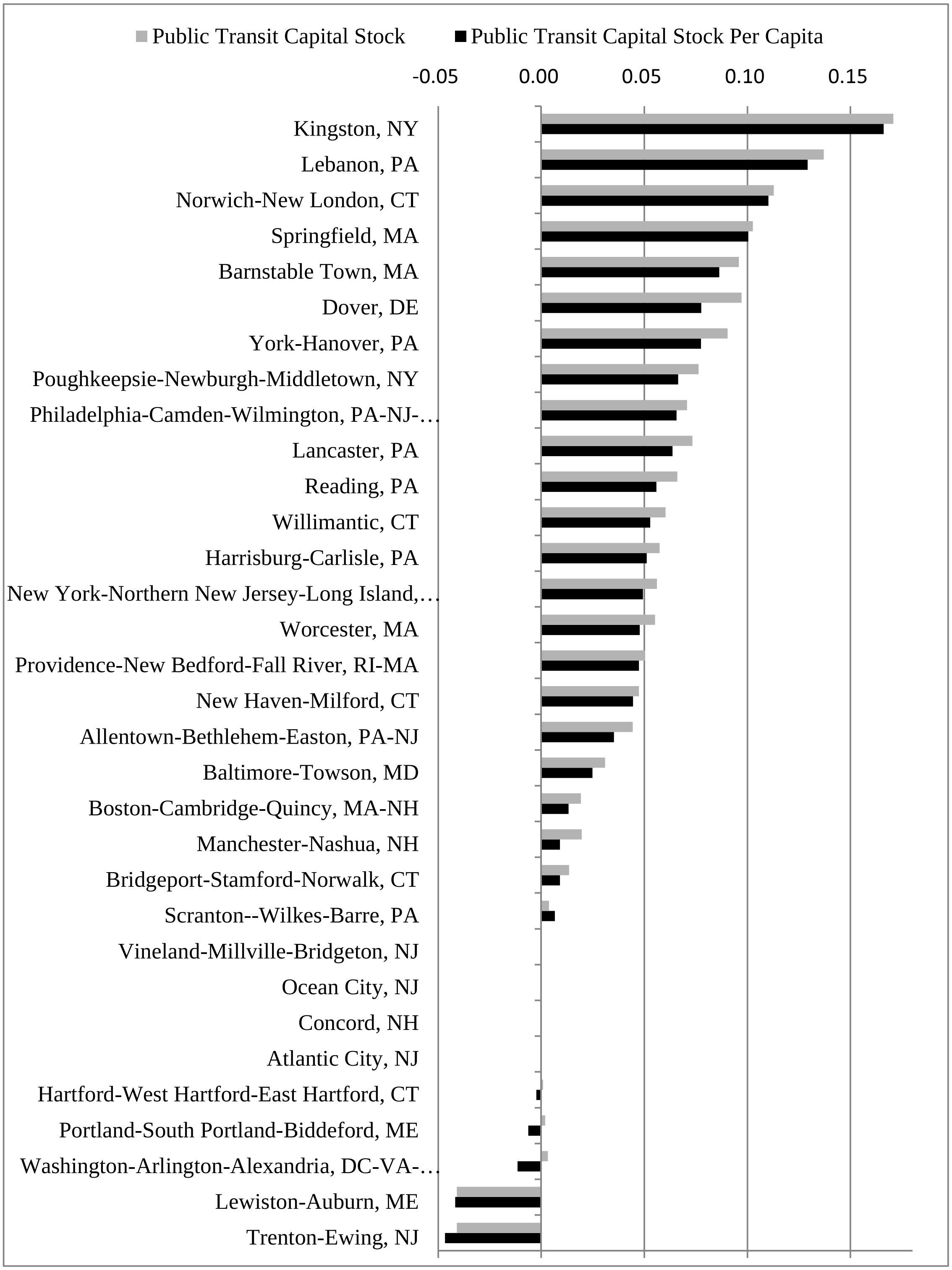


Figure 10 Average Annual Growth Rate of Public Transit Capital Stock

Chapter 3 Literature Review

The theories regarding regional impact of public transportation infrastructure are reviewed from three fields according to different analytic approaches: traditional neoclassical economic theory, spatial economics analysis and general equilibrium theory. Meanwhile, the necessity for a multimodal multiregional investigation is also discussed.

3.1 Traditional Economic Theory

The discussions of the economic impact of transportation infrastructure were not burst until the emergence of a series of papers by Aschauer (1989; 1990; 1994), which argued that enhancing infrastructure provision would facilitate regions to achieve their economic potentials. Since then, a large number of studies evaluating impact of infrastructure investment were carried out by following the neo-classical theory through some forms of aggregated production function approaches (Gramlich, 1994; 2001; Harmatuck, 1996; Nadiri & Mamuneas, 1996; Fernald, 1999; Bhatta & Drennan, 2003; Boarnet, 1997; Boarnet & Haughwout, 2000; Mattoon, 2002; Duffy-Deno & Eberts, 1991). Because of different evaluation methods, time periods, measures of economic outcomes, control variables being used, findings of these studies are not consistent. Some argued that the U.S. highway system had a positive and a large effect on productivity; (Harmatuck, 1996; Fernald, 1999; Keeler & Ying, 2008), although such effects diminished after the completion of the systems (Fernald, 1999). Others cast doubt on effects of public infrastructure by adopting different data, methods (Harmatuck, 1996; Boarnet, 1997; Button, 1998).

Specifically, Aschauer (1989) and Munnell & Cook (1990) analyzed the relationship between public capital and economic performance from 1970 to 1986 at the national and 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 & Cook, 1990) respectively, with highway alone contributing over a third of that benefit (0.06) (Munnell & 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 lower value of public capital elasticity of around 0.1, much smaller than what Aschauer and Munnell had found.

Scholars also argue that the scale of analysis matters in this kind of assessment. The rate of return declines in significance from the state to the national level. By using a general equilibrium model as well as a state level public capital data, Holtz-Eakin & Lovely (1996) found that public capital did not affect output significantly. Garcia-Mila *et al.*(1996) also found there was no positive relationship between public capital and private output.

These studies have been subjected to a variety of criticisms. After synthesizing related issues, Gramlich (1994) provides five summaries on the defects of these studies:

- Unclear causal relationship between infrastructure provision and economic performance;

- Vague definition of “infrastructure” making the quantitative analysis speculative.
- Policy variables should be short term levels to be consistent with infrastructure variable.
- Isolation of factors influencing macroeconomic performance is critical: from transport, to soft infrastructure including law, education, business services and defense.
- Different methodologies applied on different types of dataset, results in implications that attribute an imprecise quantitative estimation.

Further, these early studies do not consider the spatial interactions among unit of geographic location. These early analysis assume the existence of spatial homogeneity. However, as geographic scale of researched area changes, impacts of estimation change as well. Based on a meta-analysis on a large number of studies discussing highway infrastructure and economy, Shatz *et al.* (2011) indicate that the effects of highway infrastructure on the economic output vary when different levels of data are applied. They concluded that studies tended to find higher rates of return and strong productivity effects of highway infrastructure at the national level than at the state level and the sub-state level.

3.2 Spatial Economic Theory

Impact analysis of transportation infrastructure has also used spatial economic theory which considers the nature of spatial dependence and heterogeneity. Munnell

(1992) pointed out that the estimated impact of public capital becomes smaller as the geographic focus narrows. She believed that this is because of the effects of leakages from an infrastructure investment that 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, two issues arise due to violation of the Gauss-Markov assumptions: the first one is spatial dependence between observations and the second is spatial heterogeneity. Without considering these spatial issues, the estimation results may be statistically biased.

Thanks to the development of spatial econometric techniques by Cliff & Ord (1981), Anselin (1988), LeSage & Pace (2009), Elhorst (2010) and many other spatial scientists, a number of empirical analysis with spatial considerations have burgeoned in the field of regional science in recent years. One of the attractive functions of spatial econometrics is to allow for measuring spatial spillover effects. 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 a spillover effect on regional economic growth because the benefits generated from infrastructure would not be confined to that specific region (Moreno & López-Bazo, 2007). To test the hypothesis empirically, different types of spatial models were adopted (Holtz-Eakin & Schwartz, 1995; Kelejian & Robinson, 1997; Cohen & Morrison, 2003a; 2004). Again, because of different focuses of each study, there is no consistent conclusion whether spillover effects of transportation infrastructure are positive and exist significantly.

Boarnet (1998)constructed a spatial lag model in Cobb-Douglas production function form to investigate the spatial effects of public infrastructure (roads and highways) in California counties. His study found a negative spatial effect for the Californian road system, which he believed was caused by migration. By relying on panel data for the 48 contiguous states over the years from 1969 to 1986, Holtz-Eakin and Schwartz (1995) found that highway stocks do not have important spillover effects on private productivity. In Kelejian and Robinson's study (1997), a state-level aggregate production function was expanded to explicitly consider spillover. They found the estimation results are sensitive to model specification. A negative effect of highway stock is also found when introducing a variable representing the investments made in counties located further away from the investment location (Ozbay *et al*., 2007). In the case of Spain, through a spatial investigation on transportation infrastructure, Moreno and López-Bazo (2007) found a negative spillover in transport capital investment in Spain, despite the fact that a significant return to transport infrastructure was observed.

On the other hand, positive spillover effects of transportation infrastructure are found (Cohen & Morrison Paul, 2003; 2004; Cohen, 2007; Mohammad, 2009). Cohen and Morrison Paul conducted a series of studies aiming to find benefits of airports, highways and ports to the U.S. manufacturing sector, respectively. They applied cost functions with consideration of spatial autocorrelation adjustments on the data from 1982 to 1996. In their analysis, positive and significant spatial autocorrelation parameters were obtained, which they concluded as indications of positive spillover effects (2003; 2004). In terms of ports, they found that the elasticity of the shadow value of neighbors' ports with respect to their own state's ports infrastructure is negative and significant (2007).

Mohammad (2009) used a spatial panel model to explain the determinants of the spatial location of foreign direct investment (FDI) in Indonesia for the period of 1991-2004. He found a positive sign of the spatial lag of FDI, which he argued, is an indication of agglomeration. He also found that road infrastructure contributes to FDI location positively and significantly in the case of Indonesia. The neighboring effects were also found to exist.

A brief review of the existing literature regarding the economic impact of transportation infrastructure shows that the conclusions are not consistent given the fact that different data, methods, regions and periods are applied in each analysis. Despite the development of spatial econometric techniques enabling scholars to investigate spillover effects of infrastructure in a much comprehensive perspective, very few studies provide a clear theoretical motivation for the selection of spatial econometric models. In the circumstance when no solid evidences indicate whether a spatial dependence or spatial error model is preferred, LeSage and Pace (2009) recommend a spatial Durbin model be applied. Without adequate interpretation of the reasons for why a specific spatial model is used, it is likely that results of these studies may have estimation bias because of the potential of neglecting a certain kind of spatial issue.

3.3 General Equilibrium Theory

According to the traditional and spatial economic theories, impact analysis of infrastructure is conducted under the assumption of partial equilibrium. The associations of economic output and infrastructure projects are usually evaluated only from the supply side by assuming the demand of infrastructure is constant during research period. Obviously, under such an analytical framework, the outcome of economic impact is partial since the impact caused by the change of demand cannot be captured. 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 on both supply and demand sides, a general equilibrium framework is required.

Computable General Equilibrium (CGE) which was firstly developed by Johansen (1960) is an economic model that enables impact analysis with consideration of both demand and supply. CGE is constructed from neo-classical economic theory. The theoretical framework relies on the Walras-Arrow-Debreu theory of general equilibrium, with modern modifications and extensions allowing for imperfect markets (Bröcker, 2004, p269). Because CGE provides a clear linkage between the microeconomic structure and the macroeconomic environment, the model can be used to not only describe the interrelationship among multiple industrial sectors and markets, it can be also used to assess both direct and indirect effects from the change of public policy on various kinds of economic variable such as output, employment, prices, income and welfare.

The structural units of a CGE model consist of producer, consumer, government, and foreign economy. The fundamental assumptions on producers and consumers in CGE are that producers are seeking profit maximization while consumers seek utility maximization both within constraints of their resources. The process of production can be normally illustrated by a production function or a constant equation substitution function. 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 on the economy. On the other hand as a consumer, government revenue that comes from taxes and tariffs 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 domestic market and export is illustrated by a constant elasticity transformation (CET) in the CGE model (Bröcker, 2004).

The economic equilibrium in CGE includes a set of equilibriums:

- Market equilibrium of goods requires equilibrium on both quantity and value.
- Assuming no labor migration and institutional barriers, market equilibrium of factors requires equilibrium in the labor market.
- Equilibrium of capital markets indicates total social investment equals total social saving.

- Government budget equilibrium requires that the budget deficit must equal the difference between governmental revenue and expenditure.
- Assuming personal income only comes from wage and interest of saving, personal balance equilibrium indicates that personal saving must be equal to the difference between personal income and expenditure;
- International market equilibrium requires foreign deficit represents inflow of foreign capital while foreign saving represents outflow of domestic capital.

The applications of CGE in evaluating impact of transportation infrastructure are quite abundant. Depending on the stages of infrastructure, impacts can be evaluated differently. For instance, the direct impact of transportation investment such as job creation, demand for raw materials, etc., can be measured by examining linkages of the transportation sector with other agencies including, consumer, producer, government. On the other hand, the indirect impact of transportation infrastructure such as reduction of transportation cost due to network improvement, can be measured by examining the variation of trade margins among different regions. Because the impact is measured under a general equilibrium among multiple regions, this model is often named as spatial CGE or SCGE.

In the recent decades, different types of SCGE models were established to evaluate impacts of certain transport policies. Miyagi (2006) evaluated economic impacts in relation to the accessibility change using 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).

Another SCGE that applied to transportation evaluation was conducted by Goce-Dakila and Mizokami (2007) with a focus on the Philippines. By considering seven production sectors and three types of households by income level, they established a five-region Social Accounting Matrix (SAM) to calibrate the baseline parameters of the SCGE. Their findings show that technological improvement in land transport has the highest impact on output (Goce-Dakila & Mizokami, 2007).

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.

The theoretical rationale behind the spatial economic impact of passenger transport is that "technical change results from knowledge production, the main input …is knowledge. Interregional transfer of knowledge is costly, even with modern telecommunications. To a large extent, high level and tacit knowledge is incorporated in human beings, and these knowledge exchanges require face-to-face contact. Hence, interregional knowledge flows are influenced to a great extent by the cost of passenger transport. This implies that passenger transport cost may influence the speed and the spatial pattern of innovation and thus have an impact not only on the levels of but also on the rates of the growth of economic activity." (Bröcker, 2004, p284)

Generally speaking, depending on the specific research needs, different types of SCGE models are developed for impact analysis of transportation infrastructure. For instance, the *Pingo* model was a static CGE model used to forecast regional and interregional freight transport (Petersen, 2004). *CGEurope* is another SCGE model developed by Bröcker (1998). It 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 *MONASH* model is another widely used multi-regional, multi-sectoral dynamic CGE model, which allows for different choices of the levels of sectoral and regional disaggregation (Dixon & Rimmer, 2000). Transportation sectors in this model are treated as marginal sectors where the costs are imposed on the purchase price of goods tradables in trade and service (Sundberg, 2005). The *Diao and Somwaru* model which was originally used to analyze effects of the MERCOSUR (Southern Common Market including four South American countries), is a multi-regional, multi-sectoral dynamic CGE model. This model is not a transportation SCGE model since no transport cost inferred on trade is considered (Sundberg, 2005).

3.4 Unimodal vs. Multimodal

In addition, as mentioned earlier, most of these studies only provide a unimodal focus. Some only focused on public capital or transportation infrastructure in general (Duffy-Deno & Eberts, 1991; Berndt & Hansson, 1992; Kelejian & Robinson, 1997) while others only focused on a specific mode such as highways, airport or ports (Holtz-Eakin & Schwartz, 1995; Cohen & Morrison Paul, 2003a; 2004; Cohen 2007; Ozbay *et* *al.*, 2007). Only a few of studies investigated the issue with a multimodal perspective (Addersson *et al.*, 1990; Blum, 1982; Cantos *et al.*; 2005).

For instance, Andersson *et al.* (1990) provided an investigation of the linkages between output and infrastructure for Sweden in 1970 and 1980, in which air, road, rail and building capital were included. Their findings reveal that the regional outputs of different modes vary in different times (Andersson, *et al.* 1990). Blum(1982) studied transportation infrastructure and regional growth of Germany in 1970 and 1976, in which four types of infrastructure were included: long-distance road infrastructure, all other roads, rail and ports. His results showed that all roads and ports have significant impacts while rail has a zero and even a negative impact (Blum, 1982). The main criticism of these studies is that non-dollar values of infrastructure stocks were used. As a result, the estimations may be seriously biased.

Another comprehensive analysis including modal comparisons was conducted by Cantos *et al.* (2005) with a focus on the Spanish system during the period of 1965 to 1995. By using a production function and the total productivity function, they found that roads and ports have comparatively more important network effects than rail and airports (Cantos *et al.*, 2005). However, their study doesn't explain whether monetary or approximate values of infrastructure stocks were used. The estimation results also lead to a suspicion of multicollinearity as some of the variables may be serially correlated.

Chapter 4 Research Questions and Hypothesis

Although a large number of studies were conducted to evaluate the regional impact of transportation infrastructure, there are very limited studies use a general equilibrium framework that controlling for spatial issues such as dependence. It is rare to find studies that have a perspective allowing for modal comparison. The lack of a multimodal perspective may constrain understandings on regional impacts of the overall transportation infrastructure, particularly in regions where multimodal transportation infrastructure are well established (mature). In general, the existing literature regarding regional impact analysis of transportation is still not sufficient due to:

- lack of a general equilibrium analysis with consideration of spatial dependence;
- lack of analysis with a multimodal perspective that allows for modal impact comparison;
- lack of attention on the transportation infrastructure in the northeast megaregion in the US, where the infrastructure networks are well established.

This study intends to fill these gaps by conducting an empirical investigation with a multimodal focus on the transportation infrastructure in the northeast megaregion of the U.S. The analysis is conducted under a general equilibrium framework while controlling for spatial dependence. The expected findings differentiate the relative importance of transportation infrastructure by mode and by comparing their impact on regional output. To achieve these research objectives, the following questions are answered sequentially in this study:

Question 1: how does the public transportation infrastructure capital contribute to regional economic growth after controlling for private capital and labor?

In this analysis, transportation infrastructure includes four modes: airports, highways, public railways, and public transit. Despite the fact that there are no empirical studies that specifically investigate the regional impact of transportation infrastructure in the northeast megaregion, there is evidence that highways and public rails do have a positive influence on the economic output (Nadiri & Mamuneas, 1996; Fernald, 1999; Bhatta & Drennan, 2003; Boarnet, 1997; Boarnet & Haughwout, 2000; Mattoon, 2002;Duffy-Deno & Eberts, 1991; Amtrak, 2012). Therefore, the hypothesis for this question is defined as: the transportation infrastructure does have a positive influence on regional output.

Question 2: how do such impacts vary among airports, highways, public rails and transit?

Since the existing literature doesn't provide any impact comparison among different transportation modes, it is inconclusive how impacts of transportation by mode may differ. However, given the fact that highway is the most dominant transportation mode in terms of vehicle miles travel as well as public financial support, it is reasonable to assume that highway may have a dominant regional impact as compared to airports, public rail and transit infrastructure.

Question 3: are there any spillover effects from the transportation infrastructure? And if yes, how do these effects vary for each mode?

Transportation infrastructure investment may have spillover effects because of the potential network effects as well as the competitive nature of public investment. On the one hand, completion of transportation infrastructure network among two regions may benefit each other due to better connectivity and accessibility. As a result, regional economic growth could be achieved because of the significant reduction of transportation cost of both goods delivery and labor mobility. On the other hand, economic agglomeration may happen because of declining of spatial and temporal distance. Labor and raw material may start to flow into one region from other regions. Consequently, the growth of one region may be achieved while leaving other regions stagnant when assuming the existence of scant resources in the society.

This unequal regional impact of transportation infrastructure may also happen due to the competitive nature of public investment. In other words, positive economic growth is likely to be achieved when a heavy public investment occurs in one region relative to other regions. This may induce a negative impact on regional growth in other regions because of insufficient public investment. In sum, whether spillover effects exist among different modes of transportation deserves thorough investigation. Thus the null hypothesis can be defined as there is spillover effect from transportation infrastructure.

Question 4: does the impact differ when comparing the estimation with and without consideration of spatial dependence in CGE?

One of the highlights of the research is to evaluate the impact of transportation infrastructure under a general equilibrium context but also consider issue of spatial dependence. To test whether considerations of spatial issues does have statistical difference from traditional approach, a comparative analysis will be conducted under the general equilibrium context with different scenarios of spatial consideration. Thus the null hypothesis for question 4 is defined as: there is no statistical difference of impact when comparing the estimation with and without consideration of spatial dependence in CGE.

Chapter 5 Spatial Econometrics: Metropolitan Level Assessment

The theoretical motivation of this study is to follow the path of the new economic geography theory in testing for spillover effects of public transportation infrastructure under a systematic spatial econometric approach. As Fingleton & López-Bazo (2006) and Gibbons & Overman (2012) pointed out many regional studies modeled externalities in a somewhat *ad hoc* manner which often fails to consider the causes of externalities. For example in Boarnet (1998)'s path breaking work, spatial dependence was only considered for the variable of streets and highway. The externalities of regional output as well as labor and private capital were not mentioned. Given the nature of his modeling structure, the finding of a negative spillover of public streets and highways may be suspect.

