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Are We Done Fighting Traffic? Planning Congestion Resilient Regions

Abstract

Congestion alleviation has long been a core planning objective in most transportation programs, but existing policy portfolios have been both costly and unsuccessful at alleviating congestion. Road gridlock is inconvenient, but it remains unclear under which conditions this indicator of active urban places also impedes other social objectives, among which this dissertation focuses on the economy. This dissertation contributes by estimating congestion's economic drag and identifying how policy can contribute to high-functioning regions despite congestion. First, I use panel data for 88 U.S. Metropolitan Statistical Areas (MSAs) to estimate congestion's drag on employment growth (1993 to 2008) and productivity growth (2001 to 2008). Next, to identify "better" regional adaptations to congestion, I explore congestion resilience using a metric of economic growth per unit "cost" of congestion growth. Using panel data for 88 MSAs, I estimate the relative contributions of policies in enabling congestion resilience. Finally, using case studies of high-congestion MSAs, I explore policies distinguishing congestion resilient Los Angeles and Washington, DC from congestion unresilient Chicago and Houston.

Results indicate that higher congestion is not associated with slower productivity growth, but is associated with slower employment growth rates above congestion levels of 39 (shorter-term) or 57 annual hours of delay per commuter (longer-term). When pooling MSAs across the range of congestion levels using panel data, sources of congestion resilience parallel "good" economic policy, more generally. But when focusing on four high-congestion MSAs, results suggest an important role for planners. Road transportation policy, public transit policy, and urban spatial structure distinguish congestion resilient Los Angeles and Washington, DC from congestion unresilient Chicago and Houston.

In conclusion, evidence suggests that regional economies are highly adaptive to congestion and that planning policy can contribute to congestion resilience, particularly for high-congestion MSAs, but that context matters. Lessons from case studies of high-congestion MSAs are critical for other large and congested MSAs, but are less applicable across the spectrum of lower regional congestion levels. In fact, lessons from panel models including MSAs with a large-range of regional congestion levels indicate that congestion resilience is largely a function of "good" economic policy generally for most regions.

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ARE WE DONE FIGHTING TRAFFIC?
PLANNING CONGESTION RESILIENT REGIONS

Matthias N. Sweet

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REGIONS

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Matthias Nathaniel Sweet

DEDICATION

To my family. In particular, to Karen. Karen reviews my work and yet continues to believe in me. Lucas is two and a half and is anxiously awaiting his personal book about trucks and trains. Eleanor is still operating strictly on the basis of faith in warmth, meals, and sleep. They are the oxygen in my lungs.

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ABSTRACT**ARE WE DONE FIGHTING TRAFFIC?
PLANNING CONGESTION RESILIENT REGIONS**

Matthias N. Sweet

Dr. Rachel R. Weinberger

Congestion alleviation has long been a core planning objective in most transportation programs, but existing policy portfolios have been both costly and unsuccessful at alleviating congestion. Road gridlock is inconvenient, but it remains unclear under which conditions this indicator of active urban places also impedes other social objectives, among which this dissertation focuses on the economy. This dissertation contributes by estimating congestion's economic drag and identifying how policy can contribute to high-functioning regions despite congestion. First, I use panel data for 88 U.S. Metropolitan Statistical Areas (MSAs) to estimate congestion's drag on employment growth (1993 to 2008) and productivity growth (2001 to 2008). Next, to identify "better" regional adaptations to congestion, I explore *congestion resilience* using a metric of economic growth per unit "cost" of congestion growth. Using panel data for 88 MSAs, I estimate the relative contributions of policies in enabling congestion resilience. Finally, using case studies of high-congestion MSAs, I explore policies distinguishing

congestion resilient Los Angeles and Washington, DC from congestion unresilient Chicago and Houston.

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CHAPTER 1. INTRODUCTION

The practice of justifying new transit and road capacity expansion on the basis of traffic congestion alleviation, the *congestion alleviation model*, remains the dominant paradigm in transportation planning. Federal surface transportation legislation, state transportation agencies, and metropolitan planning organizations identify congestion reduction as a critical objective and performance indicator of transportation policy. But by most accounts, both politicians and the public at large lack the will to institute the controversial policies (principally, peak-period pricing or parking supply management) necessary to reduce congestion. Congestion is here to stay but there is a deficiency in robust research identifying how best to live with it. Economic and travel behavior theories reason that congestion is a diseconomy and is inconvenient, but little research explores the more extensive impact of congestion (and congestion alleviation policy) on second-order outcomes, including the support of economic opportunities, equity, and quality of life. This dissertation focuses on economic outcomes. Transportation policy continues to follow the *congestion alleviation model* despite its poor track record. The comparatively newer *accessibility planning model* grounds transportation policy recommendations in the notion of travel as a derived demand which can enable broader social outcomes, including economic activities. However little research has applied the accessibility planning model to ground conventional wisdom about traffic congestion alleviation, in

spite of the more fundamental importance of transportation services' second-order impacts in supporting the economy, individual opportunity, and broader social objectives.

Many transportation interest groups characterize traffic congestion as a heavy economic burden (Chan, 2005; Hartgen & Fields, 2009), arguing that its alleviation would lead to more productivity and economic growth. In fact, federal legislation explicitly identifies congestion reduction and economic support as joint primary policy objectives. However, research on the link between congestion alleviation and economic growth is conflicted. Some of the largest urban economies in the world are also among the most congested. Yet, some suggest that traffic congestion reduces city competitiveness and that only peak-period pricing, a highly unpopular tool, can reduce congestion to increase competitiveness (Boarnet, 1997; Hymel, 2009; Winston & Langer, 2006). Others suggest that few common planning policies reduce traffic congestion (Downs, 1992) and that one should temper optimism about using transportation infrastructure investment to foster new economic growth (Banister & Berechman, 2000; Boarnet & Haughwout, 2000; Paez, 2004). How can regions support vibrant economies despite the potential drag of traffic congestion? This is the topic of this dissertation: *congestion resilience*.

In this dissertation, I apply quantitative research methods to make two new contributions to research on traffic congestion and transportation policy. First, I use panel data models to estimate congestion's drag on economic growth, comparing the relative importance of other explanations of regional economic outcomes. Second, I use both panel data models

and case studies to identify regional characteristics and planning policies which lead metropolitan areas to become resilient to traffic congestion's diseconomy.

1.1. Dissertation Road Map

The balance of this dissertation is organized as follows:

Chapter 2: Statement of Problems and Objectives

I explore the importance of this research and establish the broad context within city planning scholarship and practice. Transportation policymakers justify billions of dollars in public expenditures on the basis of congestion alleviation and overcoming congestion's economic burden. However, with the exception of politically-unpalatable pricing proposals, congestion alleviation policies have had limited success. By focusing on economic outcomes, I frame traffic congestion and discourse on its high cost as important to more fundamental outcomes insofar that a) we understand when congestion impedes the economy and b) we understand how policy can enable adaptation by fostering high-functioning places despite congestion.

Chapter 3: Review of Related Research

I review existing research on the role of traffic congestion and its outcomes within the broader context of transportation and planning policy. I define congestion, identify its causes, and compare the relative success of select policies justified on the basis of

congestion alleviation. In addition, I discuss the findings of previous research that identifies congestion as a potential drag on economic growth and productivity.

Chapter 4: Research Methods

While existing transportation planning practice justifies policy on the basis of congestion alleviation and first-order travel time savings, this dissertation focuses on the extent to which congestion, congestion alleviation policies, and planning policies can be shaped to support more important second-order economic outcomes. This research focuses on policies which can foster high economic function despite congestion, thereby placing the burden of proof for policy intervention on strengthening positive second-order economic outcomes and not predominately on congestion alleviation and travel time savings, as employed in much contemporary practice. I propose four hypotheses designed to 1) identify conditions under which congestion impedes the economy, 2) identify firm-level adaptations to congestion, 3) explore policies which contribute to congestion resilience, and 4) identify policies most critical to congestion resilience for high-congestion regions. I introduce hypotheses which are tested using inferential statistics and case studies, I discuss study areas and study data, and I explain important theoretical contexts needed to interpret results.

Chapter 5: How Strong is Congestion's Drag?

I present results for empirical tests of Hypothesis 1, in which I estimate the magnitude and conditions under which congestion may be a drag on regional economic growth. I focus on both employment growth and productivity growth and interpret findings.

Chapter 6: Contributors to Congestion Resilience

I display results for empirical tests for adaptation to congestion through firm location decisions according to their relative sensitivities to congestion's drag (Hypothesis 2) and through policies which contribute to regional congestion resilience (Hypothesis 3). Congestion resilience represents the success of an economy to function well despite congestion, and in the case of this dissertation is measured as the capacity of an economy to grow at a relatively lower "cost" in terms of congestion growth. I discuss findings and interpret results for the purposes of planning practice.

Chapter 7: Case Discussions in Congestion Resilience

I focus on transportation policies and urban spatial structure in four high-congestion MSAs which (according to Chapter 5 results) are also among the most vulnerable to congestion's potential economic drag. While each of these MSAs has grown significantly since 1990, two are highly congestion resilient and two are congestion unresilient. I use descriptive statistics to explore differences in transportation and land use planning which may explain the relative differences in congestion resilience among

each of these high-congestion MSAs (additional tests of Hypothesis 3). I discuss findings and the relevance of lessons to other regions.

Chapter 8: Conclusion

Finally, I highlight the major gaps addressed by this dissertation and integrate key findings within dissertation subsections. Results indicate that the best avenues towards congestion resilience are not uniform across all MSAs (particularly not for those most vulnerable to its drag). I conclude by identifying the potential role for planners to limit congestion's drag and enable congestion resilience and adaptation in different contexts.

CHAPTER 2. STATEMENT OF PROBLEM AND OBJECTIVES

U.S. policymakers spend billions of dollars per year on failed congestion alleviation policies (Winston & Langer, 2006) and yet they continue to justify these investments based on the high economic cost of traffic congestion. This rationale is based on two potentially misleading assumptions: 1) that the existing policy portfolio can lead to congestion alleviation and travel time savings and 2) that congestion is costly. First, research suggests that the existing policy portfolio (road capacity expansion and transit investment) is wasteful and ineffective at alleviating congestion and that congestion pricing should be applied instead. But as pricing is a political non-starter in most U.S. contexts, planners are limited to focusing scarce resources using ineffective long-term congestion alleviation policies. Second, research on congestion's costs has been incomplete in identifying the extent and conditions under which congestion most inhibits economic activity and other more fundamental social objectives. Instead, planners have justified transportation planning policies by focusing on first-order costs which are likely overstated due to the fleeting nature of travel time savings (Metz, 2008). Travel time savings are short-term because induced demand (other individuals expanding system use to access new destinations) negates travel speed benefits. Planners have little guidance on fostering resilience to the congestion which most impedes more fundamental second-order impacts – in the case of this dissertation, I focus on economic activity.

Metropolitan regions are critical economic and cultural centers which provide access to individual opportunity (Brookings Metropolitan Policy Program, 2010). But living and working in cities to realize urban access benefits also includes potential external costs. Traffic congestion, a defining characteristic of metropolitan regions and big cities, is one such potential diseconomy which transportation policymakers adopt as a key travel performance metric and justification for policy intervention, but which has unclear second-order impacts on the urban economy. Without distinguishing congestion's potential negative second-order impacts on economic activities from congestion's inextricable link with urbanization and agglomeration benefits, congestion alleviation policies may not support economic outcomes (Arnott, 2007). Planners need better guidance on how to shape congestion policy to advance economic activities and how to foster high-functioning regions despite traffic congestion. This dissertation contributes to filling these gaps.

2.1. Business as Usual: The Congestion Alleviation Model

Planners and engineers have guided transportation policy using standard industry metrics of road congestion as conventional justifications for transportation investment. Planners and engineers have applied technical analyses of road traffic for more than 100 years (Brown, Morris, & Taylor, 2009) using relatively static definitions of system output with very little direct correlation with broader social outcomes (Meyer, 2001). Congestion alleviation and technical analyses of road traffic flow are standard within industry

practice and are even established in case law. But while congestion alleviation and mitigating congestion's first-order impacts on travel times traditionally serve as compelling justifications for transportation planning interventions, the larger benefits of transportation planning and policy accrue through second-order impacts: supporting economic activities and enabling individual opportunity.

The predominant paradigm for congestion and transportation policy has been the *congestion alleviation model*, an approach informed by the traffic engineering discipline. Urban residents have been concerned with the ills of traffic – regardless of travel mode – since before Julius Caesar restricted carriage use in Rome (Morris, 2007; Downs, 1992). Modern city planning began with the utopian design-based ideas of Fredrick Law Olmsted and Ebenezer Howard, but progressive reform movement planners quickly shifted attention to the inconvenience of urban transportation. City residents and modern planners alike have consistently viewed traffic congestion as an undesirable phenomenon which should be reduced (Weinstein, 2002). This model has guided much transportation policy in the intervening century (Gifford, 2005), but research suggests that in the absence of peak-period pricing – a political non-starter in most U.S. cities – policy levers will be ineffective at significantly alleviating regional congestion (Sorensen, et al., 2008).

Traffic engineers claimed purview over technical analyses of congestion and traffic flow during the early 20th century progressive reform movement. To counter the power of big city bosses and political machines, progressive reformers strove to overhaul governance,

improve city services, and increase health using technical analyses and scientific decision-making by expert administrators (Glaab & Brown, 1976). Traffic planning stemming from the progressive reform movement managed traffic congestion explicitly to encourage downtown business, thereby viewing congestion policy partly as a means to support city function – an early view that has not been maintained (Brown, Morris, & Taylor, 2009). In fact, subsequent transportation policies, principally highway building, appear to have undermined the important role of center cities at the expense of suburbs and exurbs (Baum-Snow, 2007).

Technical analyses of congestion-induced travel delay have directly shaped practice and are important tools in everyday transportation planning. Such technical analyses began with the rational decision-making model for transportation planning practice. Traffic engineers widely adopted measures of congestion in the 1950s to assess the management and operation of public road infrastructure (Meyer, 2001). But the roots of congestion metrics began in early nationally-scoped Bureau of Public Roads (BPR) plans, including *Toll Roads and Free Roads* (1939) and *Interregional Highways* (1944). These plans applied early understandings of traffic volumes to roadway capacity limits to identify those corridors in most need of high-speed roadway capacity expansions. Planning for the U.S. Interstate Highway System standardized the practice of estimating travel delay using output from travel demand models, of which the Detroit Metropolitan Area Traffic Study in the mid 1950s was one of the first (Weiner, 1997).

Technical analyses of travel demand establish compelling cases for policy intervention, thereby supporting large capacity-building infrastructure projects, perhaps most notably the U.S. Interstate Highway System. Travel demand modelers use congestion to frame a city's transportation system as a potential set of over-used or undersupplied components, thereby establishing persuasive arguments for advancing capacity building programs. But the second-order impacts of transportation policy, including the U.S. Interstate Highway System, have been most important in linking communities, by acting as direct economic inputs, and by increasing the productivity of workers and businesses (Bell & McGuire, 1997).

The role of traffic congestion in planning policy extends to nationally-scoped, state-wide, and highly-localized contexts of implementation. For example, the National Environmental Policy Act (NEPA) and state equivalents, such as the California Environmental Quality Act (CEQA) or New York State's Environmental Quality Act (SEQA), have extended debates on congestion to local parcel-level planning. In preparing NEPA environmental review documents for specific transportation investments, using congestion alleviation as a purpose and needs statement can strengthen the case for preferred alternatives. Projects subject to technical environmental reviews must reduce their environmental impacts (including traffic flow and congestion) to the maximum extent practicable (New York State, 1995). Court cases have

consistently interpreted roadway traffic as an environmental impact, thereby placing congestion policy within the purview of the environmental review process.

Planners and engineers have built a far-reaching industry designed to debate the merits of site developments and public capital investments, frequently on the basis of changes in traffic congestion. But, despite the intent of environmental regulation to more closely analyze the second-order impacts of changes in the built environment, it is unclear that mitigating local congestion is equivalent to enabling broader access to opportunities and economic health.

Politicians use congestion alleviation as a means to justify popular transportation policies (Taylor, 2004) and residents, businesses, and developers argue for or against new developments and policies on the basis of increased traffic (Cervero, 1991). Congestion is almost universally framed as a negative outcome (Weinstein, 2002). But, political responses appear to be opportunistic and insincere in proposing measures to alleviate congestion and in shaping the development process (Taylor, 2004; Wachs, 2002). Within the realm of practice, more informed discussions of congestion's impact on important second-order economic and social impacts are hidden by a web of negotiations and technical analyses through which different groups compete over development decisions and policymaking.

2.2. Shifting the Burden of Proof

To build better planning theory and practice, it is critical to shift the burden of proof for policy intervention from congestion alleviation to supporting more fundamental second-order outcomes – in the case of this dissertation, economic opportunities. Current transportation policies are justified on the basis of congestion alleviation and travel time savings which are eroded over the long term by induced demand (Metz, 2008). But even if congestion could substantially be reduced – for example, through pricing – it is not clear how such an outcome would align with second-order impacts on the economy or individuals' opportunities. The *accessibility planning model* promises to refocus the attention of transportation policymakers from mobility to the derived demand for travel and transportation policy's more fundamental second-order impacts: access to economic activities, opportunities, equity, positive environmental outcomes, and quality of life (Grengs, Levine, Shen, & Shen, 2010; Handy, 2002; Handy, 2005; Krizek, 2005).

But identifying the causal link between congestion and economic outcomes is methodologically challenging because of a potential dual-feedback loop: large regional economies lead to more traffic and congestion potentially leads to a drag on economic activity. In econometrics, this issue is referred to as *endogeneity*. Large regional economies are inherently more congested and may be more susceptible to congestion's drag. Yet the urban agglomeration benefits of big cities with large and highly-educated labor pools, returns to scale, and potential access premiums are each (among others)

competing explanations of economic outcomes which are challenging to separate from the potential drag of big-city traffic, all else being equal. As such, congestion's diseconomy must be assessed when evaluated against the trade offs for other inherently urban benefits. While existing transportation practice focuses on congestion alleviation, identifying means of advancing economic opportunities despite congestion can enable planners to better advance social welfare. Firmly rooting the discussion of congestion policy (and transportation policy, more generally) within the construct of travel as a derived demand is important and two shifts in planning practice further challenge the justification of transportation policy overwhelmingly on the basis of congestion alleviation.

First, both the geography of traffic congestion and the geography of its consequences have been changed across and within metropolitan areas (Cervero, 1986). Within cities, traffic congestion is no longer overwhelmingly a downtown phenomenon, as it was in the early 20th century. Instead, metropolitan regions with polycentric and dispersed spatial structures have displaced the traditional monocentric model of urban form and traffic congestion (Giuliano & Small, 1991; Gordon, Kumar, & Richardson, 1989). Congestion is no longer strictly a downtown phenomenon, so analyses of congestion's second-order impacts do not only concern whether the benefits of urban proximity outweigh congestion's diseconomy (Giuliano, Redfean, Agarwal, Li, & Zhuang, 2007). Instead,

increasing suburban and exurban congestion may make the difference between having and not having important urban or suburban opportunity access (Weber & Kwan, 2002).

Second, discourse about congestion policy has become the battlefield for normative discourse about mode-specific transportation planning interventions (Taylor, 2004).

While technical analyses of congestion alleviation measures have expanded to include a diverse portfolio of policies, the discourse remains normative and reflects planners' and the public's preferences to advance particular modes and policy solutions (Taylor, 2004).

With the financial backing of federal and state highway programs in the decades following the National Interstate and Defense Highways Act, road capacity expansion has traditionally been the preferred policy response. However, large-scale capacity expansion programs are restricted by environmental regulation, changing social preferences, and the limits of public coffers (Gifford, 2005). More recently, politicians have used congestion alleviation to justify transit capacity expansion, urban growth management, and travel demand management (Taylor, 2004). But despite expanding the capacity for net travel and/or increasing system efficiency, induced demand has decreased regional congestion-alleviation benefits and travel time savings of both supply-side and demand-side transportation policy interventions (Cervero, 2002; Fulton, Noland, Meszler, & Thomas, 2000; Metz, 2008; Taylor, 2002; Melo, Graham, & Canavan, 2012).

Conflicting research findings have been one reason why the question of how to address congestion to support social goals and its second-order impacts remains conspicuously

absent from policy discussions. While some identify congestion as a first-order travel inconvenience and a potential second-order economic cost (Boarnet, 1997; Hymel, 2009; Schrank, Lomax, & Turner, 2010) others highlight it as a consequence of big-city urbanization benefits (Graham, 2007; Mondschein, Brumbaugh, & Taylor, 2009). However, implementing existing findings on using congestion policy to support social goals according to the *accessibility planning model* has been challenging. For one, some social goals and second-order impacts are more difficult to measure (e.g. quality of life, equity, and sustainability) and existing knowledge on the links between congestion and second-order impacts leaves unclear guidance for technical analyses in practice. Moreover, engineers and planners already have a deeply-rooted tradition of measuring congestion and first-order travel delay as indicators of system performance. As a result policies, case law, best practices, and learned standards continue to support congestion alleviation as an important indicator of transportation policy success (Meyer, 2001).

2.3. Research Design Overview

Planners spend substantial public funds on expensive congestion-alleviation measures, but it remains unclear how strong congestion's economic drag is and how planners can best shape policy to adapt and become resilient to its potential diseconomy. To help fill these gaps, this dissertation's research design is organized into three sections. The three sections address the following questions. First, I estimate traffic congestion's drag on

economic activity and the conditions under which its drag might be strongest (Chapter 5) using the following hypothesis.

Hypothesis 1: Congestion adversely impacts economic activity.

Second, using the following hypothesis, I explore “natural” adaptation processes to congestion’s potential drag, by which firms choose metropolitan areas in accordance with their relative trade-off of urban benefits with congestion’s drag (Chapter 6).

Hypothesis 2: Different industries and types of economic activity have varying sensitivities to congestion’s drag.

Finally, I explore how planning policy may enable some high-functioning regional economies to be “better” at being resilient to congestion’s potential drag (Chapters 6 and 7) using the following hypothesis.

Hypothesis 3: I expect policymakers in congestion resilient MSAs to have intervened in order to become congestion resilient. Alternately, congestion resilience may simply be a matter of becoming accustomed to congestion over time and the role for planning policy may be limited.

2.3.1. Estimating Congestion’s Drag

Schrank, Lomax, and Turner (2010) report that congestion “costs” urban areas millions of dollars worth of wasted time and economic activity. However, discourse about

congestion's costs should properly be deconstructed when compared to the important accessibility benefits afforded by large and inherently congested regions (Mondschein, Brumbaugh, & Taylor, 2009). Congestion is inconvenient, but it is tolerated because of the access benefits derived from traveling. Traffic congestion is inextricably linked to urbanization and agglomeration benefits realized in large cities with highly-skilled labor pools and major trip attractors (e.g. ports or airports), but it may be a diseconomy which slows or stops regional economic growth. It can potentially impede economic activity because, under certain conditions (to be estimated in this dissertation), it may outweigh the positive dynamic externalities of urban access and agglomeration (Boarnet, 1997; Graham, 2007) (to which I refer as the *congestion diseconomy threshold*).

To estimate congestion's economic drag, I compare it with competing explanations for regional economic activity, many of which – like congestion – are inherently big-city attributes: agglomeration economies, large and highly-educated labor forces, and returns to scale. I propose expectations and an organizing hypothesis which enable estimates of congestion's regional economic drag on productivity and employment growth. Upon outlining expectations, I describe empirical hypothesis tests using panel data (1993-2008) for 88 of the largest Metropolitan Statistical Areas (MSAs) in the United States. Finally, I discuss and interpret empirical results.

First, I test whether congestion adversely impacts economic activity. This study differs from others that test this hypothesis (Boarnet, 1997; Graham, 2007; Hymel, 2009)

because it compares competing explanations of economic activity and it jointly focuses on two chief indicators of economic outcomes: employment growth and productivity growth. The foci in other studies are constrained in economic outcome of interest most likely due to limitations in data availability and quality.

2.3.2. Estimating Sources of Congestion Resilience

Much planning practice focuses on policy intervention to alleviate traffic, but the persistent nature of regional congestion and the shift towards the accessibility planning model have highlighted the potential importance of adaptation . To enable places to be high-functioning despite congestion's potential drag, I identify means of adapting to congestion in a congestion resilient manner by advancing economic activity at a relatively lower congestion "cost".

I propose hypotheses organized around two potential sources of congestion resilience: firm-level adaptations and planning policies which facilitate adaptation. Individual travel behavior adjustments are other potentially important adaptations, but are beyond the scope of this research. Firm-level adaptations may be realized through self-sorting into metropolitan areas according to the relative benefits from urban proximity and other big-city attributes and the relative drag of congestion to specific economic industries.

In contrast, policy-related adaptations can potentially enable a region to facilitate individuals and firms to adapt to congestion, allowing an economy to grow despite a

comparatively small “cost” in terms of congestion growth. To the extent that road networks, transit services, agglomeration economies, or a highly-educated workforces (each, as congestion, attributes of big cities) can enable regional economies to grow rapidly despite relatively slower congestion growth, these policies can potentially encourage better adaptation through congestion resilience.

I begin by exploring the extent to which *firm-level* location decisions serve as a natural economic self-adjustment in response to congestion’s drag.

Exploring Firm-Level Adaptations

Firm location decisions can act as a mechanism through which industries and economic activities that are more vulnerable to congestion’s drag can avoid exposure to highly-congested regions. Graham (2007) highlights how productivity varies by industry in response to congestion’s diseconomy, but it is not clear how varying types of economic activity respond differently to congestion in terms of employment growth. If firms self-select metropolitan areas according to their congestion-sensitivity (trading off urban benefits for congestion’s drag), one would expect employment growth rates’ sensitivities to congestion’s drag to vary across firms and by economic industry. Implicitly, congestion resilient industries would prefer large, dense, and congested metropolitan areas, while congestion-sensitive industries would locate to smaller regions. To identify the extent to which such self-selection acts as a natural means of regional economic adaptation to congestion’s potential drag, I explore inter-industry variation in sensitivity

to congestion's drag. Using data on different industries in 88 metropolitan areas, I focus on industry heterogeneity in sensitivity to congestion's potential diseconomy.

Testing for Policy-related Resilience

Beyond individual travel behavior (not discussed here) and location decision adjustments by firms and individuals to congestion, planners and policymakers can establish conditions under which regions are structurally better positioned to adapt to congestion and become congestion resilient. Planning policy can potentially "push" the threshold at which higher congestion is associated with slower economic growth (the *congestion diseconomy threshold*). I estimate policy contributors to congestion resilience across metropolitan areas of all levels of congestion experience using the following organizing hypothesis:

At its core, congestion is inextricably linked to economic activity and can conceptually be thought of as one cost of economic growth. To advance economic activities, the key to planning a congestion resilient region becomes how to maximize economic growth at a relatively lower cost in traffic congestion growth. I use two metrics: *congestion resilience in employment growth* and *congestion resilience in productivity growth*. Each metric estimates the relative cost of productivity or employment growth in terms of congestion growth – thereby embracing congestion's endogeneity in the economy and treating congestion as an input with potential economic returns. On the other hand, if the role for policy in advancing congestion resilience is quite limited, congestion resilience

may be a matter of simply becoming more accustomed to congestion over time. Thus, congestion resilience could alternately be a matter of attaining high initial congestion levels (one indicator of congestion experience), above which additional congestion growth may be more challenging even with additional economic growth.

2.3.3. Case Studies: Congestion Resilience in High-Congestion Regions

Finally, while Chapter 6 explores policy sources of congestion resilience for MSAs along the entire spectrum of regional congestion levels, I next use descriptive statistics to further test Hypotheses 2 and 3. I explore whether a lower proportion of congestion-sensitive industries serves as a “natural” adaptive process which distinguishes congestion resilient from congestion unresilient MSAs. In addition, I identify those road transportation policies, public transit policies, and spatial structures which distinguish congestion resilient from congestion unresilient MSAs among high-congestion regions. I focus on four of the most congested MSAs in the country according to metrics of auto commuting delay: Chicago, Houston, Los Angeles, and Washington, DC.