This study intends to test Boarnet's hypothesis of negative output spillovers from public infrastructure. To make the analysis consistent with Boarnet's study, a neoclassical growth model in the form of a Cobb-Douglas function is established. In addition, the study expands Boarnet's work in the following ways: first, public infrastructure includes not only highways and streets, but also public airports, public rail and public transit. This multimodal focus differentiates the relative importance of public transportation infrastructure by mode and by their impact on regional output. Second, the Hausman test is conducted to check for the endogeneity issue of regressors in the models. Third, a systematic spatial modeling selection approach is introduced to achieve a rigorous estimation.

The scale of assessment is Metropolitan Statistical Areas (MSAs) that compose this northeast megaregion. They are defined as “a geographical region with a relatively high population density at its core and close economic ties throughout the area” (Nussle, 2008, 1-2). The reason for selecting MSA as the scale of assessment is because the transportation study area in the northeast is defined primarily as a passenger railway corridor. Most of the region is urbanized to a metropolitan level with relatively high population densities. To conduct the study at the MSA level would be appropriate to capture the scale effects of transit and public rail infrastructure on regional economic performance. A list and a map of all the researched MSAs are illustrated in Appendix I and II respectively. In total, the area includes 30 MSAs and 2 Mircopolitan statistical areas (MircoSAs).

5.1. Data

5.1.1 Data Selection

Due to data limitations, it is a challenge to find transportation capital stock data measured in real terms. Many studies use approximate variables as alternatives, such as mileages of highways, rail lines, numbers of air passengers (Adderrson, *et al.*, 1990; Jiwattanakulpaisarn *et al.*, 2009), or numbers of freight rail stations (Blum, 1982), to approximate a quantified level for infrastructure stocks. Usually, these proxies are not as accurate as the capital stock in real terms especially when the purpose is to measure the impact of infrastructure capital.

While most of the economic variables are publicly available, it is a challenge to find transportation variables measured in monetary terms which can be adjusted to real terms. This is an even greater challenge for investigation at a disaggregated level both spatially and by mode. In the U.S., most capital stock data are only available at the aggregated level provided by the Bureau of Economic Analysis (BEA). The most relevant data for transportation capital stock by mode can be found in *Transportation Statistics Annual Reports* published by the Bureau of Transportation Statistics (BTS).

However, this data is not adopted in this study for two reasons: First, the data is only available for years from 1998 to 2008. The earlier years of data were not collected. Second, the majority of the data reflects privately owned capital stock. Public capital stock of rail and transit are unfortunately combined in the category named “other publicly owned transportation”. A further follow-up with officials in BTS and BEA confirmed the impossibility of disaggregating this data. Therefore, the public rail capital stock and transit stock in the northeast corridor have to be estimated based on the financial information gathered from the U.S. Census Bureau, Federal Highway Administration (FHWA) and Amtrak.

5.1.2 Data Refining

The collected data has to be converted into a standard format so they can be used for analysis. In this study, all variables are converted into the form of per capita measured in 2005 real dollar terms. Variables at a per capita level instead of at a gross level help to reduce influences of demographic variations and the size effect of each MSA. The variables are refined in the following steps. The first step is to aggregate or disaggregate the original data to the unified MSA level based on a specific weight. Private fixed asset was disaggregated from the national level by using the ratio of industrial earning (each MSA / national level). Data of Gross Metropolitan Product (GMP) per capita (adjusted 2005 dollars) and employment are directly retrieved from the BEA website (www.bea.gov).

Second, this assessment concentrates on public transportation capital. The concept represents stock rather than flow. Public transportation capital stock is adopted as the indicator of transportation infrastructure inputs. Since no disaggregated transportation infrastructure stock data is publicly available, they have to be calculated manually. The traditional perpetual inventory method (PIM) through the following function is adopted to calculate the stock of each mode:

$$TK_t = (1 - \delta)TK_{t-1} + TI_t \qquad (1)$$

where *TK* and *TI* indicate transportation capital stock and transportation investment, respectively. δ denotes the geometric depreciation rate of transportation stock. The geometric depreciation rate has been regarded as the appropriate value for infrastructure asset studies and has been commonly adopted by BEA (Katz & Herman, 1997). As far as the value of δ is concerned, the rate normally taken is 4.1% in most literature (Holtz-Eakin, 1993; Hulten & Wykoff, 1981; Ozbay *et.al*, 2007).

Table 1 Data Refining Process

	Original Data	Sources	Initial Stock	Method
GMP	Regional Data, GDP by State	BEA	-	-
Private fixed asset	Table 6.1. Current-Cost Net Stock of Private Fixed Assets by Industry Group and Legal Form of Organization Table 6.2. Chain-Type Quantity Indexes for Net Stock of Private Fixed Assets by Industry Group and Legal Form of Organization	BEA	-	Following Garofalo and Yamarik (2002), the national capital stock estimates is apportioned to each metro area using annual private industry earning as a proxy.
Employment	CA04 Total Employment (number of jobs)	BEA	-	
Public rail capital stock	Amtrak NEC Infrastructure Expenditure Amtrak Facts Sheet of States VA, MD, DE,PA,NJ, NY, CT, RI, MA, NH, ME, and the District of Columbia	Amtrak Department of Engineering Department of Public Affairs[1]	Federal Grant to NEC project from 1972 to 1990[2]	Perpetual inventory method (PIM), infrastructure expenditure is apportioned by ridership. Capital procurement is based on geographic location.
Highway capital stock	Annual Survey of State and Local Government Finances and Census of Governments (1970-2009)[3]	U.S. Census Bureau	PIM estimated based on 1970-1990	Aggregated from individual government units based on their jurisdictional locations.
Transit capital stock[4]	Annual Survey of State and Local Government Finances and Census of Governments (1970-2009)	U.S. Census Bureau	PIM estimated based on 1970-1990	Aggregated from individual government units based on their jurisdictional locations.
Airport capital stock	Annual Survey of State and Local Government Finances and Census of Governments (1970-2009)	U.S. Census Bureau	PIM estimated based on 1970-1990	Aggregated from individual government units based on their jurisdictional locations.
Population	BEA CA1-3 Person Income Summary[5]	U.S. Census Bureau	-	-

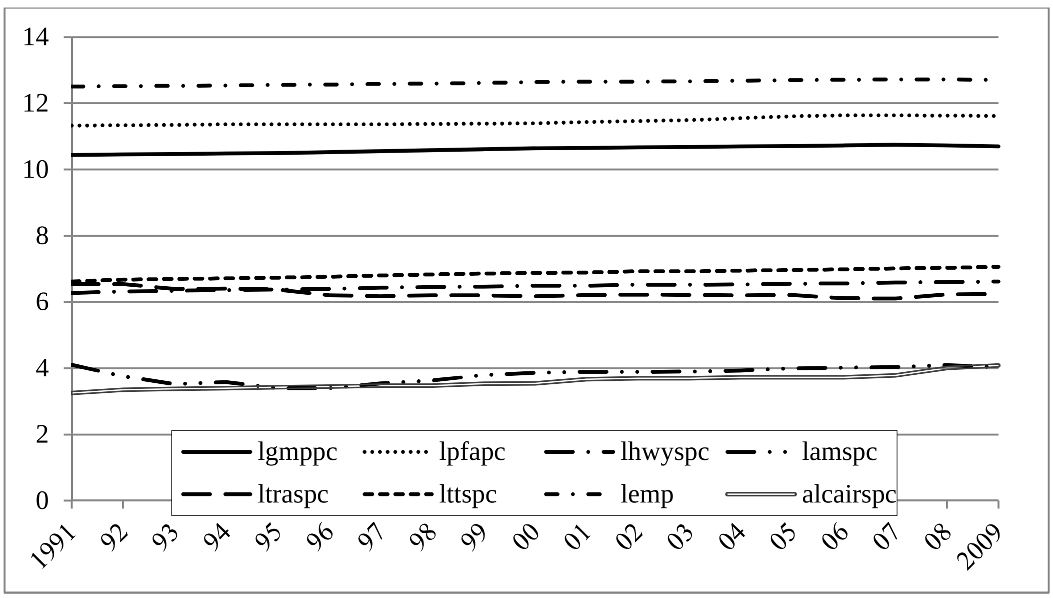
Note: 1. Northeast corridor capital infrastructure expenditure includes data from 1990 to 2009 for the mainline, and is obtained from department of engineering Amtrak. Data only includes capital expenditures on safety and reliability and high-speed rail facilities. Data includes federal, state and local government expenditure.

2. The initial railway infrastructure stock of northeast corridor contains two parts. The majority of the corridor assets were purchased from the Consolidated Rail Corporation (Conrail) during 1976-1980 as part of the disposition of the Penn Central Transportation Company's assets (U.S. Government Accountability Office, 2004, 7). The second part was formed from the Northeast Corridor Improvement Project from 1976 to 1990 (Federal Railroad Administration, 1998).

3. Data includes federal, state and local government expenditure.

4. Transit modes include bus, commuter rail, light rail and personal transit.
5. Census Bureau midyear population estimates.

The initial level TK_{1990} of each mode are collected or estimated through different sources. Despite many difficulties, the study has have tried to get as close as possible to improve the accuracy of the data. The detail of data refining process is illustrated in Table 1.



* Total number of observation: 608. All variables were measured in level and in logarithmic term. gmppc=GMP per capita, emp=employment, hwyspc=highway stock per capita, airspc= public airport stock per capita, amspc=public rail stock per capita (Amtrak Northeast Corridor), traspc=transit capital stock per capita, ttspc=total transportation stock per capita (highway+public airport + public rail+ public transit).

Figure 11 Temporal Variations of the Variable Means

Next, all stock per capita is converted to real 2005 US dollars to eliminate the impact of inflation. The World Bank Gross Domestic Product (GDP) deflator for the United States is applied to all transportation stock variables. Ultimately, all financial data were converted into 2005 US dollars. The temporal distributions of all variable means are illustrated in Figure 11. After the logarithmic transformation, the means of all variables are stable during the period between 1991 and 2009, which suggests that the per capita based variables are stationary. Descriptive statistics of all variables are displayed in Table 2.

The distribution of public transportation infrastructure in the northeast megaregion is quite uneven in terms of both mode and geography. In terms of modal comparison, highway has the highest value of average stock per capita while public rail has the lowest. As regard to geographic comparison, the regional differences of stock vary widely. For instance, the highest highway stock per capita is $2,168, which is for the Ocean City MSA in New Jersey in 2009.The lowest amount is $108 per capita, which is in Boston-Cambridge-Quincy MSA in 1991. Trenton-Ewing MSA in New Jersey has the highest amount of public rail stock per capita whereas the amount equals zero in MSAs such as Willimantic MicroMSA in Connecticut, Lebanon MSA in Pennsylvania, and Lewiston-Auburn MSA in Maine where there is no public rail service. Transit stock has a similar distributional pattern. New York-Northern New Jersey-Long Island MSA has the highest amount of transit stock per capita while MSAs such as Vineland-Millville-Bridgeton MSA in New Jersey, Willimantic MicroMSA in Connecticut has no public transit stock. Washington-Arlington-Alexandria MSA has the highest public airport capital stock per capita while some regions have almost zero public airport capital stock due to negligible amount of public airport expenditure. In sum, the distribution of public transportation infrastructure in the northeast regions is quite uneven. Understandably, most of these stocks are clustered in urbanized and population dense MSAs along the northeast corridor main lines, such as Washington D.C., Baltimore, Philadelphia, New York and Boston. This could imply the existence of positive spatial autocorrelation.

Table 2 Descriptive Statistics

Variables	**Mean**	**Std. Dev.**	**Min**	**Max**	**Unit**
gmppc	41387	9341	26408	89688	2005$
emp	874057	1846585	41942	1.10e+07	No. of jobs
pfapc	95733	23109	37527	220121	2005$
hwyspc	714	330	108	2168	2005$
amspc	71	103	0	668	2005$
traspc	281	649	0	3871	2005$
airspc	95	148	0	928	2005$
ttspc	1161	896	329	5935	2005$

* Total number of observation: 608.gmppc=GMP per capita, emp=employment, pfapc=private fixed asset per capita, hwyspc=highway capital stock per capita, amspc=public rail capital stock per capita(Amtrak Northeast Corridor), traspc=transit capital stock per capita, airspc=public airport capital stock per capita, ttspc=total transportation (highways+publicrails+transit+public airports) capital stock per capita.

Source: Bureau of Economic Analysis and Bureau of U.S. Census.

5.2 Preliminary Tests

Three preliminary tests are implemented so as to provide supportive information for model selection.

Table 3 Panel Stationary Test (32MSAs, 1991-2009)

Variable Name	Levin, lin& Chu			Pesaran's CADF		
	Stat.	Prob.	Obs	Stat.	Prob.	Obs
GMP per capita (lgmppc)	-9.279	0.000	561	-4.256	0.000	544
Employment (lemp)	-7.311	0.000	533	-1.519	0.064	544
Private capital per capita (lpfapc)	-5.894	0.000	521	-1.574	0.058	544
Total transport capital per capita (lttspc)	-4.414	0.000	570	-1.228	0.110	544
Highway capital per capita (lhwyspc)	-8.989	0.000	564	-1.832	0.033	544
Public rail capital per capita (lamspc)	-1.944	0.026	403	-	-	544
Public airport capital per capita (lairspc)	-3.203	0.000	425	-	-	544
Public transit capital per capita (ltraspc)	-13.675	0.000	425	-	-	544

* All variables were measured in level and in logarithmic term. Automatic lag length selection based on SIC: 0 to 3. "-" indicates no test result is generated due to containing zero numbers.

The first one is to test whether all the variables are stationary. This is an important prerequisite of regional impact analysis as any use of non-stationary data may lead to a spurious estimation. In addition, given the spatial nature of data being used, a panel unit root test with a consideration of cross-sectional dependence is also needed. The cross-sectional augmented ADF (CADF) statistics method proposed by Pesaran (2007) is adopted and implemented in STATA using the *pescadf* command (Lewandowski, 2007). The results of the standard panel stationary tests (Levin, *et al.*, 2002), as summarized in Table 3, suggest that all the variables are statistically significantly stationary. Although variables are generally significant at the 10 percent level in the CADF test, the variable representing the total transportation capital per capita is not significant even at the 10 percent level. This is possible due to the strong spatial dependence of transportation infrastructure across the northeast corridor region. The test suggests that the total transportation capital per capita variable is not stationary when cross-sectional dependence is considered. It should be noted this may be a potential caveat of the study.[1]

Another issue regarding the regional impact analysis of transportation infrastructure is the endogeneity between transportation stock and economic output. On the one hand, transportation investment enhances the connection of the regional transportation network, which subsequently facilitates both freight and passenger movement by reducing the generalized transportation cost. On the other hand, the improvement of economic performance may, as a consequence, lead to an increase on the demand for both freight and passenger mobility, which thus requires more investments for transportation infrastructure improvement. Failure to recognize this endogenous issue may severely jeopardize the outcome of the investigation and may even lead to mistaken policy implications. Therefore, the issue of endogeneity must be properly addressed before any concrete impact analysis is attempted.

To test the existence of endogeneity between regional output and transportation infrastructure input, the Hausman test is conducted. The rationale of the Hausman test is to compare instrumental variable (IV) estimates using the two stage generalized method of moments (GMM) estimator to ordinary least squares (OLS) estimates. If significant difference were found between the two estimates, then the test suggests that endogeneity does exist and the two-stage IV-GMM estimator is preferred. The basic OLS model structure is written as:

[1] The Pesaran's CADF test does not generate any results for public rail stock per capita (*lamspc*) , public airport stock per capita (*lairspc*) and transit stock per capita (*lttspc*). This is caused by the unbalanced panel with missing values in some panel units as not all MSAs have public rail or airport, or transit infrastructure during all the 20 years' period.

$$Y_i = \beta_0 + \beta_1 M_{1i} + \beta_2 M_{2i} + \beta_3 X_i + \varepsilon_i \quad (2)$$

where *M* represents exogenous variables which in this case are employment and private capital. *X* is the suspected endogenous variable which denotes either the total infrastructure stock variable or the four different modes of infrastructure variables. As an alternative, the two stage IV-GMM model provides the other estimator after controlling for any potential endogenous issue. The suspected *X* is regressed based on instrumental variables *Z*, denoted as

$$X_i = \alpha_0 + \alpha_1 Z_{1i} + \alpha_2 Z_{2i} + v_i \quad (3)$$

Given the fact that instrumental variable *Z* is not correlated with ε_i, X_i is uncorrelated with ε only if v_i is uncorrelated with ε_i. The test is implemented in the following equation:

$$Y_i = \beta_0 + \beta_1 M_{1i} + \beta_2 M_{2i} + \beta_3 X_i + \gamma_1 \hat{v}_i + \varepsilon_i \quad (4)$$

where $\hat{v}_i$ is the estimates of IV-GMM and $\gamma_1$is its coefficient. If the standard t-test suggests that $\gamma_1$is statistically significantly equal to zero, then the null hypothesis is rejected, indicating *X* is endogenous in the system.

It should be noted that the validity of IV-GMM approach is strongly dependent on the effectiveness of instrumental variables. The traditional approach of using lagged endogenous variables as instrument variables is used. It should be pointed out that this approach has limitations if the equation error or omitted variables are serially correlated

(Angrist & Krueger, 2001). Thus the test of overidentifying restrictions provided by the Hansen J statistic is also conducted to justify the validity of instrumental variables.

The results of the Hausman test for endogeniety and the Hansen J test for overidentifying restrictions are reported in Table 4. The insignificance of Hansen J tests suggests that all instrumental variables are valid. The first TTSPC model tests whether the total public transportation capital per capita (*lttspc*) is endogenous in the model where GMP per capita is the dependent variable, labor and private capital per capita are exogenous variables. The null hypothesis is that *lttspc* is properly exogenous in the model. The test statistic has a p-value of 0.177, suggesting that the test cannot reject the null hypothesis. In other words, the total public transportation infrastructure input variable is exogenous in the model. Likewise, in the four modes model, highway capital per capita (*lhwyspc*), public airport capital per capita (*lairspc*), public rail capital per capita (*lamspc*) and public transit capital per capita (*ltraspc*) are treated as endogenous regressors. Hansen J test shows all instrumental variables are valid to estimate coefficients at the 5% level. The Hausman test suggests that the four transportation variables are statistically significantly exogenous to the modeling structure.[2] As a result, the endogenous issue of transportation infrastructure is not considered in this assessment.[3]

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[2] This is not necessarily a generalizable finding for transportation infrastructure and regional output relationships. It is likely the result of the maturity of these relationships for this region at this period in time. However, given that consideration, the test results are clear.

[3] Endogeneity is generally regarded as being caused by measurement error, omitting variables and simultaneity. The Hausman test is powerful in diagnosing endogeneity through comparing IV-GMM and

Table 4 Hausman Test for Endogeniety

	TTSPC model		4 Modes model	
Regressors tested	lttspc		lhwyspc, lamspc, ltraspc	
	Chi-Sq	P-Value	Chi-Sq	P-Value
Hansen J statistics (overidentification test of all instruments)	0.000	0.989	8.518	0.074
Endogenous test of endogenous regressors	1.041	0.308	4.336	0.363

*The four transportation infrastructure input variables are tested separately following the per capita based production function form (see equation 10). Lag variables of the endogenous regressor are treated as instrumental variables at the first stage. Employment and private fixed asset per capita are treated as exogenous control variable in the second stage. Regional output variable (lgmppc) is the dependent variable. The null hypothesis for Hansen J test is that instrumental variables are valid. The null hypothesis for endogenous test is that the tested regressor is exogenous.

The second test is to check whether spatial autocorrelation exists and is statistically significant among the variables. The spatial autocorrelation, values of Moran's I is tested for all variables through the software *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):

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \cdot \frac{\sum_{i=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} w_{ij}(x_i - \bar{x})^2} \tag{5}$$

OLS estimators. However, the test is sensitive to validity of instrument variables. Furthermore, it has limited power in explaining the endogenous issue caused by simultaneity as the directional effects cannot be sufficiently examined. To further justify the results of the Hausman test, panel granger causality tests are also conducted for testing the causal direction between regional output and transportation inputs. Although criticism about granger test remains, the results *per se* confirm the results of the Hausman test. The explanation and results of the panel granger causality test are included in Appendix III.

where n is the number of MSAs, which in this study equals 32, x and $\bar{x}$ denote the specific MSA and the mean of x respectively. w_{ij} is an element of the spatial weight matrix, representing the spatial relationships between region i and j. This 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 5 Descriptive Statistics of Spatial Dependence

	gmppc	emp	pfapc	ttspc	hwyspc	airspc	Amspc	traspc
1991	0.214**	-0.073	0.214**	0.249**	0.084	0.070	0.209*	-0.003
1992	0.195*	-0.074	0.195*	0.233*	0.106	0.100	0.199*	-0.006
1993	0.185**	-0.075	0.185*	0.221*	0.131	0.099	0.197*	-0.011
1994	0.188**	-0.075	0.188**	0.205**	0.162	0.099	0.190**	-0.020
1995	0.189***	-0.075	0.189*	0.198*	0.200**	0.112	0.187*	-0.023
1996	0.182**	-0.076	0.182*	0.190**	0.224**	0.101	0.187*	-0.033
1997	0.171*	-0.076	0.171*	0.187	0.210*	0.135	0.191	-0.043
1998	0.148	-0.076	0.148*	0.197**	0.215**	0.152*	0.192*	-0.047
1999	0.154*	-0.075	0.154*	0.195**	0.225*	0.126	0.199*	-0.050
2000	0.157**	-0.075	0.157**	0.189*	0. 214**	0.121	0.200**	-0.056
2001	0.168	-0.074	0.168*	0.185*	0.216*	0.092	0.199**	-0.056
2002	0.160*	-0.072	0.160	0.176*	0.219**	0.083	0.200**	-0.054
2003	0.151	-0.070	0.151	0.163	0.219**	0.079	0.195**	-0.055
2004	0.150*	-0.069	0.150**	0.138	0.218**	0.085	0.195**	-0.067
2005	0.153	-0.068	0.153*	0.121	0.219*	0.088	0.192**	-0.073
2006	0.160*	-0.068	0.160*	0.114	0.240**	0.095	0.197*	-0.077
2007	0.175*	-0.068	0.175*	0.101	0.237***	0.101	0.192**	-0.083
2008	0.182**	-0.069	0.182*	0.102	0.252**	0.109	0.185*	-0.084
2009	0.170*	-0.068	0.170*	0.089	0.257**	0.112	0.185**	-0.086

Note: ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively. The spatial weight matrixes are generated based on the queen contiguity method.