CHAPTER 3. REVIEW OF RELATED RESEARCH

Much of transportation policy remains justified and informed by a discourse on congestion reduction and first-order travel time savings: the *congestion alleviation model*, according to which congestion is very costly and should be reduced using a broad portfolio of policies. The *accessibility planning model* is a newer evaluative frame which assesses transportation policy and demand management as means to promote more important second-order economic and social outcomes. However, the accessibility planning model has placed only limited focus on the link between congestion and more fundamental second-order economic outcomes.

The congestion alleviation model has dominated policymaking for more than 100 years and remains embedded in practice as a consequence of the progressive reform movement and the rational decision-making process (Brown, Morris, & Taylor, 2009), engineering and planning industry standards, and hundreds of court decisions (Meyer, 2001). But by most accounts the congestion alleviation policy model is ineffective (Winston & Langer, 2006) at best and counter-productive at worst (Taylor, 2006). Existing policies have proven ill-suited to reduce congestion and peak-period pricing, the theoretically preferred intervention, is unpalatable in practice (Wachs, 2002). The relative political failures to implement proven congestion alleviation policies indicate that either congestion is not as bad as individuals say or that congestion alleviation acts as a discourse which advances other policies and objectives (Taylor, 2004).

I explore the congestion alleviation model, as informed by common definitions, common causes, and common solutions to traffic congestion. I introduce the accessibility planning model, discuss congestion in the context of derived demand for economic activity and opportunity, and present previous research findings on congestion's economic drag.

3.1. What is Traffic Congestion?

Traffic congestion is a maddening experience. Aggressive drivers cut others off, tailgaters follow too closely, and motorists honk and flash brake lights in retaliation. Waiting in gridlock is frustrating – especially when the destination activity is important. Congestion is inconvenient, it imposes additional scheduling time for important trips, and its oppressive influence on travelers' psyches can often bring out their worst: road rage and stress (Gifford, 2005). Nobody seeks out gridlock, in and of itself; instead we bear it because we value access to the destinations made available by the very urban proximity which is inextricably linked to congestion.

Congestion benchmarks represent normative notions of how much congestion there “should” be and are rooted in standard engineering practice and empirical observations of vehicle flows. Standard congestion metrics provide effective means of assessing transportation service conditions to advance transportation agencies' stewardship of infrastructure (Meyer, 2001). Metrics are not rooted in more fundamental social needs and the derived demand for transportation. They do not distinguish congestion levels which are associated with high-function and access to opportunities from congestion

which inhibits firms' and individuals' abilities to conduct their daily lives (Mondschein, Brumbaugh, & Taylor, 2009).

There are many standard definitions of congestion, each of which frames the problem in manners designed for specific pallets of remedies. While early congestion monitoring used volume-to-capacity ratios, more recent metrics focus on either inferred or observed measures of travel delay compared to acceptable conditions (Bertini, 2005). Comparing traffic volumes with the roadway maximum design capacity remains an important metric which was already in use by the U.S. Bureau of Public Roads in the 1930s (U.S. Bureau of Public Roads, 1939). While roadway capacity varies according to road classification and the following distance which is accepted by local driving culture, comparable metrics of volume-to-capacity ratios have helped planners identify major bottlenecks and grounds for planning intervention. In fact, until 2010, even the Texas Transportation Institute's Urban Mobility Report, the most-widely cited national study of metropolitan congestion, applied volume-to-capacity ratios on key roadways to measure congestion (Schrank, Lomax, & Turner, 2010). It should be no surprise that congestion metrics based on volume-to-capacity ratios historically coincided with the most rapid advances in U.S. physical highway building. The metric explicitly leads one to frame transportation problems and alternative interventions in terms of inadequate capacity, thereby providing support for large-scale road building in "predict and provide" transportation policy cultures (Gifford, 2005).

While industry-standard capacity analyses which infer delay using volume-to-capacity ratios remain important, newer traffic congestion metrics measure delay directly. Bertini (2005) identifies common congestion metrics in practice using a survey of more than 500 state and metropolitan transportation policymakers. Among many metrics in each jurisdiction, agencies most frequently measure congestion using speed (28 percent), volume (19 percent), time (18 percent), cycle failure (16 percent), level-of-service (15 percent), and other (4 percent) metrics. Of these, over three-quarters capture congestion's travel time impacts (delay). Thus, while standard capacity-oriented metrics remain influential, planners and engineers apply diverse metrics and have varying expectations of their utility in accurately representing the extent and intensity of congestion (Bertini, 2005).

Regardless of the metric chosen, traffic engineers use benchmarks for acceptable road travel to distinguish congested from uncongested road travel conditions. For example when using speed as a congestion metric, free-flow conditions, usually the design speed or the posted speed limit, are most frequently applied (Schrank, Lomax, & Turner, 2010), but other benchmarks are also used. The Minnesota Department of Transportation uses 45 miles per hour (mph) to distinguish congested from uncongested conditions, while the California Department of Transportation threshold is 35 mph (Bertini, 2005). Congestion thresholds appear arbitrary, but they may align with public expectations or may represent

the point of maximum vehicular flow. Nevertheless, the specific threshold may be very important in shaping the magnitude of congestion's problem in a given location.

3.1.1. Congestion's Causes

There are many means of measuring congestion, but there is even less agreement on its causes – and therefore, the best policies for managing traffic. There are many advocates and critics of potential congestion alleviation policies, but the strength of each argument depends on leveraging policies to affect its causes. But regardless of whether arguments for one cause or another are more compelling, in almost every single case, each cause shares a common characteristic: congestion alleviation policies are sometimes at odds with economic outcomes. While congestion's causes shape the magnitude of congestion, they are simultaneously contributors to or indicators of second-order economic function. Thus, planners face a difficult task in managing congestion while not reducing the positive economic contributions of congestion's causes.

Traffic engineering research indicates that congestion is primarily a function of travel demand that exceeds transportation system capacity. Most engineers identify three primary sources of congestion: travel demand which exceeds transportation system capacity, inefficient operations (for example, mistimed traffic lights), and incidents (weather, construction, special events), but the relative importance of each varies somewhat by study (Hahn, Chatterjee, & Younger, 2002; Cambridge Systematics, Inc.; Texas Transportation Institute, 2005; Kwon, Mauch, & Varaiya, 2006). Such a problem

statement invariably leads to recommendations of capacity expansion (Gifford, 2005).

But many argue that such an understanding of congestion's causes is too restrictive and focuses almost exclusively on the auto network, while omitting other important causes (Downs, 1992; Sorensen, et al., 2008; Taylor, 2002).

Economists – led by the groundbreaking work of William Vickrey (Vickrey, 1955; Vickrey, 1963) – have applied the concepts of marginal travel costs and differences between social and individual costs to identify bad pricing signals (underpriced individual travel) as the root cause of traffic congestion (Anas & Rhee, 2007; Anas & Xu, 1999; Brueckner, Urban growth boundaries: An effective second-best remedy for unpriced traffic congestion?, 2007; Langer & Winston, 2008; Ozbay, Bartin, & Berechman, 2002; Wheaton, 1998). According to this research, individuals travel until their utility does not exceed their cost of travel. However, individual cost does not match social cost, resulting in a high cost to other travelers in the form of delay (Ozbay, Bartin, & Berechman, 2002). As such, economic research on marginal travel costs recommends congestion pricing as the core policy recommendation – without which congestion alleviation is nearly hopeless (Arnott, de Palma, & Lindsey, 1990; Arnott, de Palma, & Lindsey, 1994; Winston & Langer, 2006). Nevertheless, recommendations to institute congestion pricing are critiqued both on the basis of its difficulty to implement (Wachs, 1994; Wachs, 2002) and on the basis of unclear second-order impacts on access and economic benefits derived from discretionary travel (Arnott, 2007).

Urban economists and planners have also extended research on congestion beyond the confines of the roadway and pricing signals by placing the larger economic and social contexts in focus. Social affluence, population growth, spatial patterns, and individual preferences each also contribute to traffic congestion (Downs, 1992; Sorensen, et al., 2008; Stopher, 2004; Taylor, 2002). Researchers attribute congestion to both suburban spatial structures which are not conducive to transit (Sorensen, et al., 2008) and general population density and urban mass (Downs, 1992; Taylor, 2002). Affluence likewise contributes to congestion by enabling higher auto ownership rates and by increasing travel demand (Stopher, 2004; Downs, 1992). Similarly, preferences contribute to congestion and range from the preference to decide where to work and live, preferences for suburban housing and workplaces, and preferences for auto travel (Downs, 1992).

But, the policy recommendations of engineers, urban economists, and planners are mixed both in approach and in outlook. While engineers recommend capacity building (Hartgen & Fields, 2006), the outlook for long-term alleviation is poor because road users fill newly available road capacity with additional or longer trips through induced demand (Duranton & Turner, 2011). Urban economists and planners, such as Downs (1992) and Sorenson et. al. (2008), argue that affecting congestion's causes is highly challenging; metropolitan spatial structure, population growth, population density, and individual preferences are each difficult and costly to change. In fact, Downs (1992), leave little optimism about alleviating gridlock and instead, recommends limited road pricing

programs. Others maintain that congestion pricing would alleviate traffic congestion and result in more efficient travel, more efficient land use patterns, and economic benefits (Anas & Rhee, 2007; Anas & Xu, 1999; Brueckner, 2007; Langer & Winston, 2008; Ozbay, Bartin, & Berechman, 2002; Wheaton, 1998).

Although traffic engineers, urban economists, and planners provide clear recommendations for congestion alleviation, these are sometimes at odds with second-order economic outcomes. First, in the case of traffic engineers, travel demand in and of itself is an important productive input because travel enables individuals and firms to engage in economic transactions (Melo, Graham, & Canavan, 2012). Moreover, urban land is valuable and road or transit expansion entails a high opportunity cost for land owners and public finances. Therefore reducing travel demand or expanding road or transit capacity to alleviate congestion can potentially impede more economic activity than it generates. Second, economists' recommendations for peak period pricing have been critiqued based on the potential to reduce diffuse economic benefits from discretionary trip-making (Arnott, 2007). Thus, it is unclear that road pricing is always consistent with both congestion alleviation objectives and economic growth targets. Third, planners and urban economists have focused most on causes of both congestion and the economy, including population growth, affluence, and dense spatial structures (Downs, 1992). Each of these bodies of research highlights the frequently conflicting goals of congestion alleviation and economic growth.

3.2. Congestion Impacts and Policy

Some challenge the soundness of justifying transportation planning policy on the basis of congestion alleviation, arguing that the link between congestion and more fundamental social objectives is far more complex (Taylor, 2002). Congestion is overwhelmingly a big-city phenomenon: many of the most congested cities are parts of large regions with highly competitive labor pools, robust economies, and major cultural centers. Discourse about congestion's diseconomy should be properly deconstructed by comparing the benefits of urban access and opportunity (Mondschein, Brumbaugh, & Taylor, 2009). The *accessibility planning model* competes with the *congestion alleviation model*, by refocusing congestion and transportation policy from first-order congestion alleviation and fleeting travel time savings to more important second-order urban economic outcomes and access to opportunities.

Research focuses on three of traffic congestion's outcomes: *first-order* travel delay, the costs of failed *public policies* designed to alleviate congestion, and *second-order* impacts on society and the economy¹. I highlight key findings on each of these three impact

¹ This discussion of congestion's first-order, second-order, and public policy impacts (Sections 3.2.1 through 3.2.3. on pages 33 through 45) is loosely based on Sweet (2011) and paraphrases sections therein. The final, definitive version of this paper has been published in *Journal of Planning Literature*, 26/4, 2011 by SAGE Publications, Inc, All rights reserved. ©

types before focusing in this dissertation on second-order outcomes. Nevertheless, while conventional transportation planning focuses on first-order costs, these are likely overstated because of the fleeting nature of travel time savings due to induced demand (Metz, 2008). In fact, the public sector costs and second order-economic and individual costs are likely far more important (Taylor, 2002).

3.2.1. Congestion's First-Order Impacts

Traffic congestion reduces travel speeds, is inconvenient (Boarnet, Kim, & Parkany, 1998; Schrank, Lomax, & Turner, 2010), and establishes unreliable travel conditions (Cohen & Southworth, 1999; Giuliano, 1989; Noland & Small, 1995) – leading many researchers to equate congestion's economic drag with travel delay (Schrank, Lomax, & Turner, 2010). Studies of congestion's first-order impacts value the cost of travel delay (Schrank, Lomax, & Turner, 2010) and unreliability (Van Lint & Van Zuylen, 2005; Van Lint, Van Zuylen, & Tu, 2008), and identify travel behavior adaptations and substitutions (Noland & Small, 1995; Sweet & Chen, 2011). The value of congestion-induced travel delay is estimated using assumptions about the value of non-productive discretionary time. The Texas Transportation Institute (TTI)'s Urban Mobility Report, perhaps the most-cited large-scale congestion study in the U.S., estimates the value of wasted time and motor fuel to be approximately \$115 billion in 2009 (Schrank, Lomax, & Turner, 2010), equivalent to 0.8 percent of the 2009 U.S. GDP (U.S. Bureau of Economic Analysis). But while high estimates of congestion's travel delay burden suggest a strong

motive for travel behavior adaptation, empirical evidence suggests only modest observed adaptations in response to congestion (Cao & Mokhtarian, 2005b; Salomon & Mokhtarian, 1997; Ben-Elia & Ettema, 2011; Sweet & Chen, 2011) despite a wide range of available options (Cao & Mokhtarian, 2005a).

Many argue that estimating congestion's burden using traffic delay and unreliability is erroneous because of longer-term stability in travel times (Metz, 2008). Therefore measures of first-order travel delay or travel time savings are meaningless compared to second-order benefits of travel services from access to new destinations (or the opportunity cost of foregone access). Even with short-term road speed improvements, longer-term traveler adaptations would result in physically and temporally longer trips, induced demand, and eventually a return to congested travel conditions (Cervero, 2002; Downs, 1992; Metz, 2008). The benefit of travel time savings (and the cost of congestion) would accrue through short-term shifts in accessibility to new potential destinations (Metz, 2008). Conversely, congestion's most important diseconomy would be felt when travel behavior adaptations and cross-substitutions cannot overcome congestion's travel service impacts on second-order outcomes (Stopher, 2004; Metz, 2008; Taylor, 2002), including individual accessibility (Mondschein, Brumbaugh, & Taylor, 2009) and economic activity (see discussion below).

3.2.2. Congestion's Public Policy Impacts

Nevertheless, politicians continue to justify expensive supply-side and demand-side policies on the basis of congestion alleviation (Taylor, 2004) despite the poor outlook to improve first-order impacts on travel times and despite unclear impacts on second-order economic and social outcomes. Winston and Langer (2006), argue that current portfolios of congestion alleviation policies have been ineffective and have yielded only eleven cents of congestion reduction benefit from every dollar spent – inefficiency roughly equal to 0.15 percent of U.S. GDP. But while current policies are ineffective at reducing congestion, their potential to support second-order economic outcomes and individual opportunities are both more important over the long-term and more accepted within scholarship (Metz, 2008; Wachs, 2011).

While environmental review regulation, public opinion, and limits of public coffers have limited capacity building programs, capacity building continues to be a popular approach to congestion alleviation. Road capacity expansion is justified on the basis of travel speed improvements (Hartgen & Fields, 2006) and politicians invest in transit to combat congestion (Taylor, 2004). Nevertheless, research suggests that capacity-induced congestion alleviation benefits are modest over the short-term but ineffective over the long-term as a result of adaptation and induced travel demand (Cervero, 2002; Downs, 1992; Duranton & Turner, 2011). Yet, while capacity expansions yield few regional congestion alleviation benefits (perhaps even over the shorter term), evidence suggests

that induced demand and new access to opportunities, more importantly, generates productivity growth (Melo, Graham, & Canavan, 2012).

Transportation supply, including transit and road infrastructure and services, is a direct input into the production process and indirectly enhances the productivity of other inputs, such as labor (Bell & McGuire, 1997; Apogee Research, Inc. and Greenhorne & O'Mara, 1998). But while the link between transportation infrastructure and economic growth has historically been strong, the link has weakened in developed economies with highly developed transportation networks and relatively ubiquitous road systems (Banister & Berechman, 2000; Boarnet & Chalermpong, 2001). Nevertheless, even recent studies suggest that transportation investment and changed access patterns can contribute to economic growth – albeit weakly (Ribeiro, Antunes, & Paez, 2010; Jiwattanakulpaisarn, Noland, & Graham, 2009).

Likewise, research on demand-side interventions indicates that most policies do little to alleviate regional traffic congestion over the long-term because of induced demand, but that policies increase the potential for second-order benefits (accessibility and economic activity). In contrast to supply-side measures, a few demand-side interventions appear to also reduce regional (congestion pricing) and local (parking policy) congestion.

Although there are many demand-side transportation policies, I only discuss three: congestion pricing, parking policy, and transportation-land use policy integration. Others

have similarly poor outlooks to reduce regional congestion, but likewise generate different types of second-order benefits.

Congestion pricing is politically unpalatable (Hau, 1990; Ison & Rye, 2005), but is the single most important ingredient for successful regional congestion alleviation (Sorensen, et al. 2008). By using time-varying price signals to reach travel volume or speed targets, engineers can substantially improve road services. Most agree that road pricing can increase the potential for economic transactions in urban places and can generate other second-order social benefits (Anas & Rhee, 2007; Anas & Xu, 1999; Brueckner, 2000; Langer & Winston, 2008; Wheaton, 1998). But in some circumstances, it may overprice travel and hinder non-market interactions which foster diffuse economic benefits (Arnott, 2007). But while this congestion-alleviation policy appears to support both first-order travel speed improvements and second-order economic outcomes, it is politically unpalatable and challenging to implement (King, Manville, & Shoup, 2007; Manville & King, 2010).

Parking policy can likewise increase transportation system efficiency (McDonnell, Madar, & Been, 2011), manage local congestion (Shoup, 2004), and reduce road travel demand (Weinberger, Kaehny, & Rufo, 2010; Weinberger, 2012). Parking reforms include time-variable priced parking and reducing minimum or instituting maximum parking standards for developments (Kolozsvari & Shoup, 2003; Shoup, 1995; Shoup & Wilson, 1992; Weinberger, Kaehny, & Rufo, 2010). But parking policy reforms are

weaker than road pricing at alleviating regional congestion (Albert & Mahalel, 2006; Axhausen, Polak, Boltze, & Puzicha, 1994; Thompson & Bonsall, 1997). Nevertheless, such reforms can lead to second-order benefits by generating public revenues for other services and more efficient prices for other goods by unbundling the cost of parking (Shoup, 2004).

Transportation-land use policy integration has long been discussed as a means to align transportation policies with their second-order social benefits through accessibility and individual choice (Levine, 2006). But even these policies have entered the political debate on first-order travel and congestion reduction benefits (Levine, 2006). Integrating transportation and land use policies can foster better job-housing balance (Cervero, 1996) and can lead to access benefits and travel efficiencies (Deakin, 1990). But it can also redistribute congestion's geography through low-density zoning and freeway dependence (Cervero, 1991; Weinberger, 2007). Alternate smart growth strategies with higher densities and a greater land use mix are also unlikely to reduce congestion while their second-order economic and accessibility benefits are likely more important (Taylor, 2002).

Public policy may be the only means of alleviating congestion, but these same policies share responsibility for growing regional congestion (Cervero, 1991; Deakin, 1990). Cervero (1991) attributes congestion's growth to fragmented and uncoordinated municipal governments, NIMBYism, and overly restrictive growth regulations. These

interventions induce suburban sprawl, increase auto dependence, and increase congestion on select high-capacity freeways. Unwillingness by politicians and the public at large to adopt congestion pricing, has impeded the use of available tools to reduce congestion (Cervero, 1991; Deakin, 1990; Taylor, 2004; Wachs, 2002; Winston & Langer, 2006), implying that congestion's broader costs are likely overstated (Taylor, 2004). While congestion reduction is unlikely without drastic policy intervention, the outlook for success is poor – particularly over the long-term and using non-pricing interventions. But we continue to hear about the severe cost of congestion's first-order travel delay costs, policies continue to be justified based on alleviation, and the built form continues to be debated on the basis of marginal impact on road travel conditions.

3.2.3. Congestion's Second-Order Economic Impacts

Next, I turn to research identifying the magnitude of congestion's drag on second-order outcomes, while focusing on economic activity. Research on congestion's economic consequences explores changes in regional or firm productivity, impacts on city growth, and relocation responses by individuals and firms. According to the accessibility planning model, transportation policy's more important role is to advance second-order social outcomes, while first-order travel time savings or delay are more fleeting (Levine, 2006). Thus, better understanding the link between congestion and economic activity can lead to policies which significantly improve social welfare by encouraging high-function despite the potential drag of traffic congestion.

The relationship between metropolitan economic activity and traffic congestion is complex. Large regional economies lead to more congestion, while congestion may impede economic activities by degrading mobility services. In econometrics, this issue is called *endogeneity* and captures the methodological challenges of separating the competing benefits from big-city access from the drag of big-city road gridlock. Thus, while policymakers emphasize the severe economic costs and lost competitive edge due to traffic congestion, this relationship is far from clear (Taylor, 2002). Studies suggest that congestion makes regions less economically competitive (Boarnet, 1997; Hymel, 2009), but intra-metropolitan research suggests that firms adapt by co-locating with their employees (Gordon, Kumar, & Richardson, 1989) or that workers adapt by bearing a greater overall transportation burden (Cervero, 1996). Thus, while most agree that congestion can potentially lead to travel inefficiencies and lost regional competitiveness, it is unclear under what circumstances urbanization benefits and adaptations by individuals, firms, or through policy can no longer outweigh congestion's potential drag.

Economists have long highlighted the congestion of common public goods – including roads, policing, and fire protection– as a potential detriment to urban productivity (Oates, 1988; Edwards, 1990; McMillan, 1989). Much of this research has used production functions with congestion parameters which estimate the degree of publicness of publicly-provided goods – in effect, the degree to which publicly-provided goods are truly accessible to municipal residents at-large without over-use hindering access.

Studies have found that locally-provided public goods are quasi-private goods which are subject to high-degrees of congestion (McMillan, 1989; Edwards, 1990), but that there continue to be significant differences among recommended solutions to overuse of common pool resources, ranging from local community management to privatization to public control (Ostrom, Gardner, & Walker, 1994). Researchers have measured the extent of congestion's effect on public service delivery, but some have critiqued high estimates of congestion's drag because of the greater diversity and stronger absolute service demand and provision in very large urban areas (Oates, 1988). Thus, while economists highlight congestion of public services as a problem (Boarnet, 1997; Hymel, 2009), the magnitude of this inefficiency must be compared with the frequently larger benefits of living in large and diverse places (Oates, 1988; McMillan, 1989; Carlino, 2005).

In a study linking traffic congestion to national productivity growth for 29 industry sectors between 1953 and 1983, Fernald (1999) concludes that traffic congestion may have slowed growth beginning in the early 1970s by leading to reduced economic returns on new road construction. Declining private-sector productivity gains were unevenly distributed across economic sectors (Fernald, 1999). For example, vehicle-intensive industries benefitted most from new roads and were most penalized by congestion, while less vehicle-intensive industries (such as manufacturing) benefitted least from new roads and were least impacted by traffic congestion on the margin (Fernald, 1999).

Other studies have focused on the potential for congestion to redistribute economic activity among regions. Inter-metropolitan area studies suggest that traffic congestion reduces regional competitiveness and causes slower growth in county gross output (Boarnet, 1997) or slower metropolitan area employment growth (Hartgen & Fields, 2009; Hymel, 2009). Both Boarnet (1997) and Hymel (2009) control for traffic congestion's endogeneity in the regional economy using instrumental variables. Boarnet (1997) finds that congestion reduces productivity in California counties and recommends pricing to increase road service benefits. Hymel (2009) finds that higher congestion leads to slower employment growth. Hartgen and Fields (2009), in contrast, highlight the influence of traffic congestion by estimating its impact on access to five major opportunity types in several metropolitan areas. The authors similarly find that congestion slows employment growth, but do not address the issue of endogeneity.

Many urban economists frame congestion's diseconomy in contrast with the benefits of urban agglomeration (Arnott, 2007; Gordon & Richardson, 1997), but most research involves theoretical and not empirical urban economic models. Agglomeration theory suggests that urban proximity to significant numbers of other firms, people, or resources reduce transaction costs by sharing knowledge and inputs, but that congestion can reduce these benefits. Few empirical studies have tested for congestion's slowing effects on agglomeration returns. In perhaps the most explicit study of congestion's influence on agglomeration, Graham (2007) concludes that England's finance, insurance, and real

estate industries enjoy positive returns to agglomeration while the manufacturing industry is most sensitive to congestion's influence.

In comparison to inter-metropolitan studies of city competitiveness, intra-metropolitan studies investigate how congestion alters the function and structure of urban economies within specific cities. These studies highlight potential means of adapting to congestion within different parts of a city. Two primary schools of thought dominate: those arguing that congestion induces firm and worker suburbanization which lowers commuting burdens (the *colocation hypothesis*) and those arguing that job-housing imbalance ensues and leads to higher commuting burdens. But while there has been no consensus on these two alternate explanations, many researchers have contributed to the question of whether metropolitan economies can efficiently adapt to congestion.

Gordon, Kumar, and Richardson (1989) offer the "colocation" hypothesis – also frequently called the rational locator hypothesis (Levinson & Kumar, 1997) – according to which a polycentric urban form leads to adaptation. Thereby, firms and individuals mutually suburbanize to less-congested areas to maintain travel time stability (Gordon, Kumar, & Richardson, 1989). Other researchers find empirical support for the colocation hypothesis, including in southern California (Wachs, Taylor, Levine, & Ong, 1993) and Washington, DC (Levinson & Kumar, 1997). In comparison, Crane and Chatman (2003) and Weinberger (2007a) find that firm and worker suburbanization decreases commuting burdens for some industries and increases burdens for others.

Woudsma et.al. (2008) provide an additional explanation of firm suburbanization, finding that logistics and distribution facilities in Calgary suburbanize to gain access to more reliable travel times, but not to gain better worker access. Much evidence supports the firm and residential suburbanization in response to congestion, but the reasons for those actions are multiple.

In contrast to the co-location hypothesis, others argue that while suburbanization is one outcome of congestion, the consequent sprawling and polycentric spatial arrangements lead to higher commuting burdens (Cervero & Wu, 1998; Schwanen, Dieleman, & Dijst, 2004; Weinberger, 2007a). Job-housing imbalance, lower job access, and higher commuting burdens appear to be core outcomes of low-density, anti-congestion zoning, housing production lags, residential immobility, and slower road travel despite auto dependence (Cervero & Wu, 1997). After revisiting previous findings consistent with the co-location hypothesis (Levinson & Kumar, 1997) Levinson and Wu (2005) revise their conclusions, noting that increased exurban development subsequently leads to job-housing imbalance. Thus, while research identifies intra-metropolitan adaptation to congestion through firm and worker location decisions, it is unclear whether such adaptations can continue to outweigh congestion's potential regional economic drag.

3.2.4. Explanations of Economic Activity

But while congestion is one contributing factor, there are many other explanations of economic activity and growth – some of which are inextricably linked to big-city road

gridlock (Boarnet, 1997; Graham, 2007; Hymel, 2009). Thus, when contextualizing the economic drag of congestion, other explanations must be taken into account. Actions by individuals and firms are not the only potential means for regional adaptation to congestion; instead, other policies and big-city access benefits can also play an important role. I introduce findings on three categories of explanations of economic activity and discuss why the relationship between each and traffic congestion is challenging to disentangle: regional economic demand, urban spatial structure, and municipal governance.