Because Moran's I can only be tested in a yearly base, Moran's I of each year from 1991 to 2009 is calculated. The global Moran's I of each variable is displayed in Table 5. Interestingly, except for employment, the Moran's I value of most variables are significant, which indicates that spatial autocorrelations exist across most of the variables. Negative values of the Moran's I are found for the employment and transit capital, which indicate a tendency toward dispersion. With respect to GMP per capita, private fixed asset per capita, total transportation capital, public highway capital and rail capital, positive and significant Moran's I values are found, indicating a tendency toward clustering. The existence of spatial dependence among both the dependent variable and independent variables implies a complicated spatial issue for this analysis.

5.3 Methodology

5.3.1 Non-Spatial Assessment

To test Boarnet's hypothesis of negative spillover effects of public infrastructure, the study follows the same neoclassical growth model structure in a Cobb-Douglas production function form. The basic equation is defined as:

$$Y = A \cdot L^{\beta_1} K^{\beta_2} T^{\beta_3} \tag{6}$$

where *Y* denotes the economic output, which is measured by GMP per capita, *A* is the technological coefficient, *L* and *K* denote level of employment and private capital asset per capita respectively. *T* denotes public transportation stock per capita, either in total or by mode. All variables are converted in the logarithmic term, so the coefficients from the log-linearized estimation can be interpreted as elasticity. The equation can thus be written as:

$$LnY = A + \beta_1 LnL + \beta_2 LnK + \beta_3 LnT \tag{7}$$

Assuming the production function has constant returns to scale, then,

$$\beta_1 + \beta_2 + \beta_3 = 1 \tag{8}$$

Subtracting log of population (*LnP*) on both sides, the function can be transformed as follows:

$$LnY - LnP = A + \beta_1 LnL + \beta_2 LnK + \beta_3 LnT - (\beta_1 + \beta_2 + \beta_3)LnP \tag{9}$$

Therefore, the per capita based production function model can ultimately be written as:

$$Ln\left(\frac{Y}{P}\right) = A + \beta_1 Ln\left(\frac{L}{P}\right) + \beta_2 Ln\left(\frac{K}{P}\right) + \beta_3 Ln\left(\frac{T}{P}\right) + u \tag{10}$$

The temporal stationarity of the infrastructure stock implies that levels of public transportation infrastructure in the northeast region remain constant over the research period, therefore it is reasonable to assume a constant impact of infrastructure over the period under analysis. The disturbance term $u_{i,t}$ follows a one way error component model, which is specified as:

$$u_{i,t} = \mu_i + v_{i,t} \tag{11}$$

where μ_i represents a MSA-specific effect assumed to be exogenous and $v_{i,t}$ is a classical random disturbance which is assumed independent and identically distributed (IID) (0, σ_v^2). μ_i can be modeled as either fixed or random. The MSA-specific effect includes regional specific factors for output such as “endowment of natural resources, the quality of public infrastructure, physical characteristics of a MSA, the ability to attract and utilize foreign investment and network effects” (Pinnoi, 1994, 130).

The non-spatial analysis is conducted through two separate models. The first model uses the total transportation stock as the policy variable while the second uses stocks of highway, public rail and transit. The Hausman test is again implemented, but to test whether fixed effects or random effects estimation is more efficient. The test results of both models indicate that the fixed effect model is more efficient than the random effects model. Through the fixed effect model, the influence of unknown or unmeasured regional specific factors can be taken into account in the estimation (Johnston and Dinardo, 1997). This will thus help to reduce estimation bias associated with correlations across units (Fulton, et al. 2000).

5.3.2 Spatial Econometric Assessment

The final step is to expand from the non-spatial analysis to a spatial analysis by considering spatial autocorrelation. The spatial statistical test (Table 5) provides a preliminary detection of spatial autocorrelation. The global Moran’s I of both the dependent variables and independent variables are found statistically significant, which implies spatial autocorrelation may exist in both dependent and independent variables. As indicated earlier in this study, spatial autocorrelation happens in the form of spatial dependence between observations. MSAs such as Washington DC, Baltimore, Philadelphia, New York and Boston function as regional growth poles that may have strong economic relations with their neighboring MSAs. Thus, a spatial dependence may exist among these MSAs.

Given the complexity of spatial autocorrelation, it is hard to assume whether a spatial lag (SAR) or a spatial error (SEM) process is efficient in achieving a more robust result. As a starting point to investigate such complicated spatial issues, a spatial Durbin model (SDM) is assumed to be an appropriate assessment. The general form of this spatial model recommended by LeSage and Pace (2009) is:

$$Y_{it} = \rho \sum_{j=1}^{n} W_{ij} Y_{jt} + X_{it}\beta + \sum_{j=1}^{n} (W_{ij} X_{jt})\,\theta + \mu_i + v_{it} \tag{12}$$

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

where Y and X denote the dependent and explanatory variables, respectively. Wy and WX denote the spatial lag terms of dependent variable and explanatory variables, respectively. ρ, β and θ denote coefficients that would be estimated.

To help identify the appropriate spatial panel model in a systematic way, Elhorst (2010) developed a spatial panel model selection routine, which can be directly executed in *Matlab*. The key process is illustrated in Figure 12:

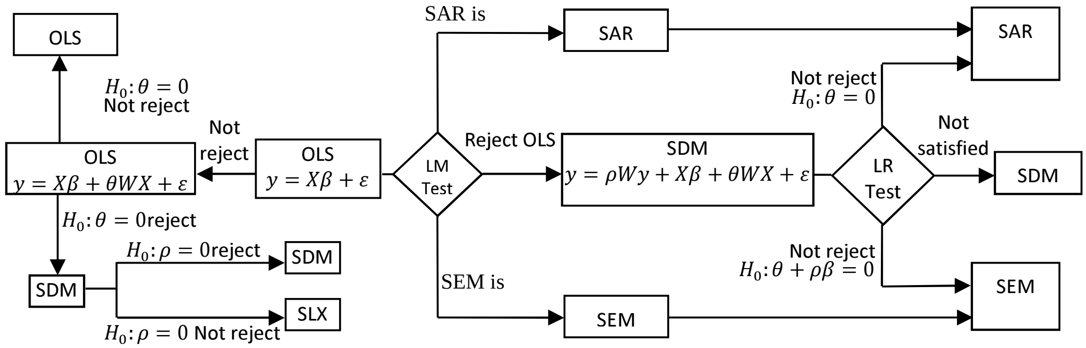


Figure 12 Elhorst Spatial Model Testing Procedure

Table 6 Lagrange Multiplier (LM) and Likelihood Ratio (LR) Tests

	TTSPC Model	**4 Modes Model**
	Test Statistic (p-value)	**Test Statistic (p-value)**
LM Lag	94.753 (0.000)	118.959 (0.000)
LM Error	27.861 (0.000)	49.379 (0.000)
LM Lag Robust	71.251 (0.000)	70.866 (0.000)
LM Error Robust	4.358 (0.037)	1.306 (0.253)
H0: $\theta = 0$		
LR Value	130.092 (0.000)	138.604 (0.000)
H0: $\theta + \rho\beta = 0$		
LR Value	217.746 (0.000)	233.772 (0.000)
Hausman Test H0: Reject fixed effect model in favor of random effect model		
Test Value	10.786 (0.01)	352.391 (0.00)
LR Test H0: Spatial FE Jointly Insignificant		
LR Value	2042.804(0.00)	2063.121(0.00)
LR Test H0: Time FE Jointly Insignificant		
LR Value	996.469(0.00)	895.938 (0.00)

This study follows the Elhorst spatial model testing procedure to test which spatial model is preferred technically. Table 6 shows the test results of Elhorst's routine. Although the Lagrange Multiplier (LM) test shows a spatial lag model is preferred, the general test (with consideration of Likelihood Ratio (LR) test) recommends that a spatial Durbin model is more efficient. The Hausman test confirms that a fixed effects approach preferred. To provide a comprehensive view of robustness, estimations of both a spatial lag model and a spatial error model are summarized in the final results.

One of the key functions of spatial analysis is to investigate the spatial effects among different MSAs. Because the spatial information of neighboring regions is added in the form of a spatial weight matrix, the 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 the "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. Although some studies (for instance, Mohammad, 2009) give these impacts different names, such as long term local effect, long-term neighbor effect and long term total effect, respectively, they represent the same classified effects as specified here.

Both spatial fixed effect and time fixed effect are also tested using Elhorst's spatial panel diagnose routine. The LR test results, as displayed in Table 6, suggest that both spatial fixed effect and time fixed effect are jointly significant. The inclusion of the significant time fixed effect may or may not change the estimation results. However, only spatial fixed effect is accounted while time fixed effect is not accounted for in this assessment. The reason is to make the analysis consistent with Boarnet's study. In addition, the study focuses on mature transportation infrastructure only, thus a constant regional impact of transportation infrastructure is considered in this investigation. This assumption indicates that the impacts of infrastructure on attracting private capital and labor are not considered. Given the fact that the panel unit root test confirms that public transportation infrastructure and the economic variables are stationary during the research period, the inclusion of time fixed effect may add influences that may contaminate the model estimation and purpose. Further, given this short time span estimated and the stable maturity of the system, time effects are outside the present purview. Again, it should be noted this may also be a potential caveat of the study.

5.4 Empirical Results

Table 7 and Table 8 display estimation results of the regional impacts of the aggregated and disaggregated transportation infrastructure capital stocks of four modes from OLS with fixed effect, SEM, SAR and SDM with spatial fixed effect, respectively. Generally speaking, the transportation infrastructure variables in four models are all statistically significant, although the values vary subtly in different models. In the non-spatial model, the general impact of transportation infrastructure is 0.088, which is lower than the result in SDM, but higher than the values from SEM and SAR. The spatial lags of both dependent and independent variables are highly statistically significant in the

SDM, which indicates both spatial dependence and spatial autocorrelation are captured. After controlling for spatial autocorrelation, employment is found to be the most important factor for regional output. The total contribution from transportation infrastructure capital stock is about 0.15 percent.

Table 7 Estimation Results from Fixed Panel and Spatial Fixed Panel Models (TTSPC Model)

	OLS	SEM	SAR	SDM
	Fixed Effect	Spatial Fixed	Spatial Fixed	Spatial Fixed
Total Effect				
lemp	0.707*** (18.960)	0.606***(16.989)	0.701***(14.584)	0.912***(17.715)
lpfapc	0.298*** (14.130)	0.375***(18.261)	0.344***(13.525)	0.140***(4.957)
lttspc	0.088***(6.600)	0.059***(4.716)	0.080***(5.000)	0.149***(7.578)
Spatial Variables				
W*dep.var.			0.270***(11.903)	0.251***(8.223)
W*lemp				0.235***(6.070)
W*lpfapc				-0.174***(-8.453)
W*lttspc				0.053***(4.728)
spat.aut.		0.215***(6.705)		
ML		1243.636	1287.463	1352.509
Sigma2		0.0010	0.0008	0.0007
R2	0.908	0.975	0.981	0.985
Corr2		0.905	0.917	0.932

Note: Numbers in parentheses are t-statistics. *, **, *** denote significant level at 10, 5 and 1 percent respectively. All variables are taken log-transformation.

Table 8 Estimation Results from Fixed Panel and Spatial Fixed Panel Models (4 Modes Model)

	OLS	SEM	SAR	SDM
	Fixed Effect	Spatial Fixed	Spatial Fixed	Spatial Fixed
Total Effect				
lemp	0.595*** (10.060)	0.560***(16.562)	0.697***(15.041)	0.891***(17.234)
lpfapc	0.371*** (11.550)	0.382***(19.226)	0.357***(14.231)	0.166***(6.070)
lhwyspc	0.080***(4.690)	0.058***(4.992)	0.094***(6.205)	0.100***(5.014)
lamspc	0.009**(2.380)	0.010***(4.234)	0.010***(3.000)	0.019***(4.160)
ltraspc	0.121 (1.250)	-0.003(-0.763)	-0.015**(-2.535)	0.009 (1.200)
lairspc	0.014***(2.250)	0.007***(3.646)	0.009***(3.637)	0.015***(4.041)
Spatial Variables				
W*dep.var.			0.287***(12.589)	0.246***(8.045)
W*lemp				0.253***(6.757)
W*lpfapc				-0.150***(-7.213)
W*lhwyspc				0.027**(2.331)
W*lamspc				0.010***(3.891)
W*ltraspc				0.009**(2.215)
W*lairspc				0.005**(2.028)
spat.aut.		0.234***(7.372)		
ML		1259.855	1307.439	1376.741
Sigma2		0.0009	0.0008	0.0006
R2	0.926	0.976	0.983	0.986
Corr2		0.909	0.921	0.938

Note: Numbers in parentheses are t-statistics. *, **, *** denote significant level at 10, 5 and 1 percent respectively.

Table 9 Spillover Effects of Transportation Infrastructure in General

	Direct		Indirect		Total	
Variable	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
lemp	0.486***	14.375	0.422***	10.636	0.908***	17.212
lpfapc	0.268***	13.454	-0.127***	-5.812	0.141***	4.883
lttspc	0.066***	6.190	0.083***	6.469	0.150***	7.925

Note: No. of Obs=608, ML=1352.217, R-Squared=0.985, Corr-squared=0.932. ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.

Next, spillover effects of transportation infrastructure are estimated in detail in SDM. Both a general form and modal comparative form are estimated respectively. Table

9 illustrates different regional effects of the general transportation infrastructure. The result shows that its direct, indirect effect and total effects are all significant. In terms of the magnitude of effects, the indirect effect accounts for 0.083 of the total effect, the rest of which comes from the direct effect. This indicates that transportation infrastructure in the northeast megaregion in general has both positive and strong local effects and spillover effects. Much of its contribution to economic output is achieved through network benefits to other regions.

The results also show a different regional effect of employment and private fixed capital. For instance, the magnitudes of direct and indirect effects of employment appear to be comparable. The total effect of 0.908 indicates employment plays a pivotal role in stimulating regional economic growth in the northeast region. On the other hand, private capital also has a significant contribution to output, despite the fact that its total effect is much smaller than employment. The direct effect is 0.268, which means that a one percent increase of private fixed asset per capita is associated with a 0.27 percent increase in regional output. On the contrary, the indirect effect of private capital is negative 0.127, meaning a one percent increase of private fixed asset per capita in region A is associated with a 0.13 percent decrease of regional output in other regions. This suggests the competitive nature of private capital investment in the regional economy.

Table 10 shows the spillover effects of transportation infrastructure by mode. Similar spillover effects of employment and private capital are also found in this model. In terms of a modal spillover effect comparison, the highway variable has both a significant direct and indirect effect, which is 0.053 and 0.047 respectively. This implies after controlling for determinants of labor, private capital and public capital in rail, transit and airport, highway infrastructure contributes not only to the local economy, but also to its neighboring regions' economy.

Table 10 Spillover Effects of Transportation Infrastructure by Mode

	Direct		Indirect		Total	
Variable	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
lemp	0.461***	14.023	0.429***	10.911	0.891***	17.234
lpfapc	0.266***	13.755	-0.100***	-4.581	0.166***	6.070
lhwyspc	0.053***	5.207	0.047***	3.345	0.100***	5.014
lamspc	0.006**	2.482	0.013***	4.300	0.019***	4.160
ltraspc	-0.001	-0.254	0.010**	2.060	0.009	1.200
lairspc	0.007***	4.378	0.007**	2.720	0.015***	4.041

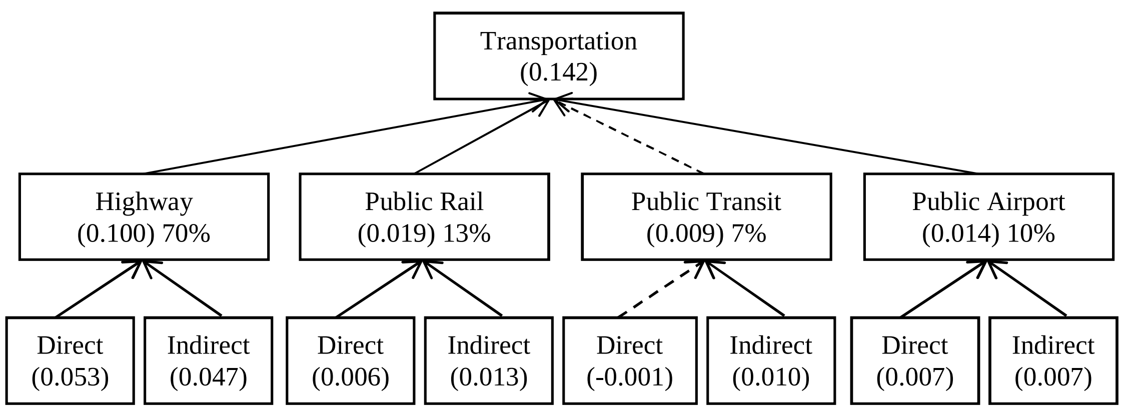
Note: No. of Obs=608, ML=1376.741, R-Squared=0.986, Corr-squared=0.938. ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.

After controlling for highways, transit and airports, employment and private capital, positive and significant impacts from public rail capital stock are found both in local effects and spillover effects. A higher magnitude of the spillover effect indicates that the intercity passenger rail does play a pivotal role in facilitating inter-regional passenger flow, which may possibly result in regional economic growth through labor mobility and knowledge spillover.

Public airport capital stock also shows positive and significant influence on regional output through both direct and indirect effects. Both effects are 0.007, which implies that one percent variation in public airport capital stock per capita is associated with 0.007 percent variations in both the local economy and its neighboring regions' economy. The result also reveals that despite the values being very close, public airports still have relatively smaller impacts than public rail in the northeast region.

Finally, public transit shows a small but insignificant effect on regional output, although the direction of the sign is correct. However, a significant indirect effect for transit is found at 0.01, which can be interpreted as a one percent change in transit stock per capita is associated with 0.01 percent change to its neighboring regions' economy.

5.5. Summary



Note: Dash line indicates an insignificant estimation; output elasticity is included in parenthesis.

Figure 13 Regional Impact of Transportation Infrastructure

Despite the well-researched linkages between regional output and transportation infrastructure, the results are still inconclusive given the challenges of data and methods being used. This study aimed to improve the understanding of such linkages between regional output and transportation infrastructure within the context of the U.S. northeast region. Unlike traditional studies, the impact assessment is improved through two approaches: 1) by adopting financial data measured in real terms with a focus on the period between 1991 and 2009; and 2) by introducing spatial analysis with a systematic approach to model specification. The regional impact of different transportation modes can be compared in Figure 13.

The major findings are summarized as follows:

In the context of the northeast corridor, transportation infrastructure has a positive impact on regional economic output (0.14), most of which is achieved through regional spillover effects (0.08).

Labor has a larger influence on output than capital through both local direct effects and indirect spillover effects, imply that the nature and importance of labor intensity in this regional economy. A positive direct effect but negative indirect effect of private capital is also found, indicating the competitive nature of private capital regionally.

In terms of modal comparison, highway infrastructure demonstrates an overwhelming impact (0.1), which consists of 0.053 from local effects and 0.047 from spillover effects. The positive spillover effect confirms the existence of a positive highway network effect.

Public railway infrastructure has the second largest impact (0.019) after controlling for labor, private capital, highways, transit and airport. The majority of its impact is achieved through a positive spillover effect, which reflects the pivotal role of intercity passenger rail service in this region.

Public airport infrastructure has the third largest impact (0.014), which is achieved through an equal effect on both the local economy and the neighboring regions' economy. However, since this study only focuses on examining regional impacts at the MSA level, it should be noted that broader national economic impacts of the gigantic international airports resting in this corridor such as Dulles International Airport, Newark Liberty International Airport, John F. Kennedy International Airport and Logan International Airport, may not be adequately captured.

The total effect of transit is not significant, but a positive, small but significant spillover effect (0.01) is found. This implies that public transit facilities that include buses, metros and commuter rails, also have a significant network effect. The increase of transit stock helps to improve regional connectivity and accessibility, which in turn contributes to regional output by facilitating labor mobility between suburbs and urban centers within the northeast corridor.

The research findings reject Boarnet's hypothesis that public capital has a negative spillover effect on regional growth. Instead, positive spillover effects are observed both for total public transportation capital stock and for highway capital in this study after controlling for the spillover effects of labor and private capital. The finding also differs from Holtz-Eakin and Schwartz (1995), who found no evidence of positive output spillover across states for the case of highway capital. The results confirm that transportation infrastructure has both positive local effects and positive output spillovers.

Chapter 6 General Equilibrium: National Level Assessment

This chapter discusses economic benefits of public transportation infrastructure at the U.S. national level using general equilibrium assessment. This study has the following three research highlights:

First, a general equilibrium analysis with a focus on multimodal transportation capital is established. The goal is to provide an analytical tool under general equilibrium to understand the relative economic importance of different modes of transportation. Specifically, 6 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, the general equilibrium model allows for a direct assessment of public transportation capital through the policy shock of the separated public capital accounts in the U.S. social accounting matrix (SAM). This model offers a 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 this assessment differ from other theoretical CGE models in having realistic, significant and practical policy implications.

Two research questions are answered in this study: what role does public transportation capital stock play in the U.S. economy under a general equilibrium framework? And how do the roles of public capital vary among nationally across modes of transportation? This chapter is organized as follows: Section 1 reviews the existing CGE models that used for transportation infrastructure assessment. Section 2 discusses data while section 3 discusses modeling specifics. Section 4 presents simulation results under different policy scenarios. The final section summarizes and addresses implications for future research endeavors.

6.1 Reviews of Transportation CGE Models

Chapter 5 assesses the regional impact of public transportation infrastructure from partial equilibrium framework. One of the weaknesses of partial equilibrium models is that the association between economic output and public transportation infrastructure is evaluated only from the supply side of the 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.[4]

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 linkages 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 assesses 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 elasticity of substitution function (CES). Government plays dual roles in a 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 taxes and tariffs is spent on a variety of

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[4] It should be noted that there are still problems with attempting to construct social welfare functions by aggregating utility across consumers under a general equilibrium framework.

public expenditures 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, 2004). The model contains 19 regions with 10 economic sectors. The *MONASH* model is the other widely used multi-regional, multi-sectoral dynamic CGE model (Dixon & 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 International Food Policy Research Institute *(IFPRI)* model is another type of 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. 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.

In sum, despite a variety of transportation CGE models that have been established, none of these models is capable of evaluating economic benefits of public transportation infrastructure explicitly. Most of these models evaluate the impact of transportation infrastructure by assuming that the 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 public transportation investment which is the real policy input and transport costs are not adequately modeled.

6.2 Structure of the U.S. Economy

This chapter fills the gap by conducting a general equilibrium assessment 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 U.S. national social accounting matrix (SAM) is explained and the major modeling structures of each institution are discussed.

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 U.S. 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 the research interest here 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 the GTAP: other transportation (OTP), water transport (WTP) and air transport (ATP). Because the surface modes of transportation such as road, rail, pipelines and auxiliary transport activities are all combined in the sector of OTP, it becomes necessary to first separate them out.

Because 2007 is the latest reference year for the input-output tables and macroeconomic data in GTAP 8 (Narayanan *et al*., 2012), the BEA 2007 annual Input-Output table after redefinition as the complement information is used 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 is to add public transportation capital accounts in the U.S. 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[5], thus a shock of public transportation capital in the CGE indicates the social and economic variations that result from level of transportation investment by mode.

Another important note is that public transportation investment in the U.S. is highly modally biased. Highway and streets receive the most public investment; airport, transit and water transportation receives relatively less public investment. The pipeline

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[5] 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 rate δ, capital stock is naturally primarily influenced by the investment level.

and rail sectors in the U.S. are primarily privately owned. So in these sectors, the massive infrastructure investments primarily rely on the private sectors. Public investment in pipeline and freight rail sectors is primarily used for safety and regulation related purpose 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 to the road, air, transit and water related sectors.

In the CGE model, the four transportation sectors are considered differently to other sectors. The factor endowments consumed by truck, air, transit and water includes 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 on national fixed assets from BEA.[6] 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 on 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: first, non-transportation sectors do not have transportation capital. They depend solely on transportation sectors for transport services. Second, the original capital account for truck transportation includes not only public capital in the truck sector, but also highway and street public capital. The original capital accounts of air transportation, transit and water transportation

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

include not only public capital in each sector, but also the public capital of all the relevant infrastructure of each respective mode.

The assumptions are made based on the unique characteristics of the transportation sectors. Capital inputs for truck transportation include not only privately owned vehicles, trailers and relevant facilities, it also includes public capital such as the road networks to produce road transport service. Air and water transportation sectors are similar. Capital stock items, such as aircraft and watercraft 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.

6.3 Modeling Structure

The modeling structure of the study adopts the edited version of a single regional GTAP CGE model developed Scott McDonald (2005). The codes are implemented in General Algebraic Modeling System (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 which there is 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. Small country assumption is relaxed with export demand function. The model allows for non-traded, non-produced and non-consumed domestic goods. The main model structures are discussed in detail for different institutional blocks as described below.

6.3.1 Consumer Block

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

$$\mathrm{PQD_i} \cdot \mathrm{QCD_i} = \mathrm{Comhav_i} \cdot \mathrm{HEXP} \quad (13)$$

Where:

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

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

$\mathrm{Comhav_i}$: Household consumption shares of commodity i in household;

HEXP: Household consumption expenditure in household.

Household income and household expenditure are denoted respectively as:

$$\mathrm{YH} = \sum_{k=1}^{f} \mathrm{hvash_k} \cdot \mathrm{YF_k} + \mathrm{hwor} \cdot \mathrm{ER} \quad (14)$$

$$\mathrm{HEXP} = \mathrm{YH} \cdot (1 - \mathrm{tyh}) \cdot (1 - \mathrm{SADJ} \cdot \mathrm{kaphsh}) \quad (15)$$

Where:

YH: Household income of household;

$\mathrm{hvash_f}$: Share of income from factor f to household;

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

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

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

tyh: Direct tax rate on household;

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

kaphsh: Shares of household income saved after taxes of household.

6.3.2 Producer Block

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 14). 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:

$$QX_a = adx_a \cdot \left(\sum_{k=1}^{f} deltax_{k,a} \cdot FD_{k,a}{}^{-rhox_a}\right)^{-\frac{1}{rhox_a}} \tag{16}$$

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:

$$QINTD_c = \sum_{k=1}^{a} ioqx_{c,k} \cdot QX_k \tag{17}$$

$$COMOUT_c = \sum_{k=1}^{a} ioqxcqx_{c,k} \cdot QX_k \tag{18}$$

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 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 equal to zero for the non-transportation sectors and the two private transportation sectors rail and pipeline.

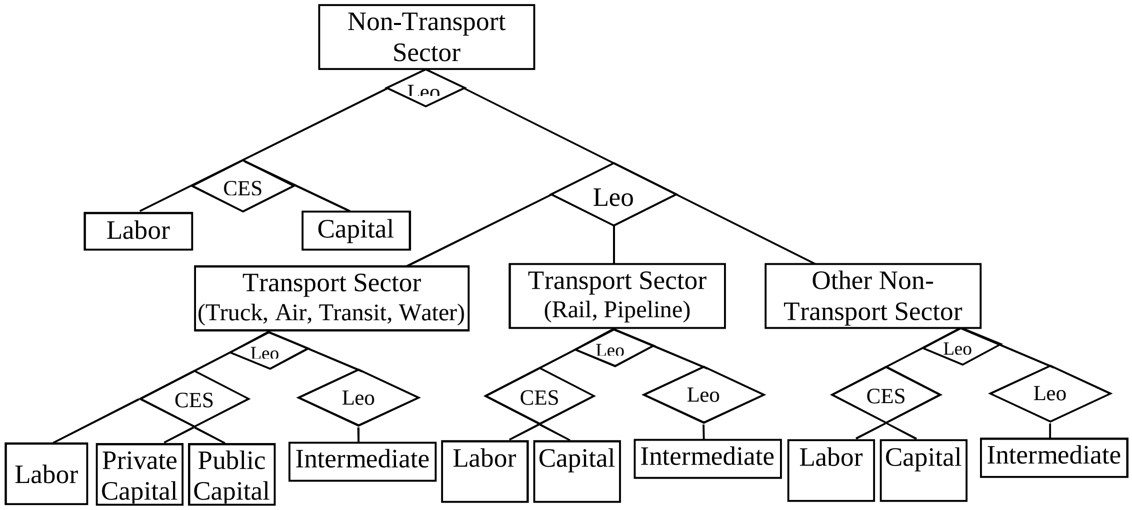


Figure 14 Nested Production Structure

6.3.3 Government Block

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:

$$MTAX = \sum_{k=1}^{c} tm_k \cdot pwm_k \cdot ER \cdot QM_k \tag{19}$$

$$ETAX = \sum_{k=1}^{c} te_k \cdot PWE_k \cdot ER \cdot QE_k \tag{20}$$

$$STAX = \sum_{k=1}^{c} ts_k \cdot PQS_k \cdot (QINTD_k + QCD_k + QGD_k + QINVD_k) \tag{21}$$

$$ITAX = \sum_{k=1}^{a} tx_k \cdot PX_k \cdot QX_k \tag{22}$$

$$DTAX = \sum_{k=1}^{h} tyh_k \cdot YH_k \tag{23}$$

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:

$$YG = MTAX + ETAX + STAX + ITAX + DTAX + (govwor \cdot ER) \quad (24)$$

$$QGD_c = QGDADJ \cdot qgdconst_c \quad (25)$$

$$EG = \sum_{k=1}^{c} QGD_k \cdot PQD_k \quad (26)$$

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;

6.3.4 Investment and Saving

Investment and saving block includes the following three equations:

$$TOTSAV = \sum_{k=1}^{h} YH_k \cdot (1 - tyh_k) \cdot SADJ \cdot kaphsh_k + KAPGOV + (KAPWOR \cdot ER) \quad (27)$$

$$QINVD_c = IADJ \cdot qinvdconst_c \quad (28)$$

$$INVEST = \sum_{k=1}^{c} PQD_k \cdot QINVD_k \quad (29)$$

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.

6.3.5 Market Clearing Condition

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

$$\mathrm{FS_f = \sum_{k=1}^{a} FD_{f,k}} \tag{30}$$

$$\mathrm{QQ_c = QINTD_c + QCD_c + QGD_c + QINVD_c} \tag{31}$$

$$\mathrm{KAPGOV = YG - EG} \tag{32}$$

$$\mathrm{KAPWOR = \sum_{k=1}^{cm} PWM_k \cdot QM_{cm} + \frac{\sum_{j=1}^{f} YFWOR_j}{ER} - \sum_{i=1}^{ce} PWE_i \cdot QE_i - \sum_{l=1}^{h} hwor_l - govwor - \sum_{m=1}^{f} factwor_m} \tag{33}$$

$$\mathrm{TOTSAV = INVEST + WALRAS} \tag{34}$$

Where

$\mathrm{FS_f}$: Supply of factor f;

$\mathrm{QQ_c}$: Supply of composite commodity c;

$\mathrm{YFWOR_f}$: 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.

6.4 Policy Simulation

The model is calibrated using the base year 2007 of the U.S. national SAM data. Key parameters are calibrated using the GAMS program. Policy simulation is conducted in two directions. First, the exogenous public capital of different modes is 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 capital in 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 comparison of different magnitudes of impacts due to the different levels of public transport capital inputs. The result also helps to identify how sensitive the output 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 11. 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 to GDP in the U.S. 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 capitals 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*. Not surprisingly, public capital in highway and streets have the biggest impact on contributing GDP growth among these four modes.

Table 11 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

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 the 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 scale of return. Public air transport capital plays the second largest role on economic growth 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' elasticity. 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' elasticity.

The results of welfare variations due to the changes of different modes of public capital inputs are illustrated in Table 12. 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.

Table 12 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

The results reveal that the increase of public capital of highways and streets generates the highest welfare gain. Public capital of air transport plays the second highest role in generating welfare gain. Assuming a 10 percent increase in public capital inputs, 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.

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

Table 13 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

The sectoral impacts of different modes of public transportation capital show some different patterns compared to aforementioned aggregated level impacts. Table 13 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.

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 air transportation sector but a relatively low increase in other sectors. Generally, the average domestic production variation caused by public air capital shock is much smaller than 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 14. 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.

Table 14 Household Consumption Variations by Sector
(10% increase of different transportation capitals)

Sector	Truck	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

Public transportation capital in air, transit and water demonstrate 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.

6.5 Summary

Unlike traditional transportation CGE studies, a new general equilibrium framework is established to evaluate economic impact of public transportation capital. In this 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. The 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 small and relatively smaller than what has been found in partial equilibrium literature, which may be explained by the following 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), as the value added GDP does not include the value of intermediate consumption.

Second, the economic impact of public transportation infrastructure has been found varies 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 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 to 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 U.S. have already been built. It is thus understandable that the economic benefits of public transportation capitals should not be expected as high as that during the earlier construction period.

This study improves the understanding of the relative importance of public investment on different transportation modes at the national scale. This study shows that public capital of 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 of water transportation and transit and other passenger transportation rank the third and fourth, respectively. Since infrastructure of rail transportation and pipeline in the U.S. are primarily funded by private sectors, the impacts of public capital in these two modes are not considered in this analysis.

Future research needs to 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 should 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 in regional transportation capital distribution, it is important to consider the integration of spatial econometric models with CGE to improve validity of regional general equilibrium analysis.

Chapter 7 Spatial Econometric Computable General Equilibrium: State Level Assessment

This chapter develops a new method called Spatial Econometric Computable General Equilibrium (SECGE) model, which integrates both spatial econometrics with equilibrium modeling to evaluate regional impact of public transportation infrastructure at the state level. This chapter has the following highlights:

First, a theoretical foundation is provided based on the extension of the new economic geography theory and general equilibrium theory. In addition, the needs for considering spatial dependence in general equilibrium analysis are discussed.

Second, through a spatial autocorrelation test, the presence of spatial dependence is observed and confirmed among the elasticities of factor substitution in the U.S. 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.

Third, transportation impact analysis is conducted under different scenarios in a general equilibrium framework. Unlike partial equilibrium analysis, general equilibrium analysis allows researchers to obtain a more comprehensive understanding of transportation infrastructure's impacts given its consideration of interactions between demand and 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 assess the spatial impacts of transportation infrastructure.

Fourth, the study is conducted with a focus on multimodal transportation systems that includes: road, rail, air, public transit, pipeline and water. Unlike a unimodal perspective, this multimodal perspective is essential to achieve a comprehensive understanding of the investment impacts in the public transportation infrastructure system as a whole. It also enables us to compare impacts and their spillovers between different types of infrastructure and understand the relative importance of transportation investment by mode.

The rest of this chapter is organized as follow. Section 1 discusses the theoretical motivation of integrating spatial econometrics and general equilibrium analysis. Section 2 addresses the key research questions. 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.

7.1 Theoretical Motivation

As discussed earlier in Chapter 3, computable general equilibrium analysis has been used for economic impact analysis of transportation infrastructure. Given the fact that impact of transportation facilities are normally achieved through increasing connectivity and accessibility after completion, many analyses are conducted in a multiregional framework with consideration of interregional flows in order to measure such impacts (Bröcker et al., 2001; Bröcker, 2004; Ivanova, 2004; Horridge et al., 2005). However, it should be noted that spatial interaction also exists among regional factor substitution, although it has not been given sufficient attention in empirical practice. The importance of the spatial interaction in factor substitution has been discussed and emphasized in both the new economic geography theory and general equilibrium theory.

Schmutzler (1999) points out that the whole approach of the new economic geography has a distinct general equilibrium flavor because the framework captures interactions in all aspects of socioeconomic activities including relationships among different markets, between firms and their suppliers and consumers. In the view of the new economic geography, regional economic activities interact under two types of forces: centripetal and centrifugal (Krugman, 1991). When the centripetal force outweighs the centrifugal force, regional agglomeration occurs, otherwise, regional spillovers dominate. Krugman also indicates the elasticity of substitution has a close linkage to economies of scale, which indirectly determines regional convergence or divergence. A higher elasticity of substitution implies smaller economies of scale under general equilibrium conditions, which then works against regional divergence. On the contrary, a lower elasticity of substitution implies higher economies of scale which is more likely to cause regional divergence.

The elasticity of substitution matters both intraregionally and interregionally due to the effects of both agglomeration and spillovers. As illustrated in Figure 15, agglomeration and spillovers occur both intraregionally and interregionally. Depending on the levels of transportation cost, changes of factor prices such as rental and wage may lead to the substitution of factors happening within regions A, B and C respectively and among them. As a result, unless the interregional elasticity of substitution equals zero, the aggregate values of the elasticity of substitution should be different from the value that is only driven by the two forces within each region.

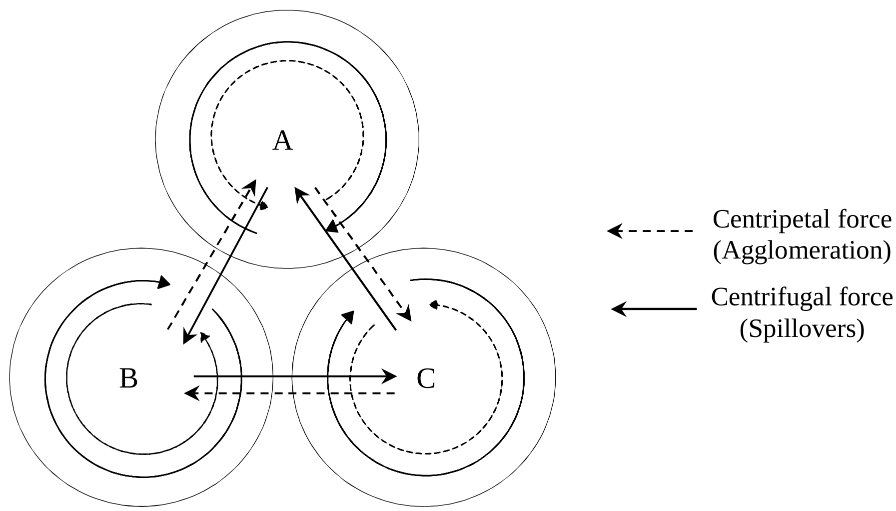


Figure 15 Regional Agglomeration and Spillovers

Because most of the elasticities of factor substitution for general equilibrium analysis are exogenously provided, many CGE models retrieve the values from relevant literature that specifically focuses on elasticity estimation (Löfgren, 2002; Dixon & Rimmer, 2013). However, a careful search of their sources (Blonigen & Wilson, 1999; Broda & Weinsten, 2006; Imbs & Méjean, 2008) show that all the elasticities of substitution are obtained either through the method of calibration or econometric estimation. Because the method of calibration requires limited data, it has been widely criticized for a lack of statistical validity (McKitrick, 1998; Jorgenson et al., 1984) and thus has only been adopted in a few cases.

The method of econometric estimation is more commonly used to compute the elasticity of substitution (Caddy, 1976). Compared to the method of calibration, substantial time series data or panel data are required to achieve robust estimation. However, spatial dependence in the process of estimating the elasticities of substitution has never been addressed, even though the data used for these estimations has a spatial perspective and may imply the existence of such an issue.

Anselin and Griffith (1988) indicate that spatial dependence matters in econometric estimation because ignoring such an issue may lead to serious estimation error. Most of the existing CGE analyses only rely on the elasticities of substitution from non-spatial econometric estimation, in other words, only the intraregional elasticity of substitution is considered. However, the interpretation of the new economic geography theory suggests that interregional activities on the elasticity of substitution may also exist. Limitations that occur due to omitting potential spatial dependence are likely to lead to negative consequences on policy impact analyses through a logical sequence as illustrated in Figure 16.

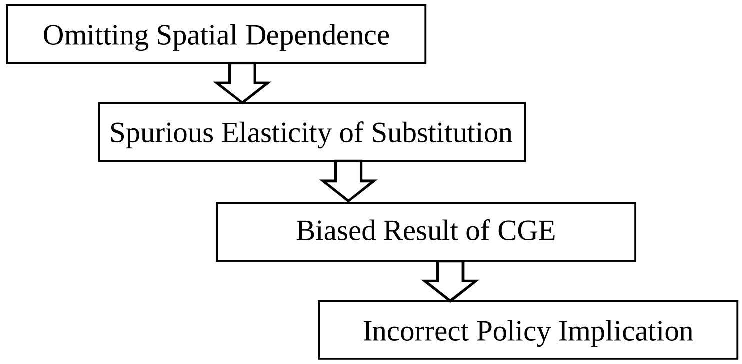


Figure 16 Consequence of Omitting Spatial Dependence

7.2 Research Questions

To address the issue of spatial dependence in a general equilibrium analysis, it becomes necessary to reconsider the process of elasticity estimation using spatial econometric estimation techniques. Literature review indicates that although spatial econometrics and CGE have been well established, there is no study that integrates the two methods to improve the validity of transportation impact analysis using CGE, not to mention allowing for transportation modal comparative analysis under such an integrated framework. The lack of a multimodal perspective limits our understandings of the spatial impacts of transportation infrastructure, particularly in counties like the U.S. where multiple modes of transportation infrastructure are comprehensively, competitively and maturely established. To fill the gaps in the literature, this chapter aims to answer the following questions:

- Question 1: how does public transportation infrastructure contribute to economic outputs in the U.S.?
- Question 2: how do such impacts vary among different modes of transportation?
- Question 3: does spatial dependence matter in CGE? If yes, how much difference exists when comparing the estimation with and without consideration of spatial dependence in a CGE context?

7.3 CGE Structure

This basic CGE is the same as the model in chapter 6, which is an edited version of a single country CGE model in the tradition of the *IFPRI* standard model, 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 represented by a one level Constant Elasticity of Transformation (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 the same as the model in chapter 6.

7.4 Estimation Procedure

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

7.4.1 Step 1 Spatial Autocorrelation Test

The spatial autocorrelation, which is measured by values of Moran's I, is tested for in the capital-labor ratio variable and in wage-rental ratio variable 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 15 Moran's I Value of Capital-Labor Ratio and Wage-Rental Ratio

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

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

Moran's I for each year from 1997 to 2011 is calculated. The results are similar for each variable in each year. Table 15 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 ratio variables of several sectors in most years are significant, which indicates spatial autocorrelation 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 that complicated spatial autocorrelation is an issue for this analysis.