Regional Economic Demand

Regional economic demand broadly describes the *quantity* (agglomeration economies), *diversity* (industry specialization), and *type* (socioeconomic characteristics) of firms and workers within a given metropolitan area. I compare each in turn, but while the first two facilitate interaction and shared inputs and scale, research increasingly emphasizes socioeconomic characteristics, and particularly education, as among the most important sources of economic growth in less industrial and more knowledge-based economies (Glaeser, 2011).

First, agglomeration theory holds that economic mass of labor, capital, or infrastructure inputs can generate knowledge-sharing, firm competition, and returns to scale which can lead to productivity and employment growth premiums (Glaeser, Kallal, Scheinkman, & Shleifer, 1992; Henderson, 2003; Henderson, Kuncoro, & Turner, 1995). Three

agglomeration theories prevail: that diversity in knowledge sharing accrues in large cities (Jacobian agglomeration), that firms can benefit from shared scale and inputs in large cities (Marshallian agglomeration), and that large cities foster more productive competition between firms (Porter agglomeration) (Glaeser, Kallal, Scheinkman, & Shleifer, 1992). However, the importance of agglomeration economies varies by industry and by economic outcome (comparing employment growth with productivity) (Glaeser, Kallal, Scheinkman, & Shleifer, 1992; Henderson, 2003; Henderson, Kuncoro, & Turner, 1995).

Second, industry specialization is an important explanation of economic productivity and growth as it allows cities to generate returns to scale for particular types of economic activities and establish potentially more important synergies and agglomeration benefits from shared skill sets and production (Storper, 2010). Industry concentration can lead to higher growth rates because knowledge sharing and other dynamic externalities can be internalized within one industry specialization (Glaeser, Kallal, Scheinkman, & Shleifer, 1992).

Third, qualitative socioeconomic characteristics (including education, age, racial inequality/discrimination, and crime) influence employment growth and productivity primarily by altering the marginal productivity of labor and the wage rate (Rose & Betts, 2004; Murnane, 2009; Ribeiro, Antunes, & Paez, 2010). Education is a hugely important determinant of productivity and economic growth, as a better-trained labor pool has

potentially higher marginal productivity (Murnane, 2009). In comparison, age influences both the quality of labor force (older adults have more experience) but may also reflect lower rates of consumption and labor force participation due to phased or complete retirement – thereby potentially reducing a region’s economic potential in aging regions (Tyres & Shi, 2007). Racial inequality and discrimination remains an important source of economic inequality across and within cities (Vigdor, 2009; Wilson, 1989). Finally, crime indirectly influences employment growth and productivity growth by increasing wage rates (compensation for crime risk or exposure) and raising land rent (for policing, insurance, or by sharing risk) while decreasing marginal productivity, all else being equal (Cook, 2009; Freeman, Grogger, & Sonstelie, 1996).

However, while large, specialized cities with talented labor pools generate agglomeration benefits, congestion can diminish these positive externalities. Proximity-based urban access and agglomeration economies are also inextricably linked to congestion: large cities have more congested roads because in dense urban areas, per capita auto travel demand does not decrease as rapidly as the increases in total travel demand per unit of road space (Taylor, 2002). Moreover, the link between productive, higher-income workers and higher rates of travel is strong, suggesting that a more talented labor pool would be expected to travel more and generate more congestion, all else being equal (Polzin, 2006). Likewise, one may expect industry specialization to lead to tighter

clustering of work hours and more competition for scarce road space at select periods of time.

Urban Spatial Structure

Urban spatial structure describes the spatial arrangement of population and jobs in metropolitan areas – each of which is important because of access and economic benefits (or inefficiencies). Spatial structure influences the potential for access and agglomeration benefits, but can also shape the intensity, extent, and geography of traffic congestion. Research linking urban spatial structure with economic outcomes has focused on three directions: 1) the extent to which spatial structure can foster agglomeration benefits (Anas & Rhee, 2007; Anas, Arnott, & Small, 1998; Fujita & Thisse, 2002; Safirova, 2002), 2) the potential for economically inefficient spatial arrangements (most notably sprawl) (Fallah, Partridge, & Olfert, 2010; Knaap, Ding, & Hopkins, 2001), and 3) the urban economic feedback loop through which more economic growth leads to polycentricity – thereby creating new clusters of urban or suburban economic growth (McMillen, 2001; McMillen & Smith, 2003).

However, the capacity for urban spatial structure to foster dynamic agglomeration externalities can also vary depending on the simultaneous relationship between spatial structure and congestion. McMillen and Smith (2003) note that the links between spatial structure, congestion, and metropolitan scale are interdependent. For example, larger cities have more employment centers and are expected to have higher levels of traffic

congestion. Thus, while polycentricity may be one means of realizing localization effects while maintaining regional economic agglomeration benefits (McMillen & Smith, 2003), polycentricity may increase regional congestion and lead to impeded access and higher commuting burdens (Cervero, 1996).

Municipal Governance

Municipal governance is also a strong determinant of economic productivity and growth – enabling regions with well-run and responsive municipal governments and services to have competitive advantages. The availability of a competitive market in local municipalities can establish the potential for economically efficient matching of services to residents (Tiebout, 1956; Hamilton, 1975). In contrast, regional governance may reduce zoning-induced growth controls and thereby lead to higher economic growth rates (Orfield, 2008). In addition, the efficient running of government, often most critically influenced by the relative cost-effectiveness of public sector laborers, transforms land values and acts as a direct input into the production process and indirectly enhances private sector productivity by contributing valued public services (Inman, 1995a; Inman, 1995b).

3.3. Research Opportunities

The transportation policy recommendations of previous research on 1) alleviating congestion and 2) mediating its economic impact are dominated by economists and are almost exclusively to initiate peak-period pricing. Yet pricing remains politically

unpopular (Wachs, 2002) and its broader economic impacts are not clear (Arnott, 2007). Nevertheless, because congestion pricing is politically unpalatable U.S. planners are limited to adopting other policy levers to advance second-order economic and social outcomes. Past research recommending transportation investment as a means to make new land accessible (Anderson & Otto, 1991; Baum-Snow, 2007; Boarnet & Chalermpong, 2001; Paez, 2004) and decrease production costs (Bell & McGuire, 1997; Gomez-Ibanez & Madrick, 1996; Weisbrod & Treyz, 1998) is no longer applicable to advanced economies with ubiquitous road networks (Banister & Berechman, 2000). Research indicates that congestion is here to stay (Downs, 1992). Instead, opportunities lie in identifying regions and conditions under which economies are vibrant and individuals enjoy extensive accessibility through adaptation, despite traffic congestion – a condition to which I refer as *congestion resilience*. In the next chapters, I estimate congestion's drag (Chapter 5), econometrically infer means by which regions grow economies at a relatively lower cost in congestion growth (Chapter 6), and highlight specific policies which enable more congestion resilient adaptation among those regions with the highest congestion (Chapter 7).

CHAPTER 4. RESEARCH METHODS

In this chapter, I introduce methods to test this dissertation's organizing hypotheses (see Chapter 2). First, I estimate congestion's drag. Second, I identify potential firm-level adaptations and public policies which contribute to congestion resilience (better adaptation to congestion). Finally, I compare congestion resilient and congestion unresilient metropolitan areas among those with the highest regional congestion levels. A key to all equation variables and their definitions is provided in Appendix B (see page 189).

4.1. Hypothesis Testing: Congestion's Drag

I expect traffic congestion to impede metropolitan economic activity (Hypothesis 1, see Chapter 2). I test the magnitude of congestion's estimated drag compared with other explanations of metropolitan productivity and job growth.

4.1.1. Empirical Methods

Using panel data, I conduct an inter-metropolitan study of 88 Metropolitan Statistical Areas (MSAs) to estimate congestion's drag on employment and productivity growth. To test the organizing hypothesis, I identify the chief predictors of MSA employment growth (data covers 1993 to 2008) and productivity growth (data covers 2001 to 2008). I employ three and five-year lag structures for employment growth models and two or three-year lag structures for productivity growth models. Many alternate lag structures are possible using the panel design, but the presented models are chosen based on trade-

offs between potential causal processes (leading to longer lags), sufficient observations for causal inference (leading to shorter lags), and the temporal availability of productivity (2001 to 2008) or employment data (1993 to 2008). Thus, in the case of employment growth models using panel data with three-year lags, I simultaneously estimate predictors of growth between 1993 and 1996, 1996 and 1999, 1999 and 2002, 2002 and 2005, and 2005 and 2008 for all 88 MSAs (in the event of no omitted outliers, $N=88*5=440$). I use employment and productivity data from the Bureau of Economic Analysis for 88 of the largest and most congested metropolitan areas in the U.S. I estimate congestion's economic drag while controlling for the following competing explanations for economic activity: *regional economic demand, urban spatial structure, transportation infrastructure, and municipal governance*. Data sources include the Bureau of Economic Analysis, the Census Bureau, the Federal Highway Administration's Highway Statistics series, the Federal Transit Administration's National Transit Database, the U.S. Census of Municipalities, the U.S. Decennial Census, the FBI crime statistics program, and the Census Transportation Planning Package.

Big metropolitan areas are inherently more congested and represent larger economies, so I test for the need to use instrumental variables, an econometric technique which can cope with congestion's potential endogeneity in the economy. However, I dismiss two-stage least squares (TSLS) regression using instrumental variables in favor of ordinary least

squares (OLS) models with panel data. I explain tests for endogeneity and reasons for rejecting instrumental variables in Appendix E (see page 202).

To measure the economy, I focus on per capita gross metropolitan product (PCGMP) and employment growth. These metrics have advantages and disadvantages. Data on PCGMP (to which I henceforth refer as *productivity*) are available from the Bureau of Economic Analysis for 2001 to 2008 – a comparatively short timeframe. But when using this metric, since I do not control for capital inputs, I must make the simplifying assumption of constant relative returns to capital. I do not look at aggregate gross metropolitan productivity because of issues with unit roots and because per capita productivity provides a metric which more closely reflects the experiences of individuals. I do not explore cross-sectional models or productivity per worker because of issues with sufficient observations, independence among observations (across industries or across years), and severe endogeneity issues between cross-sectional economic activity and congestion.

First, I define employment growth as follows:

Equation 1: Employment Growth

$$y_{1m,t-1} = \frac{y_{1m,t}}{y_{1m,t-1}}$$

$y_{1m,t}$ represents the employment at time t ; and

$y_{1m,t-1}$ represents the employment at time $t-1$, which is at least two years before t , each in metropolitan area m ;

I define productivity growth as follows:

Equation 2: Worker Productivity Growth

$$y_{2mt,t-1} = \frac{y_{2m,t}}{y_{2m,t-1}}$$

$y_{2m,t}$ represents the productivity at time t ; and

$y_{2m,t-1}$ represents the productivity at time $t-1$, which is at least two years before t , each in metropolitan area m ;

Next, I use ordinary least squares (OLS) regression to estimate predictors of economic growth, including traffic congestion, while controlling for regional economic demand, transportation infrastructure, municipal governance, and urban spatial structure. I model employment growth in non-overlapping time periods using panel data as follows:

Equation 3. Predictors of Employment Growth

$$y_{1mt,t-1,q} = \beta_0 + B_1 T_{t-1} + B_2 A_{m,t-1} + B_3 X_{m,t-1} + B_4 \Phi_{m,t-1a} + B_5 \Gamma_{m,1} + \beta_6 H_m + B_7 \Theta_{m,t-1} + \varepsilon_{mt,t-1}$$

$y_{1mt,t-1,q}$ indicates the employment growth (see Equation 1) in metropolitan area m between times $t-1$ and t according to a q -year lag structure ranging from three to five;

β_0 represents the intercept, in this case interpreted as the mean job growth rate beginning the initial year ($t-1=1993$) and t : either 1996 (using three-year lags) or 1998 (using five-year lags);

B_1 represents a vector of parameter estimates controlling for year fixed effects, for one of which T_{t-1} equals zero (the reference case and intercept), and estimated using OLS;

T_{t-1} represents a series of dummy variables for each year ($t-1$) in the given lag structure. For example, if the initial year is 1993 and five year lags ($q=5$) are employed, $t-1$ equals 1998 or 2003, while the first value of $t-1$ (1993) is omitted and the beta coefficient for 1993 is represented by the intercept, β_0 .

$A_{m,t-1}$ indicates a vector of regional economic demand characteristics which apply to metropolitan area m at time $t-1$;

$X_{m,t-1}$ indicates a vector of transportation infrastructure characteristics in metropolitan area m at time $t-1$;

$\Phi_{m,t-1a}$ indicates a vector of municipal governance characteristics in metropolitan area m in either 1990 or 2000, depending on whether or not year $t-1$ is before 2000²;

$\Gamma_{m,1990}$ indicates a vector of spatial structure metrics for metropolitan area m in 1990;

H_m indicates the average weather of metropolitan area m between 1971 and 2000;

$\mathfrak{G}_{m,t-1}$ indicates the congestion level in metropolitan area m at time $t-1$ plus a constant one in order to allow natural logging.

B_2 Through B_5 and B_7 indicate vectors of beta coefficients estimated using ordinary least squares for each vector of explanatory variables;

β_6 represents the beta coefficients estimated for the weather control variable;

$\varepsilon_{mt,t-1}$ represents the error term, which is assumed to be independently and identically distributed across observations.

² As both U.S. Census Bureau data and U.S. Census of Governments data do not correspond specifically to individual years, the most recent available dataset in or before year $t-1$ is used in both of these cases. This eliminates potential issues by which (for example) high job growth MSAs may lead to changes in independent variable characteristics (for example, changed municipal structure), thereby leading to additional endogeneity concerns.

Next, I estimate productivity growth in non-overlapping time periods as follows:

Equation 4. Predictors of Productivity Growth

$$y_{2mt,t-1,q} = B_0 T_{t-1} + B_1 A_{m,t-1} + B_2 X_{m,t-1} + B_3 \Phi_{m,t-1a} + B_4 \Gamma_{m,1-9} + \beta_5 H_m + B_6 \vartheta_{m,t-1} + \varepsilon_{mt,t-1}$$

$y_{2mt,t-1,q}$ indicates the productivity growth (see Equation 2, page 53) in metropolitan area m between times $t-1$ and t according to a q -year lag structure ranging from two to three;

All other variables are described above in Equation 3.