7.4.2 Step 2 Non-Spatial CES Estimation

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

$$Q = \left[\alpha_{kl} K^{\frac{\sigma_{kl}-1}{\sigma_{kl}}} + (1-\alpha_{kl}) L^{\frac{\sigma_{kl}-1}{\sigma_{kl}}}\right]^{\frac{\sigma_{kl}}{\sigma_{kl}-1}} \tag{35}$$

$$\ln\left(\frac{K}{L}\right) = \sigma_{kl}\ln(\frac{1-\alpha_{kl}}{\alpha_{kl}}) + \sigma_{kl}\ln(\frac{w}{r}) \tag{36}$$

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 be simplified to a linear regression statement:

$$lny = \beta_0 + \beta_1 lnx + \varepsilon \tag{37}$$

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 byβ_1.

The panel data includes the 11 states and the District of Columbia for 15 years from 1997 to 2011and 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 37: employment, total employee compensation, private fixed asset and property income. In the non-spatial assessment, the elasticity of factor substitution for different sectors is estimated using OLS. 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.

7.4.3 Step 3 Spatial Econometric CES Estimation

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, "Spatial Durbin Model" (SDM) is adopted as the initial model for the assessment. The general form of substitution elasticity under SDM is written as:

$$\left(\frac{K}{L}\right)_{i,t} = \rho W\left(\frac{K}{L}\right)_{i,t} + \beta\left(\frac{w}{r}\right)_{i,t} + \theta W\left(\frac{w}{r}\right)_{i,t} + \varepsilon_{i,t} \qquad (38)$$

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

where $\frac{K}{L}$ and $\frac{w}{r}$ denote capital-labor ratio variable and wage-rental ratio variable, and $W\left(\frac{K}{L}\right)_{i,t}$ 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 need estimation. The analysis is conducted based on the same panel data as used in step 2.

To help identify the appropriate spatial panel model in a systematic way, again, Elhorst (2012)'s spatial panel model selection routine is adopted. The key process has been illustrated in Figure 12 in chapter 5.

Table 16 illustrates the specific spatial model form and effect for each industry from Elhorst's routine. The Hausman test suggests that spatial time fixed effect needs to be considered for most of the economic sectors. The spatial estimations for trade and warehousing do not include any effect. The pipeline sector is identified as needing to be controlled for both spatial fixed and time fixed effects.

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 investigate spillover 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 indirect impact and average total impact (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, the indirect effect or spillover effect, measures the influence of explanatory variables that come from different geographic units. The third impact, total effect, consists of both the direct impact and indirect impact.

7.4.4 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 was estimated under both non-spatial and spatial econometric models in step 2 and 3. These are the estimates utilized respectively for the 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 procedure.

7.5 IMPLAN Data

Data used for this analysis includes two components: the first is panel data including quantity and price of capital and labor for the 13 economic sectors covering the 11 northeastern states and 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 is a social accounting matrix (SAM) of the northeast states, which includes Maine, Massachusetts, New Hampshire, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia and District of Columbia. The SAM is constructed based on IMPLAN data for the year 2011.

IMPLAN was originally an input-output model developed by the Forest Service of the U.S. Department of Agriculture (U.S. Forest Service, 1992). It was later developed into an economic impact modeling system and operated by a private company named Minnesota IMPLAN Group (MIG). Unlike GTAP database which is a multi-national dataset, The IMPLAN data provides only social accounting information of the United States at various regional scales such as the state level, the metropolitan level, the county level and the zip code level. The data has been used for various economic impact analysis by various governments and academic institutions.

In order to evaluate the regional impact of public transportation infrastructure for the northeast megaregion, a regional SAM that representing the northeast economy needs to be established. The process of constructing the northeast SAM is illustrated in Figure 15.

The first step is to aggregate the 12 individual SAMs that represent the 2011 regional economy of each states using the software *IMPLAN version 3.1*. Then sectoral aggregation is implemented based on the initial northeast states SAM. During this step, the original 440 sectors are aggregated into 13 sectors, with specific accounts for each transportation mode. The sectoral classification is consistent with the national SAM used in chapter 6. The detailed sectoral list is illustrated in appendix VI.

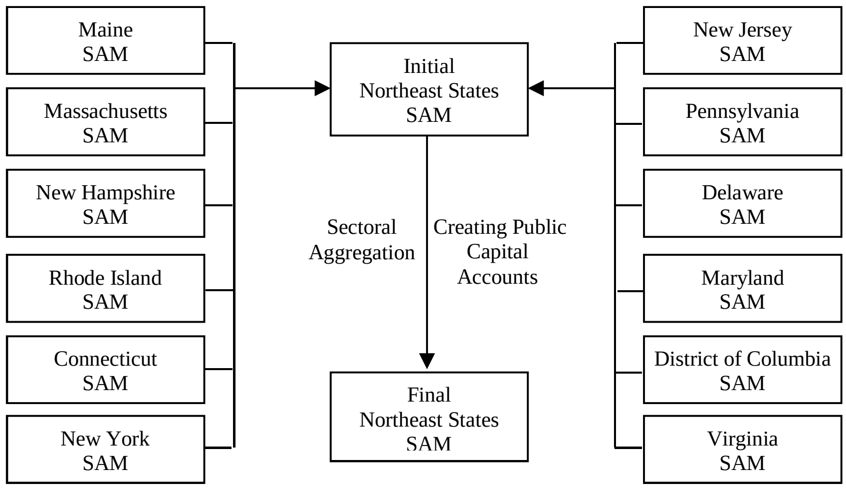


Figure 17 Process of Creating the Northeast States SAM

Similar to the previous national CGE framework, four transportation sectors that involve public transportation capital are considered differently to other sectors. The factor endowments consumed by truck, air, transit and water includes labors and private capital and public capital. The ratios of public capital for road, air, transit and water are calculated based on the information of national fixed asset from BEA. Since the original capital account in IMPLAN Data Base includes the entire capital stock (both public and private) in the economy, values of public capital of road, air, transit and water can be calculated using the public capital ratio times the total capital stock for each specific transportation sector.

7.6 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 16.

Table 16 Estimation Results of CES Elasticity of Substitution (State Level)

Sector	OLS	Spatial Econometric (SE)				
	Coef.	Total Coef.	Direct	Indirect	Model Type	Spatial or Time Effect
Agriculture	0.52***	0.41***	0.48	-0.07	SDM	TF
Manufacture	0.50***	0.36***	0.39***	-0.03***	SDM	TF
Utility&Construction	0.41***	0.16***	0.20***	-0.04***	SAR	TF
Trade	0.84***	0.84***	0.84***	0.00	SDM	N/A
Truck	0.73***	0.73***			SEM	TF
Rail	0.47***	0.24***	0.23***	0.01	SDM	TF
Air	0.74***	0.62***			SEM	N/A
Transit	0.76***	0.69***			SEM	TF
Water	0.79***	0.72***	0.70***	0.02	SDM	TF
Pipeline	0.04***	0.70***	0.47***	0.23***	SDM	SF+TF
Warehouse	0.92***	0.94***	0.93***	0.01	SDM	N/A
Information	0.99***	0.96***			SEM	N/A
Service	0.97***	0.97***			SEM	N/A

Note: 1. ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.
2. Model type indicates the specific spatial model used for Spatial Econometric (SE) estimation.
3. Spatial or time effect indicates the types of effects being used based on the Elhorst (2012) testing routine. TF denotes time fixed effect, SF denotes spatial fixed effect, and N/A denotes no effect.
4. OLS indicates result is estimated through OLS analysis while SE indicates result is estimated through spatial econometric analysis.

The results show that the elasticities of factor substitution vary significantly across different sectors. The utility and construction sector has the lowest value of substitution elasticity while the service 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 pipeline and warehouse from the spatial econometric estimation are relatively higher than OLS estimation, which implies the existence of positive spillover effects of factor substitution, whereas the values for sectors of agriculture, manufacture, utility and construction, rail, air, transit and information from the spatial econometric estimation are relatively lower than OLS estimation, which indicates a negative spillover effects of factor substitution exist among these sectors in the northeastern economy.

The spatial interactions of substitution elasticities are observed in the direct effects and indirect effects (See Table 16). Significant and positive indirect effects are found in sectors of pipeline, which indicate that wage-rental ratios from adjacent regions have positive impacts on the local region itself. The negative indirect effects are found in sectors of manufacture, utility and construction, which indicate that wage-rental ratios from adjacent regions have negative impacts on the local region. 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 a 10 percent change. The impacts on welfare, GDP value added, household income and domestic production of each sector are simulated and compared, *ceteris paribus*.

Table 17 Economic Impact of Transportation Infrastructure by Mode

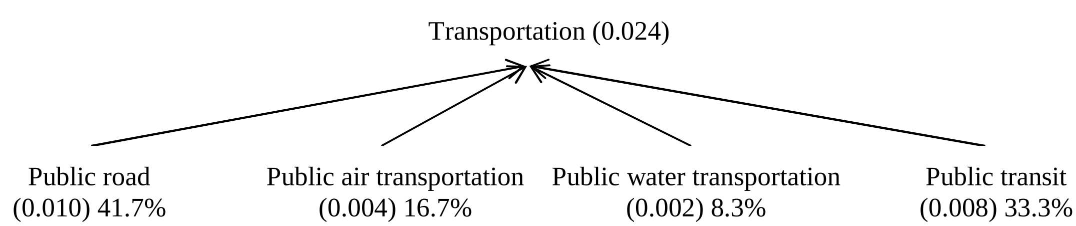
	Truck		Air		Water		Transit		All modes	
	OLS	SE	OLS	SE	OLS	SE	OLS	SE	OLS	SE
Agricul	-0.082	-0.080	-0.123	-0.111	-0.056	-0.054	-0.112	-0.109	-0.372	-0.353
Manufact	0.034	0.033	-0.003	-0.002	-0.002	-0.002	0.001	0.001	0.030	0.032
Util &Con	0.003	0.004	-0.022	-0.019	-0.008	-0.008	-0.024	-0.022	-0.051	-0.046
Trade	0.007	0.007	-0.001	0.000	-0.001	-0.001	-0.002	-0.001	0.003	0.004
Truck	1.403	1.362	-0.004	-0.003	-0.002	-0.001	-0.007	-0.006	1.390	1.352
Rail	0.058	0.056	-0.016	-0.013	-0.005	-0.005	0.022	0.021	0.059	0.059
Air	-0.008	-0.008	2.980	2.636	-0.008	-0.008	-0.033	-0.031	2.929	2.587
Transit	-0.007	-0.007	-0.012	-0.010	-0.004	-0.004	5.080	4.835	5.055	4.812
Water	-0.007	-0.007	-0.011	-0.010	5.898	5.663	-0.016	-0.016	5.861	5.628
Pipeline	-0.028	-0.027	-0.051	-0.046	-0.023	-0.023	-0.063	-0.062	-0.165	-0.157
Warehou	0.086	0.085	-0.038	-0.031	-0.010	-0.009	-0.043	-0.038	-0.005	0.007
Informat	0.004	0.004	-0.002	-0.001	-0.004	-0.004	-0.009	-0.009	-0.011	-0.010
Service	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.003	-0.002	0.016	-0.003
Househo	0.010	0.010	0.003	0.004	0.002	0.002	0.009	0.008	0.024	0.024
GDPVA	0.010	0.010	0.004	0.004	0.002	0.002	0.008	0.008	0.024	0.024
Welfare	243	243	95	97	55	56	235	236	628	632

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 represents the results simulated using CES estimates from OLS models. SE indicates the results simulated using CES estimates from spatial econometric models.

The spatial impacts of different transportation modes are summarized in Table 17. The result shows that a 10 percent increase shock of total public transportation capital is associated with a 0.024 percent increase in both GDP value added and household income. In terms of the modal influences, the economic impacts vary significantly. For instance, a

10 percent increase of public capital in the truck sector, in other words, a 10 percent increase of highway and street capital is associated with a 0.010 percent increase in both the value added to GDP and to household income in 2011, *ceteris paribus*. The second major impact is from public transit sector as a 10 percent increase of public transit capital increases the value added GDP for about 0.008 percent. Assuming a 10 percent increase of public capital in air transportation sector, the value added to the northeast regional GDP and household income are likely to increase by 0.004 percent, *ceteris paribus*. Compared to truck, transit and air sectors, the economic impacts of public capital in water transportation sectors are much smaller. A 10 percent increase of public capital in water sector is associated with 0.002 percent increase in value added to GDP and to household income respectively, *ceteris paribus*. The comparison clearly indicates that public capital in highway and streets has a major impact on growth 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 16.



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 in value added GDP and/or household income.

Figure 18 Economic Contribution of Transportation Infrastructure by Mode in the Northeast States

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 17 indicates that in the U.S. northeast states, the increase of public capital in highways and streets generates the highest welfare gain. Public capital of transit has the second largest impact on welfare generation. Public air transportation and public water transportation rank the third and the fourth in terms of their impact on welfare, respectively.

Table 18 Estimation Ratio of SECGE and traditional CGE (State Level)

	Truck	Air	Water	Transit	All modes
Agriculture	-3%	-10%	-3%	-2%	-5%
Manufacture	-1%	**-43%**	-13%	**93%**	6%
Utility&Construction	8%	-13%	-4%	-5%	-9%
Trade	1%	**-69%**	-16%	**-35%**	**65%**
Truck	-3%	-29%	-13%	-15%	-3%
Rail	-2%	-15%	-6%	-2%	1%
Air	-1%	-12%	-3%	-6%	-12%
Transit	0%	-15%	-5%	-5%	-5%
Water	1%	-11%	-4%	-4%	-4%
Pipeline	-4%	-10%	-3%	-2%	-5%
Warehouse	-2%	-19%	-11%	-13%	**-242%**
Information	4%	-24%	-5%	-6%	-11%
Service	-27%	**-59%**	**-40%**	-24%	**-33%**
GDPVA	0%	**33%**	0%	-11%	0%
Household	0%	0%	0%	0%	0%
Welfare	0%	2%	2%	0%	1%

Note: Bolded number indicates large difference (over ±30%) from the estimation ratio of SECGE and CGE based on OLS.

To assess whether 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 18 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 based on OLS estimation of substitution elasticities. The comparative ratio suggests that the results vary substantially among different sectors and by different modes.

To demonstrate clearly, large difference (over ±30%) from the estimation ratio of SECGE and CGE based on OLS is bolded in Table 18. The impacts on manufacture, trade, trucking, warehouse and service sectors are substantial when considering the spatial econometric estimation as compared to traditional OLS estimation. The negative values of ratio suggest that SECGE provides lower values of simulation outcomes than traditional CGE. This is because the negative spillover effects of wage-rental ratios on the factor demand are effectively captured. In some cases, such as the impact of manufacture production from the shock of public transit capital increase, and the impact on trade demand due to the shock of all public transportation capital increase, a positive comparative ratio is observed, which suggests that the inclusion of positive spillover effects makes the policy simulation results greater under SECGE than traditional CGE.

7.7 Summary

This study develops a new method that integrates both spatial econometrics and equilibrium modeling 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 U.S. are confirmed to be positive under the general equilibrium framework. Similar to the national level general equilibrium assessment, the magnitude of impact is smaller than that have been found in previous studies (Boarnet, 1998; Holtz-Eakin & Schwartz, 1995; Kelejian & Robinson, 1997; Ozbay *et al.*, 2007; Cohen & Morrison, 2003; 2004; Cohen, 2007). There are two possible causes of this. This 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 U.S. is mostly complete, it is reasonable to believe that the general impacts of the mature U.S. transportation infrastructure are no longer as significant as they used to be during their evolving stages. Next, general equilibrium analysis may find 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 U.S. northeast states from a multimodal and comparative perspective. Under the same percentage of increase of public transportation capital, contribution from highways and streets takes about 42 percent of total impacts of transportation, while the modes of public transit, air transportation and water transportation take 33 percent, 17 percent and 8 percent, respectively (See Figure 16). The assessment confirms that the U.S. highway and streets plays a dominant role among all transportation infrastructure systems in economic development even at the state level. Unlike the previous equilibrium assessment at the national level, public transit and passenger rail transportation together is found to be the second major modes in stimulating regional economic growth. This is consistent with the finding in the partial equilibrium assessment at the metropolitan level in chapter 5. Regional impacts of air transportation and water transportation rank the third and the fourth respectively among the systems.

Third, the study develops a SECGE model for the 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 these spatial autocorrelation tests. Without considering this issue, the elasticity of factor substitution will be biased in traditional OLS estimation, which then may impair validity of CGE assessments. This has been confirmed in this comparative analysis using both OLS estimation and spatial econometric estimation.

The differences are found to exist among the sectoral productions especially among those sectors where spatial dependence is explicitly identified, but not among all 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 general, negative percentage variation of outputs is observed among most sectors when a 10 percent increase of either specific mode of transportation capital or the overall transportation capital being implemented. The lower values of simulation output could possibly be explained by the inclusion of the negative spillover effects under SECGE, which could not be measured in traditional CGE models.

Given the fact that the study is conducted in a static and single region CGE framework, the results on specific sub-region cannot be adequately assessed. It should be noted that regional impacts of public transportation infrastructure are measured through the variations in aggregate GDP, household income, welfare and sectoral production. Future study will focus on expand to multi-regional CGE framework so that more sensitive disaggregated regional assessment can be achieved.

Chapter 8 Spatial Econometric Computable General Equilibrium: Metropolitan Level Assessment

This chapter assesses the regional impact of public transportation infrastructure at the northeast metropolitan level. A metropolitan level assessment is important as it provides more specific regional understanding of public transportation infrastructure. The assessment in this chapter has three purposes: firstly, the study provides an empirical investigation of the regional impact of public transportation infrastructure by mode at the metropolitan level. Secondly, since the spatial econometric computable general equilibrium (SECGE) model integrates both spatial econometric techniques and computable general equilibrium modeling, the study applies the model to the metropolitan level data to further test the sensitivity of the elasticity of factor substitution. Thirdly, the study provides a comprehensive examination of public transportation infrastructure's regional impacts by comparing the results at three geographic scales (at the national, the state and the metropolitan levels).

The rest of this chapter is structured as follows. Section 1 discusses the sensitivity issue of scale in economic impact assessment. Section 2 presents the data structure used for the assessment. Section 3 presents the results of the estimation procedure while section 4 discusses findings of the metropolitan level SECGE assessment. Section 5 discusses the results of multilevel assessments. Section 5 summaries and concludes.

8.1 Sensitivity of Geographic Scale

Regional economic impact of public infrastructure can be assessed in various ways. The classical approaches include estimating the economic rate of return on investment (Solomon 1959; Hayes & Garvin 1982) and output elasticity using econometric regression analysis. Each assessment needs to be conducted at a specific geographic scale depending on the research objectives, which often determines the differences in research findings. Munnell (1992) pointed out that the estimated impact of public capital becomes smaller as the geographic scale of analysis narrows, which, she argues, may be due to the effects of leakages from infrastructure investments that are not captured in a small geographic area.

The variation in impact assessment with respect to scale has been discussed extensively by Shatz *et al.* (2011). Based on a broad literature survey, they found that studies of highway infrastructure using national level data were more likely, than studies using state-level or substate-level data, to find a positive and significant relationship between infrastructure and economic outcomes. The reasons for such differences may be explained by the tendency of highway infrastructure to reallocate economic activity. Therefore, negative spillover effects are more likely to be found at a smaller geographic scale. On the other hand, a national-level assessment may be more likely to capture geographically distant (and often positive) spillovers that may not be found in state or substate-level analysis (Shatz *et al.*, 2011). While these arguments sound theoretically plausible, they have never been empirically tested under a uniform analytical structure.

The sensitivity of scale of analysis also relates to the methodologies for spillover estimation. To effectively account for the spillover effects of infrastructure, spatial econometric techniques are usually adopted. A plethora of studies have been conducted to estimate the impact of infrastructure investment using spatial econometric methods. Results vary substantially and even contradict each other. For instance, by using a spatial lag model in the Cobb-Douglas production function, Boarnet (1998) found a negative spatial lag effect for the Californian road system on economic output at the county level, which he explained was caused by migration. However, based on a different analytical scale, Jiwattanakulpaisarn *et al*. (2009) found a completely different answer in that the interstate highway system in terms of growth in the roadway density had a positive spillover effects on state employment growth.

Strictly speaking, the comparison between Boarnet (1998) and Jiwattanakulpaisarn *et al.* (2009) is not fair due to the differences in analytical framework and research focus. However, these two studies are exemplary of the complexity of comparing the scale differences across independent studies using different scales and methodologies. In order to understand the sensitivity of scale on impact assessment result, the comparative environment needs to be identical. To achieve this goal, the present study cautiously designs two research components: first, the same analytical framework and process using SECGE is applied, and second, the data for the multilevel assessment originates from the same source and in the same format. The research objective is to understand to what extent the impact of public transportation infrastructure differs across geographic scales of analysis within the same analytical framework.

8.2 Data Structure

Similar to the data structure used for the state level SECGE assessment, two types of data are required for the metropolitan level analysis. In addition, in order to make the multilevel assessment comparable, a national level dataset that originates from the same data source has to be constructed. The first is a panel dataset that includes the quantity and price of capital and labor. This is used to estimate elasticity of factor substitution. Despite detailed industry level data available at the national and the state levels, it is usually not available at the metropolitan level due to confidentiality.[7] Therefore, in order to make the assessment at different geographic scale comparable, elasticity of factor substitution of all industries is estimated rather than the specific elasticity for each sector.

In order to compare the results from a multilevel assessment, the national level data excludes Hawaii and Alaska. Only the 48 contiguous states plus the District of Columbia are included in order to reduce the regional bias due to the demographic and geographic heterogeneities. The state level data only focuses on the 12 regions in the U.S. northeast including Maine, Massachusetts, New Hampshire, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia and the District of Columbia. The metropolitan level data consists of the 32 MSAs that lie within the 12 northeast states.

[7] U.S. Bureau of Economic Analysis doesn't release confidential information such as wage, rental, employment and output by sectors at the Metropolitan Statistical Areas level to public due to the concern of private sector confidentiality and national security.

Data is collected from BEA. Following Balistreri *et al.* (2003)'s approach, four data series are collected for the estimation of factor substitution: employment, total employee compensation, private fixed asset and property income. In the non-spatial assessment, the elasticity of factor substitution for different sectors is estimated using OLS regression. Panel regression including both fixed effect and random effect estimations are also implemented. The Hausman test is carried out to determine which effect provides more efficient estimators.

The second data type in this study is the social accounting matrix (SAM), which is used for the computable general equilibrium assessment. SAMs at three geographic scales – the national, state and metropolitan levels – are constructed based on the regional data from IMPLAN.

The process of data construction is illustrated in Figure 17. To make the assessment consistent, the three levels of SAMs are constructed using the same data source. The first step is to create the 12 northeast states SAM, which is an aggregation of the 12 individual SAMs that represent the 2011 regional economy of each state. Then sectoral aggregation is implemented based on the initial northeast states SAM. During this step, the original 440 sectors are aggregated into 13 sectors, with specific accounts for each transportation mode.

Public transportation infrastructure capital accounts are constructed based on the same approach as illustrated in Chapter 6. Four transportation sectors that involve public transportation capital are considered differently from other sectors. The factor endowments consumed by truck, air, transit and water includes labors, private capital and public capital. The ratios of public capital for road, air, transit and water are calculated based on the information on national fixed assets from BEA. Since the original capital account in the IMPLAN data base includes the entire capital stock (both public and private) in the economy, values of public capital of road, air, transit and water are calculated using the public capital ratio times the total capital stock for each specific transportation sector.

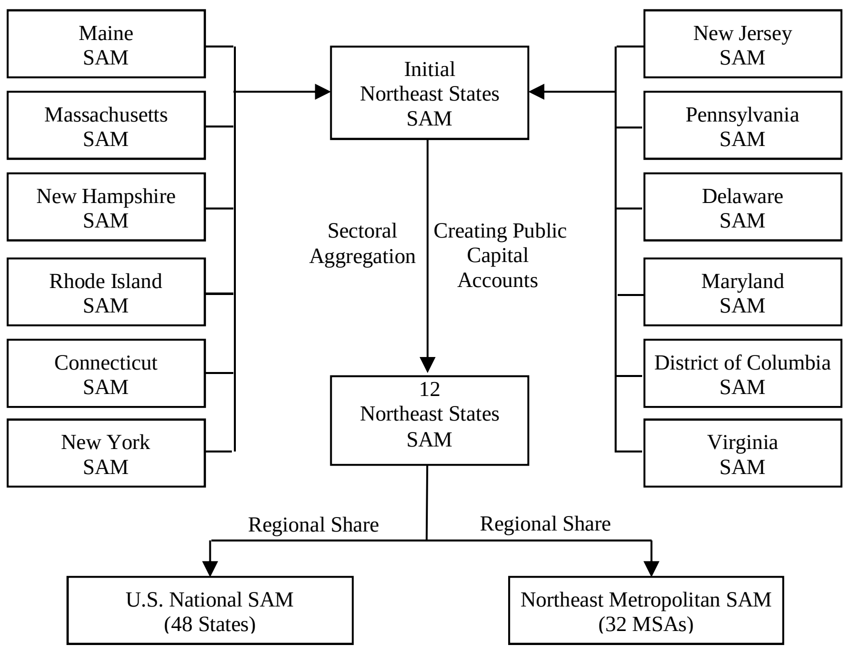


Figure 19 Process of Creating the Multilevel SAMs

Table 19 Regional Share of Industrial Earnings and Factor Inputs (2011)

Sector	Northeast MSAs	Northeast States	National Level	Regional Share for MSAs	Regional Share for Northeast States
Agriculture	2018961	5203268	102463348	0.388	0.051
Manufacture	128272824	188761607	942239747	0.680	0.200
Utility and Construction	97235496	144160168	571349671	0.674	0.252
Trade	190192625	256421404	1046800303	0.742	0.245
Air Transportation	6884086	7521589	38975792	0.915	0.193
Rail Transportation	1498384	2394463	12954664	0.626	0.185
Water Transportation	958524	1620721	7267495	0.591	0.223
Truck Transportation	9702652	15806943	98260420	0.614	0.161
Transit Transportation	7463943	9321156	21728512	0.801	0.429
Pipeline	4079	1084502	18403573	0.702*	0.059
Warehouse	5696844	8564873	34033256	0.665	0.252
Information	88113551	97406102	307316137	0.905	0.317
Service	1490006324	1820867852	5961033622	0.818	0.305
Average Industrial Share				0.702	0.221
Wage and salary disbursements	1474334902	1837456520	6603780069	0.802	0.278
Industry Earnings	2072379138	2584487780	9383787175	0.802	0.275

Note: * Since most of the industrial earnings data of pipeline sector is not available at MSA level due to confidential reasons, average industrial share is used to represent the regional share.

The 12 northeast states include Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia and District of Columbia.

Data sources are: CA05N Personal income by major source and earnings by NAICS industry,
SA05N Personal income by major source and earnings by NAICS industry,
US Bureau of Economic Analysis, Regional Data Account.

Due to the high cost of purchasing the IMPLAN SAMs at both the national and the metropolitan level, the U.S. national SAM and the northeast metropolitan SAM are constructed respectively based on an approximate approach by using regional shares of each sector as proxies for aggregation or disaggregation.[8] As displayed in table 19,

[8] The national SAM requires the total IMPLAN state package of 2011 which costs $13,850. The 32 northeast metropolitan SAM requires the aggregation of the total 111 county SAMs, which costs about $38,850 ($350X111). As a matter of fact, IMPLAN uses the similar approach as we discussed to construct regional level data. The only

regional shares of industrial output and factor input are calculated respectively based on industrial earnings.

8.3 Estimation Procedure

The estimation procedures of the assessment are carried out sequentially in four steps, which is the same process as outlined in Chapter 7.

Step 1 Spatial Autocorrelation Test

Table 20 shows the global Moran's I of capital-labor ratio (*KL*) and wage-rental ratio (*wr*) by year and by scale. The Moran's I values of the capital-labor ratios are significant for all years for the metro level and national level data, implying spatial autocorrelation exists across different regions and years. The positive value indicates a tendency toward clustering while the negative value indicates a tendency toward dispersion. The Moran's I values of wage-rental ratio are consistently significant at the national level but only partially significant at the metro level. The existence of spatial dependence among both the dependent variable and the independent variable suggests that a complexity of spatial autocorrelation exists in this analysis.

Step 2 Non-Spatial Assessment

The second step is to obtain the basic values of elasticity of factor substitution for the CGE analysis. This study follows the classical CES production function estimation of elasticity of factor substitution.

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difference is that it uses much more specific data such as the U.S. Census Bureau's Annual Survey of Manufactures to achieve a more accurate estimation for sectoral activities.

Table 20 Moran's I Value of Capital-Labor Ratio and Wage-Rental Ratio (Multilevel)

Scale	Metro Level (32MSAs)		State Level (12 Northeast States)		National Level (48 States)	
Year	Ln(KL)	Ln(wr)	Ln(KL)	Ln(wr)	Ln(KL)	Ln(wr)
1980	-0.493**	0.107	0.088	-0.778***	0.363***	0.287**
1981	-0.442***	0.113	0.086	-0.410**	0.341**	0.296***
1982	-0.412**	0.124*	0.001	-0.380**	0.332***	0.404***
1983	-0.394**	0.101	-0.033	-0.292**	0.337**	0.364***
1984	-0.403***	0.093	-0.047	-0.308*	0.371***	0.367***
1985	-0.422***	0.040	-0.075	-0.302*	0.361***	0.340***
1986	-0.431***	0.022	-0.092	-0.278	0.335***	0.364***
1987	-0.412**	0.027	-0.049	-0.329**	0.412***	0.397***
1988	-0.409***	0.054	-0.046	-0.417***	0.465***	0.348***
1989	-0.445***	0.097	-0.039	-0.355**	0.473***	0.306***
1990	-0.456***	0.157**	-0.038	-0.261	0.459***	0.303***
1991	-0.473**	0.122	-0.133	-0.484***	0.472***	0.292***
1992	-0.478***	0.146*	-0.115	-0.465***	0.450***	0.287***
1993	-0.474**	0.164*	-0.107	-0.499***	0.449***	0.281***
1994	-0.465**	0.165*	-0.143	-0.566***	0.481***	0.315**
1995	-0.408	0.109	-0.075	-0.640***	0.468***	0.363***
1996	-0.359**	0.092	-0.052	-0.551***	0.436***	0.355***
1997	-0.382**	0.025	-0.061	-0.679***	0.440***	0.331***
1998	-0.390***	0.028	-0.008	-0.541***	0.423***	0.346***
1999	-0.353**	0.018	-0.046	-0.626***	0.404***	0.331***
2000	-0.353***	0.001	-0.104	-0.363**	0.384**	0.330***
2001	-0.334**	0.012	-0.229	-0.389***	0.385***	0.361***
2002	-0.300**	0.079	-0.269	-0.242	0.393***	0.399***
2003	-0.323**	0.067	-0.263	-0.277*	0.386***	0.455***
2004	-0.312*	0.129*	-0.250	-0.442**	0.394***	0.436***
2005	-0.321*	0.118	-0.239	-0.752***	0.402***	0.424***
2006	-0.307**	0.181*	-0.172	-0.702***	0.407***	0.316***
2007	0.315**	0.060	-0.117	-0.564***	0.398***	0.248**
2008	-0.304**	0.037	-0.140	-0.597***	0.379***	0.318***
2009	-0.295*	0.015	-0.231	-0.503***	0.435***	0.297***
2010	-0.292**	-0.001	-0.164	-0.571***	0.428***	0.317***
2011	-0.301**	-0.018	-0.147	-0.577***	0.415***	0.292***

Note: ***,**, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.
The observations at the metro, state and national levels are 32, 12, and 49, respectively.

Step 3 Spatial Econometric Analysis

The third step is to estimate the elasticity of factor substitution using spatial econometric estimation to control for spatial dependence. Again, Elhorst's (2012) Spatial

Model Testing Procedure is used to determine the appropriate spatial econometric models. Table 21 illustrates the results of specific tests for spatial dependence. The Hausman test suggests that fixed effects need to be considered in all three levels of analysis. A further test on fixed effects suggests that both the spatial and the time fixed effects should be considered. The LM test and the LR test are used to justify which spatial model is preferred in terms of providing efficient estimators. The results suggest that the SEM is preferred for both the northeast metro level and the national level estimation. A SDM should be adopted for the northeast state level estimation.

Table 21 Specific Tests for Spatial Dependence

Specific Tests	Metro Level Test Statistic (p-value)	State Level Test Statistic (p-value)	National Level Test Statistic (p-value)
The Hausman Test H0: Reject fixed effect model in favor of random effect model	14.022 (0.003)	23.520 (0.000)	7.0412(0.071)
LR Test H0: Spatial FE Jointly Insignificant	1331.791 (0.000)	979.742 (0.000)	3716.782 (0.000)
LR Test H0: Time FE Jointly Insignificant	2384.642 (0.000)	961.675 (0.000)	2715.978(0.000)
LM Lag	1310.509 (0.000)	0.037 (0.849)	521.294(0.000)
LM Error	1411.415 (0.000)	0.133 (0.716)	560.702 (0.000)
LM Lag Robust	1.619 (0.203)	0.850 (0.357)	8.823 (0.003)
LM Error Robust	102.525 (0.000)	0.946 (0.331)	48.232 (0.000)
H0: $\theta = 0$			
LR Value	41.859 (0.000)	1.049 (0.789)	12.156 (0.007)
H0: $\theta + \rho\beta = 0$			
LR Value	2.037 (0.565)	0.948 (0.814)	-4.935 (1.000)

Note: H0 denotes null hypothesis. LM denotes Lagrange Multiplier while LR denotes Likelihood Ratio.

Step 4 SECGE

In the step 4, a CGE model with an integration of spatial econometric estimates is established. The elasticity of factor substitution is estimated using both non-spatial and spatial econometric models as illustrated in step 2 and 3. These are the estimates utilized respectively for the CES production function in the CGE. The SECGE is the second integration. The estimation result of elasticity of substitution in Table 22 clearly indicates that at all levels of geographic scales, the elasticity of substitution using spatial econometric estimation is much smaller than both OLS estimation and panel regression estimation. A small value of the substitution rate between capital and labor implies that switch from one factor to the other is difficult as the two factors are likely to be complementary.

Table 22 Results of CES Elasticity of Substitution Estimation (Multilevel)

Scale of Assessment		OLS	Panel Regression	Spatial Econometrics
Northeast Metro Level	Coefficient	0.274***	0.231***	0.189***
(Obs.=1024)	Adj-R2	0.156	0.191	0.935
	Effect	N/A	Fixed	TF+SF SEM
Northeast State Level	Coefficient	0.450***	0.421***	0.303**
(Obs.=384)	Adj-R2	0.411	0.570	0.975
	Effect	N/A	Fixed	TF+SF SDM
National Level	Coefficient	0.407***	0.308***	0.139***
(Obs.=1568)	Adj-R2	0.268	0.348	0.952
	Effect	N/A	Fixed	TF+SF SEM

Note: 1. ***, **, * denote coefficients are significant at 1%, 5% and 10% statistical level, respectively.
2. TF and SF denote time fixed effect and spatial fixed effect, respectively
3. SEM and SDM denote spatial error model and spatial Durbin model.

This makes sense when the nature of spatial dependence is considered. Substitution of factors occurs both intraregionally and interregionally. Traditional estimation such as OLS or panel estimation provides a higher estimation value of the substitution rate because interregional factor mobility which leads to the complement relationship among factors is neglected. Therefore, in order to achieve a comprehensive regional impact assessment, spatial econometric estimation is critical.

Given the fact that the elasticity of factor substitution is exogenously estimated based on historical data using spatial econometric models, the value 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 and included in the general equilibrium assessment.

8.4 Results

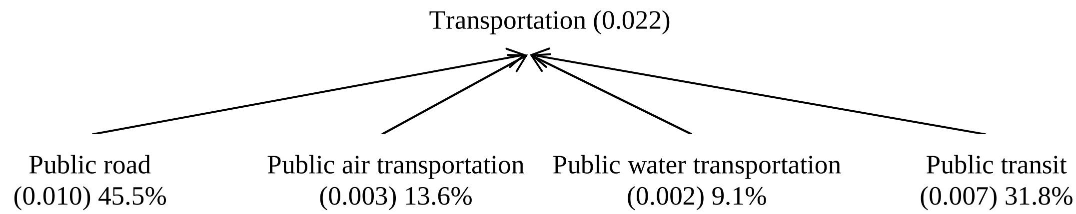
The metropolitan level economic impact of different transportation modes are displayed in Table 23. The result shows that a 10 percent increase shock of total public transportation capital is associated with a 0.022-0.023 percent increase in both GDP value added and household income. In terms of the modal influences, the economic impacts vary significantly. For instance, a 10 percent increase of public capital in the truck sector, in other words, a 10 percent increase of highway and street capital is associated with a 0.010 percent increase in both the value added to GDP and in household income in 2011, *ceteris paribus*. The second major impact is from the public transit sector as a 10 percent increase of public passenger rail and transit capital increases the value added GDP by about 0.007 percent. Assuming a 10 percent increase of public capital in air transportation sector, the value added to the northeast regional GDP and household income are likely to increase by 0.003 percent, *ceteris paribus*. Compared to truck, transit and air sectors, the economic impacts of public capital in water transportation sectors are much smaller. A 10 percent increase of public capital in water sector is associated with 0.002 percent increase in value added to GDP and to household income respectively, *ceteris paribus*.

Table 23 Economic Impact of Transportation Infrastructure by Mode (Metropolitan Level)

	Truck		Air		Water		Transit		All modes	
	OLS	SE	OLS	SE	OLS	SE	OLS	SE	OLS	SE
Agricult	-0.001	0.003	0.001	0.002	-0.009	-0.006	-0.001	0.002	-0.009	0.000
Manufact	0.053	0.048	0.010	0.010	0.007	0.007	0.022	0.022	0.092	0.088
Util& Con	0.021	0.020	0.003	0.003	0.000	0.001	0.004	0.006	0.029	0.030
Trade	0.010	0.010	0.002	0.002	0.000	0.000	0.003	0.004	0.015	0.017
Truck	1.032	0.740	0.002	0.002	-0.004	-0.003	0.003	0.005	1.034	0.744
Rail	0.036	0.030	0.003	0.003	0.001	0.001	0.017	0.015	0.057	0.050
Air	0.009	0.010	0.440	0.309	0.001	0.002	0.004	0.005	0.455	0.327
Transit	0.005	0.007	0.001	0.002	-0.002	-0.001	1.937	1.426	1.942	1.434
Water	-0.019	-0.014	0.000	0.000	4.275	3.404	-0.008	-0.005	4.248	3.384
Pipeline	-0.027	-0.016	0.000	0.001	-0.019	-0.014	-0.015	-0.009	-0.060	-0.038
Warehou	0.055	0.051	0.006	0.007	-0.003	-0.001	0.012	0.016	0.070	0.074
Informati	-0.006	-0.001	0.000	0.001	-0.007	-0.006	-0.004	-0.001	-0.017	-0.008
Service	0.000	0.002	0.001	0.002	-0.001	0.000	0.002	0.003	0.002	0.006
Househo	0.010	0.010	0.003	0.003	0.002	0.002	0.007	0.007	0.022	0.023
GDPVA	0.010	0.010	0.003	0.003	0.002	0.002	0.007	0.007	0.022	0.023
Welfare	189	196	60	59	36	38	137	137	422	429

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 represents the results simulated using CES estimates from OLS models. SE indicates the results simulated using CES estimates from spatial econometric models.



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 in value added GDP and/or household income.

Figure 20 Economic Contribution of Transportation Infrastructure by Mode in the Northeast MSAs (Metropolitan Level)

Similar to the state level assessment in Chapter 7, the comparison among transportation modes indicates that public capital in highway and streets has the highest impact on the growth of gross regional product and household income at the metropolitan level assessment. The relative economic contributions among the four modes of public transportation are summarized in Figure 18.

The results of the welfare impact of public transportation infrastructure are similar to its economic impacts. Welfare effect at the northeast metropolitan level assessment varies by mode. The increase of public capital in highways and streets generates the highest welfare gain. Public capital of transit has the second largest impact on welfare generation. Public air transportation and public water transportation rank the third and the fourth in terms of their impact on welfare, respectively.

Again, the sensitivity of the elasticity of factor substitution estimated using both OLS and spatial econometric models is evaluated using the estimation ratios of SECGE and traditional CGE. The ratio is calculated using the difference of CGE results based on the spatial econometric estimation and OLS estimation divided by the result of the 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 based OLS estimation of substitution elasticities. The comparative ratio suggests that the results vary substantially among different sectors and by different modes.

Table 24 Estimation Ratio of SECGE and traditional CGE (Metropolitan Level)

	Truck	Air	Water	Transit	All modes
Agriculture	**-385%**	56%	-27%	**-259%**	**-105%**
Manufacture	-9%	-2%	1%	2%	-5%
Utility&Construction	-8%	14%	**379%**	40%	4%
Trade	4%	15%	**-154%**	32%	16%
Truck	-28%	18%	-32%	43%	-28%
Rail	-16%	9%	84%	-11%	-12%
Air	14%	-30%	29%	36%	-28%
Transit	42%	34%	-49%	-26%	-26%
Water	-26%	**863%**	-20%	-28%	-20%
Pipeline	-41%	**382%**	-23%	-39%	-36%
Warehouse	-7%	24%	-74%	31%	5%
Information	-74%	**-999%**	-25%	-66%	-55%
Service	**-943%**	18%	-65%	67%	**234%**
GDPVA	3%	-1%	6%	1%	2%
Household	4%	-2%	6%	1%	2%
Welfare	3%	-2%	6%	0%	2%

Note: Bold number indicates large difference (over ±100%) from the estimation ratio of SECGE and CGE based on OLS.

Clearly, the difference of output becomes much larger at the metropolitan level (Table 24) than the state level (see Table 18). The impacts on agriculture, utility and construction, trade, water transportation, pipeline, information and service sectors differs significantly between the spatial econometric estimation of the elasticity of factor substitution and the traditional OLS estimation. The negative value of ratios suggests that SECGE provides lower values of simulation outcomes than the traditional CGE. This is possible because the negative spillover effects of wage-rental ratios on the factor demand are effectively captured. In some cases, such as the impact of water transportation and pipeline production from the shock of public air transportation capital increase, positive estimation ratios are observed for these sectors, indicating that the inclusion of positive spillover effects makes the policy simulation results greater under SECGE than traditional CGE.

8.5 Multilevel Comparison

The comprehensive examination of public transportation infrastructure is achieved through the multilevel comparison both by mode and by scale. Public capital of all transportation modes and different modes are shocked sequentially and respectively at the same level of a 10 percent change in the three scales of assessments. The impacts on welfare, GDP value added, household income, domestic production of each sector are simulated and compared, as illustrated in Table 25.