Models retain the form of Equation 3 and Equation 4, but I test variations. For example, I include quadratic effects for congestion and congestion-squared, as I expect the strength of congestion's predicted diseconomy to increase at higher congestion levels. Moreover, I mean-center each explanatory variable in order to allow the intercept to be interpreted as the economic activity change for the initial lag period (e.g. beginning in 1993) for Equation 3 and Equation 4, if all variables are at their average values. Moreover, I transform all dependent and independent variables by taking the natural log, thereby allowing parameter estimates (except for quadratic specifications) to be interpreted as elasticities.

Thus, if parameter estimates on congestion's drag (B_6) indicate that higher levels of congestion are associated with slowing employment growth, this would provide evidence

of traffic congestion as an economic drag. But as OLS models do not explicitly separate congestion effects from urbanization benefits (and such separation is also intractable with the rejected TSLS models using instrumental variables), the congestion parameter estimates must be interpreted as the sum trade-offs of congestion's diseconomy with urbanization benefits.

I describe metrics and data sources for each category of explanatory variables below.

Regional Economic Development

Regional economic development ($A_{m,t-1a}$ in Equation 3) is measured using two types of data sources: those available yearly and those available only through the decennial U.S. Census. Some variables are measured for each specific starting year ($t-1$ according to Equation 3 on page 53 and Equation 4 on page 56) within the panel dataset (e.g. for three-year lags, $t-1$ values would include 1993, 1996, 1999, 2002, and 2005), including crime, and industry specialization. But some variables, including age, education, and racial demographics are measured using Census data which corresponds to either 1990 (for $t-1$ values before 2000) or 2000 (for $t-1$ values greater than or equal to 2000). Thus, the variance in some variables from U.S. Census data is comparatively less than if data were available on a rolling basis between census years, and estimated model parameters rely more on the variance in 1990 and 2000. But as variance in U.S. Census Bureau variables for 1990 and 2000 capture important explanations of potential economic

growth, I retain these important controls in analyses. I describe specific control metrics below:

- Crime is estimated using property crime rates per 100,000 city residents and data are available annually from the Federal Bureau of Investigation (FBI) Uniform Crime Reports for year $t-1$.
- Median MSA resident age is estimated using the most recent U.S. Census data for either 1990 or 2000, depending on whether or not year $t-1$ is before 2000.
- Education levels for MSA resident are estimated using the most recent U.S. Census data for either 1990 or 2000, depending on whether or not year $t-1$ is before 2000.
- Resident racial demographic characteristics and the potential for race-based sources of inequality and discrimination are estimated using the most recent U.S. Census data for either 1990 or 2000, depending on whether or not year $t-1$ is before 2000.
- Industry specialization captures the degree to which a metropolitan area is highly-specialized in one particular industry compared to other industries and is measured using the maximum industry location quotient for any given industry in an MSA (see Equation 14 in Appendix B, see page 193).

Transportation Infrastructure

Transportation infrastructure ($X_{m,t-1}$ in Equation 3, page 53) is measured for both roadway infrastructure and transit infrastructure across all study years. Transportation supply controls include the following:

- Transit stock is estimated annually using the number of transit vehicles per square mile of land area according to Federal Transit Administration through the National Transit Database Program.
- Road stock represents the number of road miles per square mile of land area according to FHWA's Roadway Extent, Characteristics, and Performance database – HM71 series.

Data for each transit service provider from the National Transit Database are manually identified according to the U.S. Census Bureau's Metropolitan Statistical Area (MSA) boundary definitions. However, FHWA data on roadway stock is only available for the Urbanized Area (UA) portion of MSAs – thereby omitting many rural portions of each MSA, but arguably capturing the most important road stock for the purposes of congestion alleviation and economic support. Road and transit infrastructure change relatively little over time, similarly to gross regional spatial patterns, but some metropolitan areas have key temporal variations (see Chapter 7, for example).

I considered and tested metrics of transportation infrastructure per person (instead of by area), but such metrics were also sensitive to changes in population between years. In comparison, land area did not change and therefore changes in the metric across time reflect changes in transportation service only, and not population growth. Metrics of both transit and road infrastructure are available according to functional class. However, early results suggested that distinguishing among transit mode types or roadway functional

classes was a relatively less important when compared to the benefits of a parsimonious and meaningful interpretation. Thus, for the purposes of modeling, I omit distinctions among roadway subclasses and transit mode types.

Municipal Governance

Metropolitan areas' municipal governance structures ($\Phi_{m,t-1a}$ in Equation 3, page 53) are measured using up to four metrics: the degree of regionalization in municipal structure, the potential for better matching of residents and firms to public services by self sorting into municipalities, the degree of public-sector unionization (Hirsch & Macpherson, 2010), and the availability of special districts (only in models of productivity). Similarly to the U.S. Census data used for regional economic demand controls (see page 57), these data (gathered from the U.S. Census of Governments) correspond to one of two potential years – in this case, 1992 or 1997, depending on whether $t-1$ is less than 1997 or greater than or equal to 1997. Variance in these variables is sufficient to capture and control for important variations in municipal structure across the 88 study MSAs in models using panel data. Governance controls include the following.

- Regional governance captures the level of regional dominance by one or several regional municipalities and the potential to coordinate regional policy. It is estimated using a Gini coefficient comparing the relative distributions of residents and municipalities in U.S. Census of Governments (in either 1992 or 1997) occurring most recently before year $t-1$ (see Equation 15 in Appendix C, page 196).

- The average number of residents per municipality is measured using data from the U.S. Census of Governments (in either 1992 or 1997). This metric controls for the potential for resident and firm sorting into municipalities which better meet their demands for public services.
- The public sector unionization rate (union members per 100 public sector employees) is measured using data from the Current Population Survey (CPS) and available from Hirsch and Macpherson (2010). This metric is interpreted as an indicator of the relative cost-effectiveness of governance (Inman, 1995b).
- The number of special districts (public authorities and business improvement districts) is measured using 1997 U.S. Census of Governments data and is only included in the productivity models due to limitations in data availability. This metric provides an additional metric for the capacity for firms or residents to efficiently match their public service needs.

Controlling for Urban Spatial Structure

Metrics of urban spatial structure ($\Gamma_{m,1990}$ in Equation 3, page 53) are key indicators of urban form and of the potential for agglomeration benefits – either centrally, in urban concentration, through polycentric subcenters, or through endowed land mass. Spatial structure is measured for all panel data models using 1990 Census Transportation Planning Package data. As 1990 precedes all study years (using Equation 1, $t-I \geq 1993$ for all employment growth models and using Equation 2, $t-I \geq 2001$ for all productivity

growth models), these metrics capture base land use characteristics. Regional spatial structure changes very slowly over time (Giuliano, Redfearn, Agarwal, Li, & Zhuang, 2007), so these metrics capture significant and important variations between MSAs.

These spatial structure controls can account for potential early competitive advantages in urban form. Metrics include the following.

- Central urban density is measured using the natural logged central business district (CBD) intercept estimate from a regression of employment density on distance from the CBD center using a log-linear model (Equation 16 in Appendix D, see page 198). This metric captures regional economic mass and central density, indicating MSA size and agglomeration economies within the constant boundaries. For example, CBD density estimates vary from a maximum of 13,700 jobs per square mile (Honolulu) to 1,700 (average) to a minimum of less than 200 jobs per square mile (Poughkeepsie).
- Spatial concentration is measured using the natural logged absolute value of the central business district (CBD) slope estimate from a regression of employment density on distance from the CBD center using a log-linear model (Equation 16 in Appendix D, see page 198). Thus, the monocentric job density gradient, interpreted as a given percent decrease in job density with each mile distance from the center, indicates the relative concentration of jobs centrally (a steep job density gradient) or relatively more comparable densities across the region (a flat job density gradient).

Values vary from the relatively flattest job density gradient of 5% job density decrease (Miami) to a 21% job density decrease (average) to the steepest gradient of 70% job density decrease (Laredo, TX) for each mile from the CBD.

- Available MSA land area is measured for all MSAs according to the U.S. Census Bureau's 2008 MSA boundary definitions.
- Employment centers are measured using a methodology which identifies job clusters which are significantly denser (1.96 times the standard error higher) than monocentric expectations at $p < 0.05$ confidence level. As shown in the discussion on Identifying Employment Centers on page 199 in the Appendix D, I test for other subcenter definitions, such as a) significantly denser clusters than the monocentric expectation at the $p = 0.10$ confidence level or b) using absolute job density thresholds (> 10 jobs per acre). I demonstrate results using the $p < 0.05$ confidence level metric, but each metric yields the same substantive conclusion because final results are consistent regardless of which of these subcenter definitions is used.
- Job-housing balance is measured as the ratio of jobs to workers within 30 miles of the central business district. As discussed in the literature review, studies on job-housing balance indicates that enabling spatially-efficient matching of workers and jobs may enable workers to reduce commute distances as an important means of adapting to congestion and enabling more efficient labor outcomes (Cervero, 1996).

Controlling for Weather

I control for weather (H_m in Equation 3, page 53) using the historical mean January temperature from the U.S. Census Bureau, 2002 Census of Governments. Weather controls highlight differences between Sunbelt and Rustbelt regions in industrial development and differences in individuals' preferences for warmer weather (Glaeser, 2011).

4.1.2. Estimating and Interpreting Congestion

I measure traffic congestion ($\mathcal{G}_{m,t-1}$ in Equation 3, page 53) using data for 88 of the urban areas for which the Texas Transportation Institute developed congestion metrics covering 1982 to 2009 through the Urban Mobility Report (Schrank, Lomax, & Turner, 2010). Congestion is measured as the average number of hours of travel delay (compared to free-flow speeds) experienced by the average auto commuter in a given year³. Average congestion levels for the 88 MSAs in the study set vary significantly from a high of 85 hours of delay per auto commuter per year in Washington, DC (2007) to one hour or less in Laredo, TX, Omaha, NE, and Bakersfield, CA.

To illustrate the magnitude of these congestion estimates, if one assumes that all travel delay occurs during the roughly 250 weekdays in a year, an MSA with 85 hours of delay

³ I test additional metrics of congestion, including total travel delay across an entire MSA, delay per MSA resident, and delay per urbanized area resident, but results are consistent.

(the highest observed level) would have 20 minutes of delay per auto commuter per workday ($85 \text{ hours} * 60 \text{ minutes/hour} / 250 \text{ workdays} = 20 \text{ minutes per workday}$). In contrast, an MSA with 26 hours of delay (approximately average) would have six minutes of delay per auto commuter per day ($26 \text{ hours} * 60 \text{ minutes/hour} / 250 \text{ workdays} = 6 \text{ minutes per workday}$). Thus, if congestion were only experienced during the evening and morning commutes, this would represent a difference of seven minutes per one-way auto commute: ten minutes ($20/2$) of delay per one-way auto commute for highly-congested MSAs compared to three ($6/2$) minutes of delay per one-way auto commute for average MSAs.

As a preliminary illustration of the potential link between congestion and employment growth, I display a scatter plot in Figure 1 of the MSA initial year congestion level with the annualized job growth rate using five-year lags between 1993 and 2008 (each MSA is included three times: between 1993 and 1998, 1998 and 2003, and 2003 and 2008). The figure illustrates that job growth rates appear to be lower at higher levels of congestion, but that there is significantly more variation at more moderate congestion levels.

Moreover, there are significant outliers – some of which I omit from the analysis. For example, in Figure 1, Las Vegas is the fastest growing MSA with annualized job growth rates over eight percent annually between 1993 and 1998. In addition, New Orleans and San Jose MSAs have approximately two-percent job loss annually for select years because of their respective experiences with Hurricane Katrina and the bursting internet

bubble. As these extreme circumstances are not related to congestion, I omit them from analyses.

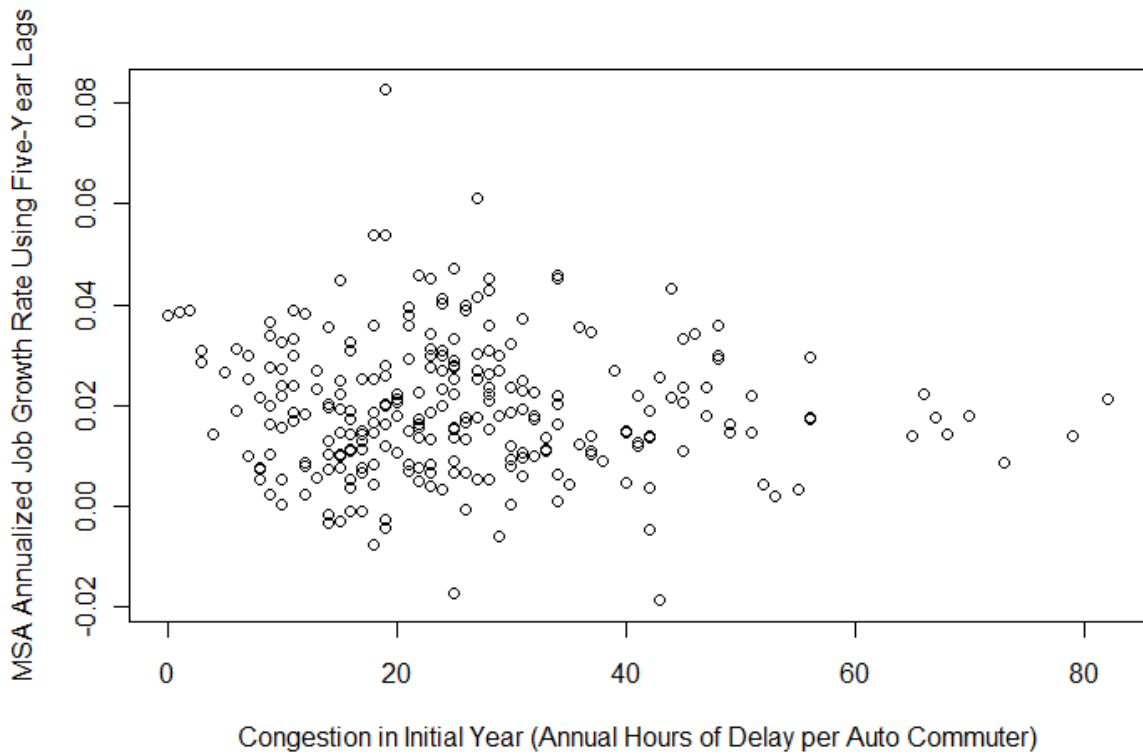


Figure 1. Scatter Plot of Congestion (annual hours of delay per auto commuter) with Annualized Employment Growth Rate, using five-year lags (1993 to 1998, 1998 to 2003, and 2003 to 2008)

Traffic congestion is endogenous to economic activity. It is challenging to separate the independent effects of a dual feedback loop by which large regional economies lead to higher congestion and congestion can potentially impede the economy (Boarnet, 1997; Hymel, 2009). Therefore, prevailing urban theory dictates that I test for the need to

instrument for traffic congestion, an econometric technique used to separate congestion both as a cause of large regional economies and a potential drag on economic outcomes. But it is not conceptually clear that instrumentation is necessary with the panel data design used in this dissertation, according to which I estimate the impact of initial congestion levels on subsequent economic growth. In fact, the endogeneity issue relies on dual causation, but using the panel research design, such a feedback loop is temporally constrained because higher future growth rates cannot “cause” higher initial congestion levels.