Table 25 Regional Impact of Transportation Infrastructure by Mode

	Truck			Air			Water			Transit			All modes		
Sector	Metro	State	National	Metro	State	National	Metro	State	National	Metro	State	National	Metro	State	National
Agriculture	0.003	-0.035	0.024	0.002	-0.065	0.000	-0.006	-0.035	0.003	0.002	-0.070	0.002	0.000	-0.205	0.029
Manufacture	0.048	0.029	0.026	0.010	0.003	0.001	0.007	0.001	0.003	0.022	0.009	0.002	0.088	0.042	0.032
Utility&Cons	0.020	0.008	0.027	0.003	-0.009	0.014	0.001	-0.004	0.006	0.006	-0.010	0.003	0.030	-0.015	0.050
Trade	0.010	0.008	0.022	0.002	0.002	0.011	0.000	0.000	0.004	0.004	0.003	0.002	0.017	0.014	0.039
Truck	**0.740**	**0.654**	**0.118**	0.002	0.001	0.005	-0.003	0.000	0.004	0.005	0.000	0.002	**0.744**	**0.655**	**0.129**
Rail	0.030	0.033	0.027	0.003	-0.006	0.004	0.001	-0.002	0.004	0.015	0.018	0.002	0.050	0.043	0.037
Air	0.010	0.001	0.018	**0.309**	**1.508**	**0.663**	0.002	-0.004	-0.005	0.005	-0.015	0.002	**0.327**	**1.490**	**0.678**
Transit	0.007	0.000	0.018	0.002	-0.005	0.004	-0.001	-0.003	0.003	**1.426**	**2.966**	**0.159**	**1.434**	**2.958**	**0.185**
Water	-0.014	-0.002	0.021	0.000	-0.006	-0.013	**3.404**	**3.588**	**0.570**	-0.005	-0.011	0.002	**3.384**	**3.568**	**0.579**
Pipeline	-0.016	-0.008	0.026	0.001	-0.026	0.013	-0.014	-0.014	0.006	-0.009	-0.038	0.002	-0.038	-0.086	0.048
Warehouse	0.051	0.057	0.030	0.007	-0.010	0.061	-0.001	-0.002	0.008	0.016	-0.008	0.002	0.074	0.037	0.101
Information	-0.001	0.006	0.019	0.001	0.001	0.011	-0.006	-0.002	0.004	-0.001	-0.003	0.002	-0.008	0.002	0.036
Service	0.002	0.004	0.016	0.002	0.001	0.008	0.000	0.001	0.003	0.003	0.002	0.002	0.006	0.008	0.029
Household	0.010	0.009	0.021	0.003	0.004	0.013	0.002	0.002	0.005	0.007	0.009	0.002	0.023	0.024	0.040
GDPVA	0.010	0.009	0.021	0.003	0.004	0.013	0.002	0.002	0.005	0.007	0.009	0.002	0.023	0.025	0.040
Welfare	196	254	1637	59	102	1005	38	59	393	137	245	163	429	660	3192

Note: 1. Numbers indicate percentage change due to a 10 percent increase of the corresponding public transportation capital input.

2. Metro denotes the 32 metropolitan areas; State denotes the 12 northeast states. National denotes the 48 contiguous states plus the District of Columbia.

3. Bold number indicates variation greater than 0.1 percent.

One noticeable finding is that the regional impacts due to public transportation infrastructure increase are relative small. Most sectoral and economic impact change is less than 0.1 percent across all scales of assessments. The biggest impact occurs in the transportation sectors which receive the corresponding public capital investment shock.

In the northeast metro and state level assessments, public capital investment in water and transit lead to relative larger increases of water and public passenger rail and transit production than road and air transportation sectors. But a larger impact is found for air transportation sector at the national level assessment. In terms of the modal impact comparison, different regional impacts are found for different modes of public transportation infrastructure. For example, public investment on road infrastructure has the biggest impact than other transportation modes. A 10 percent increase of public capital in the truck sector, in other words, a 10 percent increase of highway and street capital is associated with a 0.021 percent increase in both the value added to GDP and to household income at the national level. Assuming a 10 percent increase of public capital in air transportation sector at the national level, the value added to GDP and household income are likely to increase by 0.013 percent, *ceteris paribus*. A 10 percent increase in public water transportation capital is likely to contribute to a 0.005 percent increase in the value added to GDP and household income whereas the contribution from a 10 percent increase of public passenger rail and transit capital only contributes to a 0.002 percent increase of the value added to GDP and household income. A similar comparative result of regional impact for each mode can be found at the northeast metro and state level assessments.

The specific impact comparison by mode at different levels of assessment is summarized in Table 26. The magnitude of impact can be compared by the contribution share (in percentage) of each mode to the regional value added GDP, which is calculated from the contribution margin of each mode. The relationship is illustrated in equation 39:

$$Contribution\ Share\ of\ Mode\ i = \frac{Contribution\ Margin\ of\ Mode\ i}{Total\ Contribution\ Margin} \qquad (39)$$

Generally, the results indicate that public capital in highway and streets has the overwhelming impact on the growth of GDP and household income among the four public transportation modes. However, the regional impact of public transportation infrastructure improvement in air, water and transit varies considerably across different scale of assessment. At the US national level, the second largest contribution to the economic growth from transportation infrastructure investment is air transportation, which accounts for 32 percent. The contribution share from water transportation is 12 percent, indicating its regional impact ranks the third among the four public transportation modes. Despite the contribution share of public passenger rail and transit only accounts for 5 percent at the national level, the share are much larger at both the northeast MSA level and the northeast state level, which suggests that public passenger rail and transit infrastructure play a more important role on regional economic growth in the northeast megaregion than other places in the U.S.

On the other hand, impact of public air transportation infrastructure on the growth of GDP decreases as the geographic scale narrows. The contribution share decreases to only 17 percent at the northeast state level and 14 percent at the northeast metro level assessment. This may be explained by the fact that distant spillovers of air transportation are not found in state or metro level assessment, which confirms Shatz *et al.* (2011)'s argument.

Table 26 Multilevel Impact Comparison by Mode of Transportation

Transportation Mode	Northeast MSA Level	Northeast State Level	US National Level	Northeast MSA Level	Northeast State Level	US National Level
	Contribution Margin			Contribution Share		
Road	0.010	0.009	0.021	0.45	0.38	0.51
Air	0.003	0.004	0.013	0.14	0.17	0.32
Water	0.002	0.002	0.005	0.09	0.08	0.12
Transit	0.007	0.009	0.002	0.32	0.38	0.05
Total	0.022	0.024	0.041	1.00	1.00	1.00

Note: Contribution margin is measured in percentage. It means the economic changes due to a 10 percent increase of any type of public transportation capital.

8.6 Summary

Chapter 8 identifies the relative importance of regional impact of different public transportation modes from multimodal and multilevel perspectives. The metropolitan level assessment confirms that public highway and street infrastructure has the highest regional impact, public rail and transit has the second highest impact at the northeast metropolitan areas. Impacts from public airport and public water transportation rank the third and fourth, respectively.

In addition, the study also tests the sensitivity of the scale of analysis including the national, the northeast state, and the northeast metropolitan level. Under the same percentage of policy simulation on initial transportation capital investment, the share of economic contribution from each public mode varies substantially. Public capital investment in highway infrastructure contributes the most, despite its magnitude deceases at the state and the metro level assessments. Contribution from public air transportation investment ranks the second at the national level but ranks the third at the northeast state and metro levels. The decrease of contribution share as geographic scale narrows implies the spillover effects of highway and air transportation exist among broader geographic scale. On the contrary, public passenger rail and transit infrastructure tend to have a much larger spillover effects at the northeast metropolitan and state levels than the national level. This further confirms that public passenger rail and public transit play critical roles on regional economic growth in the US northeast megaregion.

The SECGE model developed in this study allows us to achieve a more comprehensive assessment of public transportation infrastructure. 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 the ratios of factor input and factor price through spatial autocorrelation tests. Without considering this issue, the elasticity of factor substitution is biased in traditional OLS estimation, as the negligence of spillover effects of factor substitution mistreats the complementary relationship of interregional factor mobility and thus may impair the validity of CGE assessments. This has been confirmed at both the state and metropolitan levels in the comparisons of elasticity of substitution using both the non-spatial estimation and the spatial econometric estimation.

Chapter 9 Conclusion and Policy Implication

Although the linkages between regional output and transportation infrastructure have been widely researched, results are still inconclusive given the challenges of data and method being used. This study improves the understanding of such linkages with a focus on public transportation infrastructure within the context of the U.S. northeast megaregion. Unlike traditional studies, the estimation is improved through four aspects:

First, the study adopts financial data measured in real monetary values with a focus on the period between 1991 and 2009. This enables the study to generate credible assessment than traditional studies that relied on proxy data.

Second, spatial econometric modeling techniques are adopted in order to control for spatial dependence of both regional output and public transportation infrastructure inputs.

Third, the study provides a detailed regional impact comparison of different modes of public transportation infrastructure.

Fourth, regional impacts of public transportation infrastructure are assessed under both partial and general equilibrium frameworks, and also under different geographic scales including metropolitan level, state level and national level.

9.1 Conclusion Remarks

One of the major findings of this dissertation is that public transportation infrastructure continues playing a vital role in stimulating and facilitating regional economic growth even after the maturity of the systems after the 1990s in the U.S. northeast megaregion. The positive effects of public transportation infrastructure are found under both the partial equilibrium assessment and the general equilibrium assessment.

In terms of the modal comparison, highway infrastructure is found to play a dominant role in contributing to regional economic growth at the national level, the state level and the metropolitan level. The regional impact of public passenger rail and transit varies among different geographic scales and locations, but it is significant. A higher impact was found at both the metropolitan level and the regional state level. After considering spatial spillover effects, the dissertation confirms that public passenger rail and transit infrastructure in the northeast megaregion play a substantial impact on regional economic growth. The regional impact is stronger than public airports' but significantly smaller than highways'. The impact of public airport infrastructure was found much larger at the national level rather than only in the northeast state level or the northeast metropolitan level.

9.2 Policy Implications

The research finding has the following three policy implications.

First, public transportation infrastructure is critical to regional economic development and growth. The impact of public transportation infrastructure can be undertaken not only through direct effects such as project construction and local improvements, but it can also be seen through indirect effects such as an enhanced regional connectivity and a developed transportation network from the completion of public transportation infrastructure. This dissertation, primarily focused on the period after 1990, suggesting that public transportation infrastructure continues playing a vital role on regional economic growth in especially the northeast megaregion. However, according to the descriptive statistics in chapter 2, it should be noted that public transportation infrastructure in many metropolitan areas are decaying. Therefore, a sustainable public support for transportation infrastructure is essential to maintain the economic vitality of the northeast megaregion in the future.

Second, government and metropolitan planning organizations need to better understand the merit of public transportation infrastructure by modes. The empirical evidence found in this dissertation reveals the relative importance of different transportation infrastructure, which may provide implications to shape future transportation investment policies. In particular, the multimodal investigation for the northeast megaregion suggests that public passenger rail and transit infrastructure should be given more attention given its important roles in facilitating regional economic growth.

The third implication is for methodological application. Spatial econometrics and general equilibrium are two essential aspects of an effective and realistic impact assessment for transportation infrastructure. Despite this newly developed SECGE with integration of both spatial econometrics and computable general equilibrium was used for transportation in this dissertation, the method can also be applied to other policy analysis and in different regions or scales by different institutions and in fields such as immigration policy, energy and environment policy. More robust results of impact evaluations are expected to be generated from SECGE given the direct considerations of spatial issues and general equilibrium framework.

9.3 Future Research

The ultimate goal of this dissertation is to develop a systematic assessment tool that can be applied to analyze regional impact of various public investment strategies for scholars, policymakers and practitioners. To achieve this goal, the dissertation needs further endeavors in the following directions.

The first direction is to expand the existing static single region CGE framework to a multi-regional dynamic CGE framework. As a matter of fact, CGE analysis has been widely used to assess complicated regional issues with relaxing assumptions, such as allowing the variation of wages in accordance with employment demand and capital accumulation in a long run. These considerations now can be implemented under a dynamic CGE framework. One of the future researches is to adopt some advanced dynamic CGE model such as the USAGE model. The USAGE is dynamic CGE model developed by Peter Dixon and Maureen Rimmer from the Centre of Policy Studies at Monash University. The model has a detailed 500 industrial classification and has the capacity to allow long-term equilibrium of labor supply and demand. Another alternative is to use The Enormous Regional Model (TERM) analytical framework. TERM is a multiregional CGE model of a single country, developed by Mark Horridge also from the Centre of Policy Studies at Monash University. It treats each region as a separate economy and has an ability to solve much complicated general equilibrium analysis with a large number of regions and sectors. The challenge of using these models is how to integrate the capital accumulation function of different transportation sectors.

Another direction of future research is to expand the spatial econometric method to estimate other parameters in CGE. For example, in a multiregional equilibrium model, it is highly possible that the regional trade elasticities of Armington function and the elasticities of transformation may have issues of spatial dependence. How to estimate them, and what available information can be used to provide valid estimation are questions should be researched.

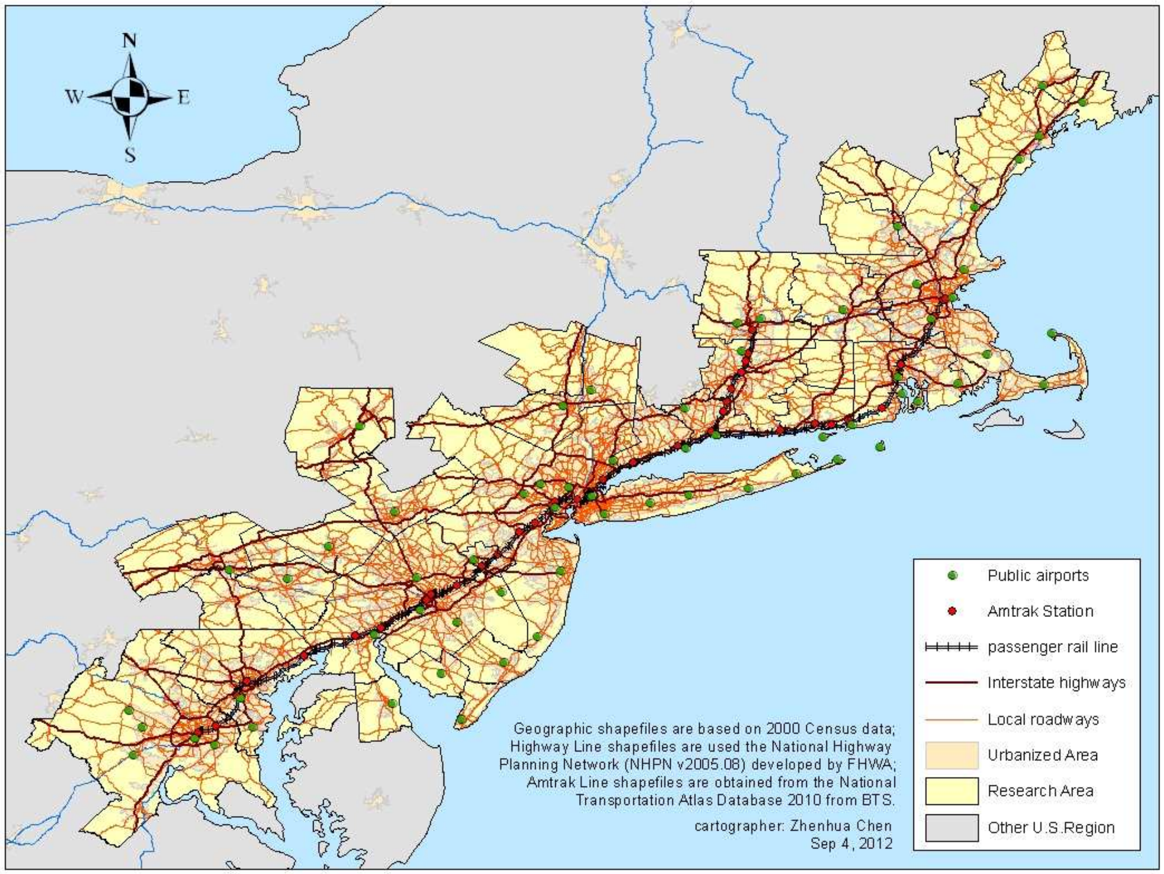
In addition, further research can also be proceeded in the direction of applying SECGE in other policy fields such as energy policy or education policy. For example, SECGE can be applied to compare different energy subsidy policies including photovoltaic energy, shale gas and oil. The relative regional impacts can be assessed in the SECGE framework with consideration of spatial dependence of industrial characteristics.

Appendix I MSAs Included in the Spatial Econometric Assessment

CBSA	NAME	TYPE	FID
10900	Allentown-Bethlehem-Easton, PA-NJ	MSA	17
12100	Atlantic City, NJ	MSA	26
12580	Baltimore-Towson, MD	MSA	31
12700	Barnstable Town, MA	MSA	9
14460	Boston-Cambridge-Quincy, MA-NH	MSA	5
14860	Bridgeport-Stamford-Norwalk, CT	MSA	14
18180	Concord, NH	McSA	2
20100	Dover, DE	MSA	28
25420	Harrisburg-Carlisle, PA	MSA	20
25540	Hartford-West Hartford-East Hartford, CT	MSA	10
28740	Kingston, NY	MSA	7
29540	Lancaster, PA	MSA	24
30140	Lebanon, PA	MSA	21
30340	Lewiston-Auburn, ME	MSA	0
31700	Manchester-Nashua, NH	MSA	3
35300	New Heaven-Milford, CT	MSA	15
35620	New York-Northern New Jersey-Long Island, NY-NJ-PA	MSA	18
35980	Norwich-New London, CT	MSA	13
36140	Ocean City, NJ	MSA	29
37980	Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	MSA	22
38860	Portland-South Portland-Biddeford, ME	MSA	1
39100	Poughkeepsie-Newburgh-Middletown, NY	MSA	8
39300	Providence-New Bedford-Fall River, RI-MA	MSA	16
39740	Reading, PA	MSA	19
42540	Scranton-Wikes-Barre, PA	MSA	12
44140	Springfield, MA	MSA	4
45940	Trenton-Ewing, NJ	MSA	23
47220	Vineland-Millville-Bridgeton, NJ	MSA	27
47900	Washington-Arlington-Alexandria, DC-VA-MD-WV	MSA	30
48740	Willimantic, CT	McSA	11
49340	Worcester, MA	MSA	6
49620	York-Hanover, PA	MSA	25

* MSA= Metropolitan Statistical Area, McSA=Micropoltian Statistical Area. Source: BEA.

Appendix II Geographic Boundaries of 32 MSAs in the Northeast Megaregion



Appendix III Panel Granger Causality Test

Dependent Variable	GMPPC-TTSPC		GMPPC-HWYSPC		GMPPC-AMSPC		GMPPC-TRASPC	
	lgmppc	lttspc	lgmppc	lhwyspc	lgmppc	lamspc	lgmppc	ltraspc
lgmppc(-1)	0.973***	0.023	1.065***	0.012	0.956***	-0.561	1.139***	-0.007
lttspc								
lttspc(-1)	-0.02*	0.973***						
lhwyspc					-0.011***	-0.102	-0.025***	-0.005
lhwyspc(-1)			-0.013***	0.963***				
lamspc			0.001	0.006				
lamspc(-1)					-0.002***	0.732***	-0.002***	0.004
ltraspc			0.002*	0.003	-0.001	-0.013		
ltraspc(-1)							0.004***	0.990***
lemp	0.003***	-0.002	-0.004	-0.006	0.001	0.045	-0.006**	0.009
lpfapc	0.001	-0.039	-0.046***	-0.061	0.018	0.516***	-0.103***	0.005
Arellano-Bond test for AR(2), (p value)	0.615	0.118	0.074	0.206	0.053	0.277	0.089	0.900
Hansen test for overid. restiction, p-value	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wald Test (H0: lags=0)	3.10*	0.47	22.3***	0.06	21.48***	2.85	21.47***	0.04
Number of Obs	576	576	403	403	333	320	403	402

* All variables were measured in level and in logarithmic term. All models are estimated using the Arellano and Bond dynamic panel system GMM estimations. * Significant at the 1 percent level, ** Significant at the 5 percent level and*** Significant at the 10 percent level. All other tests assume asymptotic normality.

The issue of endogeniety may possibly attribute to the simultaneity between regional output and transportation input. To understand the causal relationship, Granger causality test (Granger, 1969) can be implemented which is based on testing whether the lagged terms have explanatory power on the other variable. The process of testing relies on the assumption that all variables are stationary, *Yt* is regressed on its own lags and on lags of *Xt*. If the lags of *Yt* are found to be jointly statistically significant, then the null hypothesis that *Xt* does not Granger cause *Yt* can be rejected. In the dynamic panel analysis, the Granger causality test is carried out in two steps: In the first step, a pair of dynamic autoregressive models is carried out, as follow:

$$Y_{it} = a_0 + \sum_l^m \alpha_l Y_{it-1} + \sum_l^m \gamma_l X_{it-1} + \sum_k^n W_{ik} + \mu_i + \varepsilon_{it} \quad (13)$$

$$X_{it} = \beta_0 + \sum_l^m \beta_l X_{it-1} + \sum_l^m \epsilon_l Y_{it-1} + \sum_k^n W_{ik} + \delta_i + \theta_{it} \quad (14)$$

where Y_{it} and X_{it} denotes the economic variables and transportation capital stock variables in region *i* in year *t* respectively. W_{ik} represents the controlling variables including labor and private capital. μ_i and δ_i denotes MSA-specific individual effects. The disturbances ε_{it} and θ_{it} are assumed to be independently distributed across MSAs with zero means.

The second step is to run Wald tests (F-test) on the coefficients of the X_{it-1} in the equation (13) and the coefficients of the Y_{it-1} in the equation (14) to check whether they are jointly statistically different from zero.

Since all the variables are found stationary, they are utilized directly for the panel Granger test using the generalized method of moments (GMM) approach by controlling for the influences of labor and private capital. The tests are conducted in four groups, each of which includes either the total transportation capital variable or one specific mode capital variable. In each group, the dynamic vector autoregressive (VAR) models are implemented in forms of equation 13 and 14.

The wald tests suggest that coefficients of lagged transportation capital per capita is not statistically significantly equals zero, meaning it has impact on the regional output variable. However, in the opposite model where transportation capital per capita treated as dependent variable and the lagged regional output variable treated as independent variable, the wald test is not statistically significant, which suggests the lagged regional output variable does not show significant influence on the variation of transportation capital variables.

Appendix III 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	

Appendix IV List of Public Airports Included in the Study

FID	Airport	City	State	CBSA
1	ABE	Allentown/Bethlehem/Easton, PA	PA	10900
2	ANP	Annapolis, MD	MD	12580
3	ACY	Atlantic City, NJ	NJ	12100
4	BWI	Baltimore, MD	MD	12580
5	BED	Bedford, MA	MA	39300
6	BLM	Belmar/Farmingdale, NJ	NJ	35620
7	NJ1	Berlin, NJ	NJ	37980
8	BVY	Beverly, MA	MA	14460
9	B19	Biddeford, ME	ME	38860
10	BID	Block Island, RI	RI	39300
11	BBX	Blue Bell, PA	PA	37980
12	BOS	Boston, MA	MA	14460
13	BDR	Bridgeport, CT	CT	14860
14	NHZ	Brunswick, ME	ME	38860
15	ADW	Camp Springs, MD	MD	47900
16	WWD	Cape May, NJ	NJ	36140
17	CEF	Chicopee Falls, MA	MA	44140
18	DOV	Dover, DE	DE	20100
19	FRG	East Farmingdale, NY	NY	35620
20	HTO	East Hampton, NY	NY	35620
21	FID	Fishers Island, NY	NY	35620
22	WRI	Fort Dix, NJ	NJ	35620
23	MDT	Harrisburg, PA	PA	25420
24	BDL	Hartford, CT	CT	25540
25	HYA	Hyannis, MA	MA	12700
26	ISP	Islip, NY	NY	35620
27	LNS	Lancaster, PA	PA	29540
28	VA4	Leesburg, VA	VA	47900
29	LEW	Lewiston/Auburn, ME	ME	30340
30	MNZ	Manassas, VA	VA	47900
31	MHT	Manchester, NH	NH	31700
32	MIV	Millville, NJ	NJ	47220
33	MTP	Montauk Point, NY	NY	35620
34	MMU	Morristown, NJ	NJ	35620
35	EWB	New Bedford/Fall River, MA	MA	39300
36	HVN	New Haven, CT	CT	35300
37	JFK	New York, NY	NY	35620
38	LGA	New York, NY	NY	35620
39	EWR	Newark, NJ	NJ	35620
40	SWF	Newburgh/Poughkeepsie, NY	NY	39100
41	NPT	Newport, RI	RI	39300
42	ZXU	North Kingstown, RI	RI	39300
43	OWD	Norwood, MA	MA	14460

44	PHL	Philadelphia, PA	PA	37980
45	PYM	Plymouth, MA	MA	14460
46	PWM	Portland, ME	ME	38860
47	PSM	Portsmouth, NH	NH	14460
48	POU	Poughkeepsie, NY	NY	39100
49	PVD	Providence, RI	RI	39300
50	PVC	Provincetown, MA	MA	12700
51	RDG	Reading, PA	PA	39740
52	AVP	Scranton/Wilkes-Barre, PA	PA	42540
53	NJ3	Somerville, NJ	NJ	35620
54	TEB	Teterboro, NJ	NJ	35620
55	TTN	Trenton, NJ	NJ	45940
56	DCA	Washington, DC	VA	47900
57	IAD	Washington, DC	VA	47900
58	OXC	Waterbury, CT	CT	35300
59	NJ2	West Creek, NJ	NJ	35620
60	WST	Westerly, RI	RI	39300
61	BAF	Westfield, MA	MA	44140
62	FOK	Westhampton, NY	NY	35620
63	HPN	White Plains, NY	NY	35620
64	ILG	Wilmington, DE	DE	37980
65	ORH	Worcester, MA	MA	49340

Appendix V List of Transit Agencies Included in the Study

Last Report Year	CBSA	TRSID	SystemName	State	City
1999	35620	2918	Carey Transportation, Inc.	CT	New Haven
2009	35300	1042	Valley Transit District	CT	Derby
2009	14860	1050	Greater Bridgeport Transit Authority	CT	Bridgeport
2009	25540	1056	Connecticut Transit - Stamford Division	CT	Hartford
2009	14860	1057	Norwalk Transit District	CT	Norwalk
2004	14860	1103	City of Stamford Dial-A-Ride	CT	Stamford
2009	35300	1107	Milford Transit District	CT	Milford
2009	25540	1110	2Plus Partners in Transportation, Inc	CT	Rocky Hill
2009	25540	1017	Greater Hartford Transit District	CT	Hartford
2009	25540	1045	Dattco, Inc.	CT	New Britain
2009	25540	1047	New Britain Transportation Company, Inc.	CT	Berlin
2009	25540	1048	Connecticut Transit - Hartford Division	CT	Hartford
2006	25540	1052	New Britain Transportation Company, Inc.	CT	Berlin
2009	25540	1063	Middletown Transit District	CT	Middletown
2009	25540	1102	Connecticut Department of Transportation	CT	Newington
2009	25540	1108	Greater Hartford Ridesharing Corporation - The Rideshare Company	CT	Windsor
2009	35300	1049	The Greater New Haven Transit District	CT	Hamden
2009	35300	1055	Connecticut Transit - New Haven Division	CT	Hartford
2000	35300	1104	Greater Waterbury Transit District	CT	Waterbury
2009	35300	1095	Northeast Transportation Company, Inc.	CT	Waterbury
2009	35980	1040	Southeast Area Transit	CT	Preston
2009	14860	1051	Housatonic Area Regional Transit	CT	Danbury
1997	14860	1041	Westport Transit District C/O Norwalk Transit District	CT	Norwalk
2009	47900	3030	Washington Metropolitan Area Transit Authority	DC	Washington
2009	20100	3075	Delaware Transit Corporation	DE	Dover
1995	20100	3031	Delaware Administration for Regional Transit	DE	Dover
1995	20100	3047	Delaware Transit Corporation	DE	Dover
1995	20100	3032	Delaware Administration for Specialized Transportation	DE	Dover
2009	14460	1003	Massachusetts Bay Transportation Authority	MA	Boston
2009	14460	1004	Brockton Area Transit Authority	MA	Brockton
2009	14460	1005	Lowell Regional Transit Authority	MA	Lowell
2009	14460	1013	Merrimack Valley Regional Transit Authority	MA	Haverhill
2009	14460	1053	Cape Ann Transportation Authority	MA	Gloucester

2009	14460	1117	Plymouth & Brockton Street Railway Company	MA	Plymouth
2009	14460	1118	MetroWest Regional Transit Authority	MA	Framingham
1991	14460	1100	National Railroad Passenger Corporation	MA	Boston
1991	14460	1902	Brush Hill Transportation Company	MA	Boston
1991	14460	1905	Hudson Bus Lines	MA	Medford
1991	14460	1906	Plymouth & Brockton Street Railway Company	MA	Plymouth
1991	14460	1907	A Yankee Line, Inc.	MA	Boston
1991	39300	1908	American Eagle Motor Coach	MA	Fairhaven
1991	39300	1910	H & L Bloom, Inc.	MA	Taunton
1991	14460	1913	Big W Transit, Inc.	MA	Ashland
1991	14460	1917	Michaud Bus Lines, Inc.	MA	Salem
2009	39300	1064	Greater Attleboro-Taunton Regional Transit Authority	MA	Taunton
2001	44140	1089	Transit Express	MA	Springfield
2009	44140	1008	Pioneer Valley Transit Authority	MA	Springfield
2009	49340	1014	Worcester Regional Transit Authority	MA	Worcester
2009	12700	1105	Cape Cod Regional Transit Authority	MA	Hyannis
2009	39300	1006	Southeastern Regional Transit Authority	MA	New Bedford
2009	49340	1061	Montachusett Regional Transit Authority	MA	Fitchburg
2009	47900	3048	Howard Transit	MD	Ellicott City
2009	47900	3051	Ride-On Montgomery County Transit	MD	Rockville
2009	47900	3085	Prince George's County Transit	MD	Largo
1996	12580	3043	The Columbia Transit System	MD	Columbia
1992	12580	3046	Maryland State Railroad Administration	MD	BWI Airport
2009	12580	3034	Maryland Transit Administration	MD	Baltimore
2009	12580	3040	Annapolis Department of Transportation	MD	Annapolis
2009	12580	3074	Harford Transit	MD	Abingdon
2009	47900	3072	Transit Services of Frederick County	MD	Frederick
2009	47900	3088	County Commissioners of Charles County, MD	MD	Port Tobacco
2009	12580	3092	Carroll County Planning Department	MD	Westminster
2009	38860	1115	Northern New England Passenger Rail Authority	ME	Portland
2009	38860	1016	Greater Portland Transit District	ME	Portland
2009	38860	1069	Regional Transportation Program, Inc.	ME	Portland
2009	38860	1088	Casco Bay Island Transit District	ME	Portland
1995	30340	1101	Kenneth Hudson Inc. dba Hudson Bus Lines	ME	Lewiston
2009	31700	1087	Nashua Transit System	NH	Nashua
2009	31700	1002	Manchester Transit Authority	NH	Manchester
2009	14460	1086	Cooperative Alliance for Seacoast Transportation	NH	Dover
2009	14460	1119	University Of New Hampshire - University Transportation Services	NH	Durham
2009	35620	2080	New Jersey Transit Corporation	NJ	Newark
2009	35620	2098	Port Authority Trans-Hudson Corporation	NJ	Jersey City
2009	35620	2122	Academy Lines, Inc.	NJ	Hoboken
2009	35620	2126	Hudson Transit Lines, Inc.	NJ	Mahwah
2009	35620	2128	Suburban Transit Corporation	NJ	New Brunswick
1993	35620	2129	Rockland Coaches, Inc.	NJ	Newark

2009	35620	2132	New Jersey Transit Corporation-45	NJ	Newark
2009	35620	2149	Rockland Coaches, Inc.	NJ	Westwood
2002	35620	2154	New York Waterway	NJ	Weehawken
2009	35620	2160	Community Transit, Inc.	NJ	Paramus
2009	35620	2161	DeCamp Bus Lines	NJ	Montclair
2003	35620	2162	Lafeyette-Greenville IBOA	NJ	Jersey City
2009	35620	2163	Lakeland Bus Lines, Inc.	NJ	Dover
2004	35620	2164	Leisure Line	NJ	Paramus
2009	35620	2165	Olympia Trails Bus Company, Inc.	NJ	Elizabeth
2009	35620	2166	Orange-Newark-Elizabeth, Inc.	NJ	Elizabeth
2002	35620	2167	South Orange Avenue IBOA	NJ	Newark
2009	35620	2168	Trans-Hudson Express	NJ	Elizabeth
2001	35620	2170	Vanpool of New Jersey, Inc.	NJ	Newark
2009	35620	2190	Port Imperial Ferry Corporation dba NY Waterway	NJ	Weehawken
1993	35620	2923	Rockland Coaches Inc.	NJ	Bergenfield
2009	37980	2075	Port Authority Transit Corporation	NJ	Lindenwold
2007	47220	2155	Cumberland County Office on Aging	NJ	Bridgeton
2009	35620	2006	City of Long Beach	NY	Long Beach
2009	35620	2007	Metropolitan Suburban Bus Authority, dba: MTA Long Island Bus	NY	Garden City
2009	35620	2008	MTA New York City Transit	NY	New York
1993	35620	2038	Green Bus Lines, Inc.	NY	Jamaica
1993	35620	2039	Jamaica Buses, Inc.	NY	Jamaica
2005	35620	2040	New York Bus Tours, Inc., dba: New York Bus Service	NY	Bronx
1993	35620	2046	Triboro Coach Corporation	NY	Jackson Heights
2009	35620	2071	Huntington Area Rapid Transit	NY	Huntington Station
2009	35620	2072	Suffolk County Department of Public Works - Transportation Division	NY	Yaphank
1993	35620	2073	Command Bus Company, Inc.	NY	Brooklyn
2009	35620	2076	Westchester County Bee-Line System	NY	Mount Vernon
2009	35620	2078	Metro-North Commuter Railroad Company, dba: MTA Metro-North Railroad	NY	New York
2004	35620	2079	Liberty Lines Transit, Inc.	NY	Yonkers
2009	35620	2082	New York City Department of Transportation	NY	New York
2009	35620	2084	Transport of Rockland	NY	Pomona
2009	35620	2085	Clarkstown Mini-Trans	NY	Nanuet
2009	35620	2086	Transportation Resources Intra-County for Physically Handicapped and Senior Citizens	NY	Pomona
2009	35620	2089	Village of Spring Valley Bus	NY	Spring Valley
2009	35620	2096	Putnam County Transit	NY	Carmel
2009	35620	2099	Staten Island Rapid Transit Operating Authority, dba: MTA Staten Island Railway	NY	Staten Island
2009	35620	2100	MTA Long Island Rail Road	NY	Jamaica
2004	35620	2117	Liberty Lines Express, Inc.	NY	Yonkers
2009	35620	2135	Monsey New Square Trails Corporation	NY	Spring Valley
2005	35620	2136	Queens Surface Corporation	NY	Flushing
2006	35620	2147	GTJC	NY	Lynbrook
2008	35620	2159	Atlantic Paratrans of NYC, Inc.	NY	Staten Island

2009	35620	2171	Private One of New York, LLC, dba: New York Airport Service	NY	Brooklyn
2006	35620	2173	American Transit, Inc.	NY	Yonkers
2009	35620	2175	Private Transportation Corporation	NY	Brooklyn
2009	35620	2177	Adirondack Transit Lines, Inc,	NY	Hurley
2006	35620	2180	Atlantic Express	NY	Staten Island
2008	35620	2181	Roosevelt Island Operating Corporation of the State of New York	NY	Roosevelt
2009	35620	2188	MTA Bus Company	NY	New York
2009	35620	2189	BillyBey Ferry Company, LLC	NY	New York
1991	35620	2919	Erin Tours, Inc.	NY	Brooklyn
1994	35620	2920	Metro Apple Express, Inc.	NY	Brooklyn
2000	35620	8023	Atlantic Paratrans of Colorado, Inc. (APCO)	NY	Staten Island
2009	39100	2009	City of Poughkeepsie	NY	Poughkeepsie
2009	39100	2010	Dutchess County Division of Mass Transportation	NY	Poughkeepsie
2009	35620	2137	Monroe Bus Corporation	NY	Brooklyn
2009	39100	2148	Newburgh Beacon Bus Corporation	NY	New Windsor
2009	28740	2178	Ulster County Area Transit	NY	Kingston
2009	39100	2179	Hendrick Hudson Bus Lines, Inc.	NY	Newburgh
2009	39100	2182	Town of Highlands Dial-A-Bus	NY	Highland Falls
2009	39100	2183	Town of Monroe Dial-A-Bus	NY	Monroe
2009	39100	2187	Village of Kiryas Joel	NY	Monroe
2009	35620	2169	Trans-Bridge Lines, Inc.	PA	Bethlehem
2009	35620	3102	Martz Trailways, Poconos	PA	Wilkes Barre
2009	37980	3019	Southeastern Pennsylvania Transportation Authority	PA	Philadelphia
2009	25420	3057	Pennsylvania Department of Transportation	PA	Harrisburg
2001	37980	3082	Atlantic Paratrans of PA, Inc.	PA	Philadelphia
2009	10900	3010	Lehigh and Northampton Transportation Authority	PA	Allentown
2009	25420	3014	Capital Area Transit	PA	Harrisburg
2009	29540	3018	Red Rose Transit Authority	PA	Lancaster
2009	39740	3024	Berks Area Reading Transportation Authority	PA	Reading
2009	49620	3027	York County Transportation Authority	PA	York
2009	39300	1001	Rhode Island Public Transit Authority	RI	Providence
2002	39300	1109	Comsis Mobility Services, Inc., dba: Intelitran	RI	Providence
2009	39300	1116	Bonanza	RI	Providence
2009	47900	3058	City of Fairfax CUE Bus	VA	Fairfax
2009	47900	3068	Fairfax Connector Bus System	VA	Fairfax
2009	47900	3070	Potomac and Rappahannock Transportation Commission	VA	Woodbridge
2009	47900	3071	City of Alexandria	VA	Alexandria
2009	47900	3073	Virginia Railway Express	VA	Alexandria
2009	47900	3080	Arlington Transit - Arlington County	VA	Arlington
2009	47900	3081	Loudoun County Commuter Bus Service - Office of Transportation Services	VA	Leesburg
2009	47900	3103	Martz Group, National Coach Works of Virginia	VA	Fredericksburg
2009	47900	3079	Fredericksburg Regional Transit	VA	Fredericksburg

Appendix VI Detailed Sectoral List in Social Accounting Matrix

Sector	IMPLAN Sector Number	GTAP Sector Number	GTAP Code	Sector Description
AGR	1-27	1	pdr	Paddy Rice: rice, husked and unhusked
		2	wht	Wheat: wheat and meslin
		3	gro	Other Grains: maize (corn), barley, rye, oats, other cereals
		4	v_f	Veg & Fruit: vegetables, fruitvegetables, fruit and nuts, potatoes, cassava, truffles,
		5	osd	Oil Seeds: oil seeds and oleaginous fruit; soy beans, copra
		6	c_b	Cane & Beet: sugar cane and sugar beet
		7	pfb	Plant Fibres: cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
		8	ocr	Other Crops: live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
		9	ctl	Cattle: cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof
		10	oap	Other Animal Products: swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs' legs, edible products of animal origin n.e.c., hides, skins and furskins, raw , insect waxes and spermaceti, whether or not refined or coloured

		11	rmk	Raw milk
		12	wol	Wool: wool, silk, and other raw animal materials used in textile
		13	frs	Forestry: forestry, logging and related service activities
		14	fsh	Fishing: hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
		15	col	Coal: mining and agglomeration of hard coal, lignite and peat
		16	oil	Oil: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
		17	gas	Gas: extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
		18	omn	Other Mining: mining of metal ores, uranium, gems. other mining and quarrying
		19	cmt	Cattle Meat: fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird.
		20	omt	Other Meat: pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
		21	vol	Vegetable Oils: crude and refined oils of soya-bean, maize (corn),olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and canola, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu and linseed, perhaps partly or wholly hydrogenated,inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes.
		22	mil	Milk: dairy products
		23	pcr	Processed Rice: rice, semi- or wholly milled
		24	sgr	Sugar

		25	ofd	Other Food: prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.
		26	b_t	Beverages and Tobacco products
Mnf	41-318	27	tex	Textiles: textiles and man-made fibres
		28	wap	Wearing Apparel: Clothing, dressing and dyeing of fur
		29	lea	Leather: tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear
		30	lum	Lumber: wood and products of wood and cork, except furniture; articles of straw and plaiting materials
		31	ppp	Paper & Paper Products: includes publishing, printing and reproduction of recorded media
		32	p_c	Petroleum & Coke: coke oven products, refined petroleum products, processing of nuclear fuel
		33	crp	Chemical Rubber Products: basic chemicals, other chemical products, rubber and plastics products
		34	nmm	Non-Metallic Minerals: cement, plaster, lime, gravel, concrete
		35	i_s	Iron & Steel: basic production and casting
		36	nfm	Non-Ferrous Metals: production and casting of copper, aluminium, zinc, lead, gold, and silver
		37	fmp	Fabricated Metal Products: Sheet metal products, but not machinery and equipment
		38	mvh	Motor Motor vehicles and parts: cars, lorries, trailers and semi-trailers
		39	otn	Other Transport Equipment: Manufacture of other transport equipment

		40	ele	Electronic Equipment: office, accounting and computing machinery, radio, television and communication equipment and apparatus
		41	ome	Other Machinery & Equipment: electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
		42	omf	Other Manufacturing: includes recycling
Util_ Cns	28-40	43	ely	Electricity: production, collection and distribution
		44	gdt	Gas Distribution: distribution of gaseous fuels through mains; steam and hot water supply
		45	wtr	Water: collection, purification and distribution
		46	cns	Construction: building houses factories offices and roads
Trade	319-331	47	trd	Trade: all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods; retail sale of automotive fuel
Road	335	48	otp	Other Transport: road, rail ; pipelines, auxiliary transport activities; travel agencies
Rail	333			
Transit	336			
Pipe	337			
Warehouse	340			
Water	334	49	wtp	Water transport
Air	332	50	atp	Air transport
Info	339-353	51	cmn	Communications: post and telecommunications
Service	338, 354-440	52	ofi	Other Financial Intermediation: includes auxiliary activities but not insurance and pension funding (see next)
		53	isr	Insurance: includes pension funding, except compulsory social security

		54	obs	Other Business Services: real estate, renting and business activities
		55	ros	Recreation & Other Services: recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
		56	osg	Other Services (Government): public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
		57	dwe	Dwellings: ownership of dwellings (imputed rents of houses occupied by owners)

Note: The number for Implan data is “2 Digit NAICS for IMPLAN 440”.

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