Despite conceptual reasons to reject instrumentation using the panel research design, I use econometric tests to gather additional evidence on whether or not instrumentation is preferred to accommodate endogeneity issues. Thus, I estimate panel models using both ordinary least squared regression (OLS) and two-stage least squared (TSLS) regression with instrumental variables and conduct Hausman tests to evaluate the relative efficiency of each estimator. Based on Hausman tests, I further reject the need to instrument for traffic congestion and I only estimate panel data models using OLS regression. I further discuss results using TSLS with instrumental variables and why I reject instrumentation on the basis of Hausman tests in Appendix E (see page 202). But while I borrow instruments from other researchers, see Boarnet (1997) or Hymel (2009), weak instruments may nevertheless lead to the Hausman test results which suggest that the OLS estimator is likely more consistent than instrumental variables.

4.2. Hypothesis Testing: Sources of Congestion Resilience

I next turn to the question of how MSAs can continue to be high-functioning despite congestion's potential drag. I explore sources of non-policy related adaptations by firms (Hypothesis 2, see Chapter 2) before focusing on policy-related contributors to congestion resilience (Hypothesis 3, see Chapter 2). I test each of these hypotheses using the following methods.

4.2.1. Firms' Adaptations

I expect firm and industry self-selection according to their relative benefits from big-city access and drag due to big-city diseconomies, such as traffic congestion. To test for such a "natural" regional adaptation to congestion, I compare industry-variant responses to congestion's drag on employment growth and productivity growth:

I measure employment growth as follows (modified from Equation 1, page 52):

Equation 5: Industry Employment Growth

$$y_{1mi,t-1} = \frac{y_{1mi,t}}{y_{1mi,t-1}}$$

$y_{1mi,t}$ represents the employment at time t within industry i ; and

$y_{1mi,t-1}$ represents the employment in industry i at time $t-1$, which is at least two years before t , each in metropolitan area m ;

MSAs are indexed by m and the time periods are indexed as year t and industries are indexed by i , between 2001 and 2008.

I estimate predictors of industry-specific employment growth in non-overlapping increments over time while accounting for other explanatory variables as follows:

Equation 6. Predictors of Industry Employment Growth

$$y_{1mit,t-1,q} = \beta_0 + B_1 T_{t-1} + B_2 A_{mi,t-1} + B_3 X_{m,t-1} + B_4 \Phi_{m,t-1a} + B_5 \Gamma_{m,1} + B_6 H_m + B_7 \Theta_{m,t-1} + \varepsilon_{mt,t-1}$$

$y_{1mit,t-1,q}$ indicates the employment growth (see Equation 5) in metropolitan area m in industry i between times $t-1$ and t according to a q -year lag structure ranging from two to five.

All other variables are described in Equation 3, page 53.

Independent and dependent variables are natural log transformed, allowing estimated parameters to be interpreted as elasticities, and all independent variables are mean-centered. Quadratic effects are inserted as necessary based on theory and model fit.

4.2.2. Estimating Sources of Exogenous Congestion Resilience

Next, I identify those policies which, on the margins, foster congestion resilience. In order to identify the best means for regional adaptation to congestion, I define *congestion resilience* as follows – the capacity to grow a regional economy on the margins despite congestion (at a relatively lower cost in congestion growth). This both addresses the

endogeneity issue – the challenge of separating the link between high function and congestion - and enables me to test explanations for *why* regional economies may be able to overcome congestion’s potential drag through congestion resilience. This metric accounts for both the capacities for policy instruments to contribute to economic growth and to alleviate or slow congestion growth, so the relative efficacy of policies to both of these outcomes is important.

I begin by defining congestion growth for q -year lag structures using metrics by Schrank, Lomax, and Turner (2010) and measuring growth in the average annual hours of delay per auto commuter, as follows:

Equation 7. Defining Congestion Growth (average annual delay per auto commuter) using data from Schrank, Lomax, and Turner (2010)

$$\mathfrak{G}_{mt,t-1,q} = \frac{\mathfrak{G}_{mt} + 1}{\mathfrak{G}_{m,t-1} + 1}$$

$\mathfrak{G}_{mt} + 1$ and $\mathfrak{G}_{m,t-1} + 1$ represent the congestion in MSA m in times t and $t-1$ and 1 is added both to the numerator and denominator in order to allow for natural log transformations.

As such, this metric treats each MSA as if each uniformly has one additional hour of delay per auto commuter per year than estimated by Schrank, Lomax, and Turner (2010). This enables natural log transformation for the MSAs with zero hours of delay in either

year t or $t-1$. I test sensitivity to the additive factor and test for excluding zero-observations.

Next, I measure congestion resilience in employment growth, as follows:

Equation 8: Measuring Congestion Resilience in Employment Growth

$$\Pi_{1mt,t-1,q} = \frac{y_{1mt,t-1,q}}{\mathfrak{G}_{mt,t-1,q}}$$

$y_{1mt,t-1,q}$ represents the ratio of employment in year t to employment in year $t-1$ in MSA m using q -year lags (see Equation 1, page 52); and

$\mathfrak{G}_{mt,t-1,q}$ represents the ratio of congestion in year t to congestion in year $t-1$ in MSA m using q -year lags (see Equation 7).

Finally, I define congestion resilience in productivity growth, as follows:

Equation 9: Measuring Congestion Resilience in Per Worker Productivity Growth

$$\Pi_{2mt,t-1,q} = \frac{y_{2mt,t-1,q}}{\mathfrak{G}_{mt,t-1,q}}$$

$y_{2mt,t-1,q}$ represents the ratio of employment in year t to employment in year $t-1$ in MSA m using q -year lags (see Equation 2, page 53); and

$\mathfrak{G}_{mt,t-1,q}$ represents the ratio of congestion in year t to congestion in year $t-1$ in MSA m using q -year lags (see Equation 7).

These two metrics of congestion resilience (Equation 8 and Equation 9) are only measured for observations when the economy is growing – in the example of productivity growth, when $y_{2mt,t-1,q} \geq 1$. But as employment and productivity are generally rising across all panel lag structures, at most ten percent of observations are removed as a result in any given panel dataset. In fact, among those MSAs with economic decline, only Detroit exceeded the short-term congestion diseconomy threshold. If observations with both positive and negative growth were included, one could conceivably identify a region as congestion resilient because its congestion rates shrank faster than the economy declined (yielding a high metric value and misleading conclusion about congestion resilience). Diagnostics are completed for each set of models and outliers are manually removed, as appropriate. I identify outliers visually according to model fit and I test the sensitivity of parameter estimates after removing suspected outliers. In addition, I test result sensitivity to omission of comparatively unique cities (such as New York or Los Angeles), finding that results are consistent.

I expect congestion resilience to be a function of four potential categories of policies which are discussed previously beginning on page 50: regional economic demand, municipal governance, transportation infrastructure, and urban spatial structure. Policies can potentially contribute to congestion resilience by influencing economic growth (the numerator in the congestion resilience metric) and/or by slowing the rate of congestion growth (the denominator). While some explanatory variables may both predict faster

economic growth and slower congestion growth, others may be associated only with one, the other, or neither. Congestion resilient policies could facilitate high economic growth which is more transportation efficient, in that it increases congestion less on the margins. Similarly some policies may slow congestion growth but have no influence on economic growth. Alternately, other policies (such as unionization) may influence economic growth but are not theoretically expected to influence congestion. Thus, I would expect policy categories, such as transportation infrastructure, to be more likely to increase congestion's economic return because of their expected joint contributions to economic growth and their potential to alleviate short-term congestion.

I test the potential contributions of policy-related explanations of congestion resilience in employment growth as follows:

Equation 10. Predictors of Congestion Resilience in Employment Growth

$$\Pi_{1mt,t-1,q} = \beta_0 + B_1 T_{t-1} + B_2 A_{m,t-1} + B_3 X_{m,t-1} + B_4 \Phi_{m,t-1a} + B_5 \Gamma_{m,1} + \beta_6 H_m + \varepsilon_{mt,t-1}$$

$\Pi_{1mt,t-1,q}$ represents congestion resilience in employment growth (see Equation 8, page 71);

β_0 represents the intercept, in this case interpreted as the mean congestion resilience in employment growth beginning the initial year ($t-1=1993$) and t : either 1996 (using three-year lags) or 1998 (using five-year lags);

All other variables are described in Equation 3 (page 53).

Next, I test the potential contributions of policy-related explanations of congestion resilience in productivity growth as follows:

Equation 11. Predictors of Congestion Resilience in Productivity Growth

$$\Pi_{2mt,t-1,q} = B_0 T_{t-1} + B_1 A_{m,t-1} + B_2 X_{m,t-1} + B_3 \Phi_{m,t-1a} + B_4 \Gamma_{m,1-9} + \beta_5 H_m + \varepsilon_{mt,t-1}$$

$\Pi_{2mt,t-1,q}$ represents congestion resilience in productivity growth (see Equation 9);

All other variables are described in Equation 3 (page 53).

Independent and dependent variables are natural log transformed, allowing estimated parameters to be interpreted as elasticities, and all independent variables are mean-centered. Quadratic effects are inserted as necessary based on theory and model fit.

The numerator of the congestion resilience metric is explored above in the models of employment and productivity growth (Equation 3 on page 53 and Equation 4 on page 56), but I also estimate predictors of congestion growth (the denominator) in order to facilitate interpretation of results from Equation 9 and Equation 10. However, as models of congestion growth are only of secondary interest, I present results in Appendix F, see Table 13 and the discussion beginning on page 208.

A next logical step in the models of congestion resilience would be to test for industry-variant policy predictors of congestion resilience. Thus, one might identify policies

which contribute to congestion resilience (more job or productivity growth for a unit growth in congestion) in some industries but not in others. In models which are not shown here, I test for industry variations using modified forms of Equation 8 and Equation 9 to define industry-variant congestion resilience and Equation 10 and Equation 11 to estimate industry differences in policies which predict congestion resilience. However, as congestion growth cannot be separated according to whether it is a function of growth in one industry or another, the common denominators (regional congestion growth) in Equation 8 and Equation 9 preclude meaningful differences in policy predictors of congestion resilience across different industries.

4.3. Hypothesis Testing Congestion Resilience among Select Cases

Next I further test Hypothesis 3 by using descriptive analyses and case studies to explore the process of becoming congestion resilient and to identify the most important contributing policies to congestion resilience for select high-congestion MSAs. First, I explore whether one might expect regions to simply become more congestion resilient as they have more congestion experience. Next, I use case studies to compare congestion resilient (CR) and congestion unresilient (CUR) MSAs among those regions with the highest congestion levels. I choose four case MSAs based on three criteria: high regional congestion levels, exposure to congestion's potential diseconomy based on Chapter 5 results, and clear examples of either congestion resilience or congestion unresilience in

both productivity and employment growth (resilient in one outcome and unresilient in the other).

To initially identify means of becoming congestion resilient, I use descriptive statistics to explore differences in economic outcomes and congestion resilience across MSAs, according to their regional congestion levels. If MSAs simply become more congestion resilient as they have more experience with congestion, adapting to congestion may only be a matter of time and policy interventions may be comparatively unimportant. To test for systematic increases in congestion resilience linked to congestion-experience, I subdivide study MSAs using various classification schemes according to *congestion experience bands* determined by their maximum congestion levels experienced during any one year between 1993 and 2008 (in annual hours of delay per auto commuter). I use descriptive statistics to identify differences in economic growth rates and in congestion resilience, according to an MSA's congestion level. Below, I illustrate the average productivity growth rates, employment growth rates, levels of congestion resilience in both job growth and productivity growth, and the maximum congestion level experienced in any one year before 2008. Only MSAs with 39 or more hours of annual travel delay per auto commuter are shown and cities are sorted in descending order by maximum congestion level.

Table 1. MSA Productivity Growth, Job Growth, Congestion Resilience, and Congestion Levels

MSA Name	Productivity Growth Rate (2001-2008)	Employment Growth Rate (1993-2008)	Congestion Resilience in Productivity Growth (2001-2008)	Congestion Resilience in Employment Growth (1993-2008)	Maximum Congestion before 2008 (annual hours of delay per commuter)
Wash. DC	2.0%	1.6%	3.2%	1.8%	85
Los Angeles	2.3%	0.7%	6.4%	2.4%	84
Chicago	0.8%	1.1%	-4.1%	-1.6%	77
San Francisco	1.4%	1.0%	-2.4%	3.1%	74
Houston	0.5%	2.7%	-3.2%	-2.4%	63
Atlanta	-0.9%	2.9%	-0.9%	1.2%	58
San Jose	2.7%	0.8%	5.1%	3.4%	57
Baltimore	1.5%	1.1%	-1.3%	-0.6%	57
Boston	1.6%	1.0%	1.0%	-1.2%	57
Minneapolis	1.1%	1.7%	0.4%	-2.0%	54
Dallas	0.7%	2.6%	-4.6%	-1.3%	53
Colorado	0.5%	2.7%	-2.0%	-7.1%	53
Denver	0.3%	2.5%	-3.6%	-1.5%	53
Austin	1.2%	4.1%	1.3%	-1.0%	52
Seattle	1.5%	1.9%	0.4%	2.2%	52
New York	2.3%	1.0%	-0.4%	-2.7%	51
Bridgeport	1.3%	1.0%	2.1%	-1.5%	50
Orlando	1.8%	3.2%	5.1%	2.9%	49
San Diego	2.8%	1.7%	2.6%	-1.4%	46
Miami	2.1%	2.4%	0.1%	0.2%	45
Phoenix	0.4%	3.6%	0.2%	1.9%	44
St. Louis	0.7%	0.9%	2.1%	-0.5%	44
Nash.	1.4%	2.6%	4.4%	0.4%	43
Va. Beach	1.8%	1.1%	4.5%	-1.4%	43
Portland	2.9%	2.4%	3.7%	0.5%	42
Philadelphia	1.6%	0.9%	-2.0%	-2.5%	42
Detroit	-0.3%	0.4%	0.2%	1.2%	42

**All growth rates and congestion resilience metrics are converted to annualized rates. Only those 27 MSAs are shown with congestion levels of 39 annual hours of delay per auto commuter or higher.*

Next, I use descriptive statistics to identify differences in industry make-up or key policies which distinguish congestion resilient (CR) from congestion unresilient (CUR)

MSAs among those with the highest congestion levels. I compare industry make-up in the four MSAs, testing for significantly higher proportions of industries which are less sensitive to congestion among congestion resilient MSAs. In addition, I compare three types of policies: *road transportation policy*, *public transit policy*, and *spatial structure*. I compare Los Angeles and Washington, DC (two congestion resilient MSAs) with Chicago and Houston (two congestion unresilient MSAs). These regions are among the most congested, are potentially most vulnerable to congestion's drag, and these MSAs are either congestion resilient or congestion unresilient. Both CR Washington, DC and CUR Houston have very high job growth rates (the economic outcome most associated with congestion's drag), while CUR Chicago and CR Los Angeles have lower job growth rates. This provides a stratification by which I can separate high-growth effects from congestion resilience effects in exploring policies most conducive to adaptation among highly-congested MSAs. Differences between CR and CUR MSAs may indicate policies which contribute to congestion resilience, but a causal link is far from clear. Instead, I discuss plausible explanations and conditions under which differences are meaningful and important contributors to congestion resilience.

Policies or characteristics distinguishing CR from CUR MSAs can be interpreted in two potential manners: competitive advantages based on initial conditions or competitive advantages in changed policy portfolios. In some cases, differences in initial conditions may distinguish CR from CUR MSAs – for example, having more inherited road or

transit capacity at the beginning of the study timeframe, regardless of incremental policy changes. In comparison, changes in planning policy or transportation service provision may represent the key distinguishing factor between CR/CUR MSAs, implying a strong potential for planning to lead to incremental changes in congestion resilience.

Road Transportation Policy

I compare road transportation policy among the four MSAs using three evaluative categories: network density, freeway services, and road use. First, I use data from 1992 through 2008 (data is further discussed below) to compare geographic road network density, a potential indicator of network redundancy; and network load density, a measure of the ratio of people to road-miles and a potential indicator of “normal” sources of congestion (as opposed to inefficient operations or inefficient spatial arrangements). Second, I compare changes in freeway services among the four MSAs across time using metrics of freeway network density and prevalence. Third, I compare metrics of road use intensity and density among the four MSAs, including metrics based on individual travelers (daily vehicle miles traveled), metrics based on infrastructure (average daily traffic on roads), and the relative importance of freeways in carrying road users.

I use data from the Federal Highway Administration (FHWA)’s Highway Statistics Series between 1992 and 2008 for Tables HM-71 and HM-72. Data show changes in available road stock and use by functional class, road use, and general urban area characteristics. The principal shortcoming of this data is the geographic area covered by

FHWA Highway Statistics Series data. In the cases of most explanatory variables, the analyses in Chapters 5 and 6 use static regional boundaries employed by the U.S. Census Bureau to delineate Metropolitan Statistical Areas in 2008. In contrast, the FHWA Highway Statistics Series data employs changing urbanized area boundaries which are contained within the larger MSA boundaries. Many researchers, including Hymel (2009), Winston and Langer (2006), and Langer and Winston (2008), suggest that the differences between boundaries is not critical in analyzing road stock contributions to congestion or economic outcomes, but there are some potential shortcomings with the boundary changes over time. The principal locations of congestion and economic activity are within urbanized portions of MSAs, so using the urbanized area boundaries focuses on the most important attributes of a region's transportation and land use network. Nevertheless, it is challenging to separate changes in road stock and services from changes in urbanized area boundary definitions over time. Thus, for the purposes of these descriptive comparisons, I modify all metrics of road and transit stock and services to represent per unit area or per resident metrics. In cases when boundary changes must be taken into consideration when making substantive interpretations, I further discuss the role of boundary changes.

Transit Policy

Next, I compare changes in bus and rail transit services among the four MSAs between 1992 and 2008 according to transit service expansion, service competitiveness, and

transit use. I use indicators of service provisions to illustrate absolute initial levels and changes in transit services over time. I focus on the relative competitiveness of transit and changes in service competitiveness over time. Finally, I use metrics of transit use to illustrate the changing role of transit in each of the four MSAs in accommodating trips and motorized mobility.

I use data on transit service provisions and use from the National Transit Database provided by the Federal Transit Administration. I manually identify transit service providers for each of the study MSAs to conform strictly to the U.S. Census Bureau's 2008 definitions of MSA boundaries. Although transit services do not expand into all portions of each MSA, these metrics of transit service provision represent all operators, all services, all residents, and all areas in each MSA at any particular point in time.

Consequently, there are no challenges in interpreting boundary changes over time, as with FHWA Highway Statistics Series data on roadway stock and services.

Spatial Structure

Finally, I compare spatial structure among the four MSAs using two basic models: the *monocentric* and the *polycentric* models of spatial structure. Previous studies suggest that the intra-metropolitan variations in spatial structure do change but are relatively stable over time (Giuliano, Redfean, Agarwal, Li, & Zhuang, 2007; Pan & Ma, 2004; McMillen, 2003), so I focus strictly on differences in 1990 – representing cross-sectional differences in spatial structure which preceded the timeframe for the models of economic

growth (Chapter 5) and congestion resilience (Chapter 6). Thus, I use descriptive statistics to explore whether differences in spatial structure emerge in distinguishing congestion resilient from congestion unresilient MSAs.

First, I estimate monocentric population and job-density models for each of the four MSAs (discussed in Appendix D) to compare central density and job density gradients (a metric of concentration) among the four MSAs. I compare the central density and suburban density (and density gradients) among the four MSAs and focus on the relative balance of jobs and workers.

In the second and final comparison of spatial structures, I contrast the extent and intensity of polycentricity among the four MSAs using employment subcenters. As discussed in Appendix D (see page 199), I calculate three metrics of employment subcenters using Census Transportation Planning Package (CTPP) data for 1990. I identify job centers as contiguous traffic analysis zones (TAZs) with more than 10 jobs per acre and cumulatively adding up to 10,000 jobs or more. I also employ relativistic definitions according to which candidate job centers have significantly higher densities than one would expect based on the monocentric job density model (see Equation 16 on page 198 in Appendix D), but reject these estimates for the purposes of this analysis. Standard errors for the monocentric job density model are very high in Los Angeles, leaving comparatively few TAZs with significantly higher densities than would be expected based on significance at the 0.05-level or 0.10 confidence levels. Therefore, I only focus

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on differences in polycentricity among the four MSAs using subcenters identified with the absolute density and total employment thresholds.

CHAPTER 5. HOW STRONG IS CONGESTION'S DRAG?

Using the methodology presented in Chapter 4, I estimate congestion's drag on employment growth and productivity growth, testing the magnitude and conditions under which congestion is a drag (Hypothesis 1). As discussed in Chapter 4, while I also estimate models using instrumental variables to account for congestion's potential endogeneity in the economy, model diagnostics and theoretical discussions lead me to prefer and only present results using ordinary least squares (OLS). I first present results on employment growth models and productivity growth models, and finally I discuss the meaning of these findings for policymakers.

5.1. Employment Growth Model Results

First, I use Equation 3 (page 53), which employs OLS regression, to estimate predictors of total MSA employment growth by applying three-year ($q=3$) and five-year ($q=5$) lag structures. Employment growth is measured as the ratio of employment in an MSA in the later year divided by the employment in the MSA in the base year (see Equation 2, page 53). I use an initial year of 1993, for a panel dataset extending from 1993 through 2008. Thus, using the five-year lag model employment growth is observed between 1993 and 1998, between 1998 and 2003, and between 2003 and 2008. Results are shown in Table 2.

Table 2. Employment Growth Results with Ordinary Least Squares (Equation 3)

Dependent Variable: Employment Growth Rate (ln) (Equation 1)	Initial Year = 1993	Initial Year = 1993
	3-Year Lags	5-Year Lags
Variable	Estimate	Estimate
Intercept	0.086 ***	0.143 ***
Congestion	0.004	0.010
Congestion Squared	-0.006 *	-0.007
Median MSA Age	0.025	0.038
Education (BS Per Capita)	-0.007	-0.003
Race (Blacks Per Capita.)	-0.008 ***	-0.011 ***
Road-Stock (Per Area)	0.007	0.007
Transit Stock (Per Area)	0.002	0.003
Crime Rate Per 100,000 Residents	-0.004	-0.017 *
Regional Governance	-0.016	-0.015
Municipalities Per Capita	0.001	0.001
Public Sector Unionization Rate	-0.015 **	-0.022 *
Public Sector Union Rate Squared	0.006	0.010
Industry Specialization (Maximum)	-0.019 *	-0.027
CBD Job Density	-0.013 ***	-0.020 ***
Job Density Grade/Concentration	0.086 ***	0.119 **
Area (square miles)	0.019 ***	0.028 ***
Job Subcenters (p95 method)	-0.001	-0.005
Job-Housing balance (w/in 30 mls.)	0.026	0.061
Job-Housing Balance Squared	0.078	0.158
Weather (mean January Temp.)	0.024 ***	0.048 ***
Adjusted R-Squared	0.45	0.56
Observations (N)	439	260

* Statistical significance at the $p=0.10$ level.

** Statistical significance at the $p=0.05$ level.

*** Statistical significance at the $p=0.01$ level.

Year fixed effects are included but not shown. All continuous variables are natural logged and parameter estimates represent elasticities. Explanatory variables are mean-centered.

Goodness of fit tests suggest that the model has significant predictive power (Adjusted R-squared values of 0.45 and 0.531). Growth rates vary significantly across MSAs and the highest growth rates occur in the early 1990s, including almost eight percent annual

growth in Las Vegas, NV (omitted as an outlier), over six percent annually in Phoenix, AZ, and over five percent annually in Austin, TX and Raleigh, NC. Average job growth across all 88 MSAs is approximately 1.1 percent annually. In contrast, the most rapid job losses (almost two percent annually) are in New Orleans (after Hurricane Katrina) and in San Jose in the late 1990s and early 2000s (the collapse of the internet bubble); both of these observations are omitted as outliers. Year fixed effects are included in each of the panel models, but are not shown in the table. As all independent variables are mean-centered, intercepts can be interpreted as the expected growth rate for the reference timeframe (either 1993 to 1996 or 1993 to 1998) if all independent variables are at their mean. When accounting for year fixed effects, the three-year lag model estimated on average 3.3% employment growth over three years, while the five-year lag model estimated on average 5.9% employment growth over five years. After converting to annual growth rates, these each correspond to annual growth rates of 1.1 percent. For direct comparison of parameter estimates between models with different lags, parameter estimate elasticities would need to be converted to annualized elasticities (analogous to compound annual gross return)⁴. Quadratic effects are included for some variables.

⁴ Annual elasticities are calculated using the equation, $E_{qp} = (1 + B_{qp})^{1/q} - 1$, where E_{qp} represents the elasticity of economic growth with respect to given predictor variable p ; B_{qp} represents the coefficient estimate for variable p using lag structure q ; and q represents the number of years between observations according to the lag structure (either three or five).

Of the categories of explanations for economic activity, spatial structure metrics are broadly the most important predictors of employment growth. Metropolitan areas with relatively less dense central business districts, with a steeper job density grade (more compact), and/or with more land area are expected to grow more, regardless of lag structure. In addition, higher proportions of blacks within the population are associated slower growth and warmer weather is associated with higher growth. Thus, employment growth appears to be overwhelmingly a function of the potential of an MSA's spatial structure to accommodate growth: places with more land, which are already more compact, but are not yet dense (low CBD density) are associated with higher job growth. In addition, consistently with others (Glaeser & Kahn, 2003), I find that the Sunbelt premium (higher January temperatures) appears to be highly important.

When initially inserting only congestion without its squared effect (not shown here) results suggest that congestion is simply associated with higher levels of economic activity (a positive and significant parameter estimate). The preferred quadratic specification (shown in Table 2) includes both the mean-centered natural-logged congestion level and the mean-centered (and then) natural-logged and squared congestion level – thereby orthogonally separating the linear primary and squared secondary effects. I additionally estimate models including congestion squared by first natural-logging and squaring and then mean-centering (thereby not orthogonally separating the linear and squared congestion terms); but while both the linear and squared terms are statistically

significant in such a case (and not only the squared term), the estimated effects are identical. Thus, I prefer including orthogonally separated squared terms. In the final models, the linear effect is positive but statistically insignificant while the squared parameter estimate suggests statistically significant secondary effects, this implies that congestion's effects are non-linear and include thresholds beyond which higher congestion levels are associated with slower economic growth. But while congestion squared is significant at the 0.10-level using three-year lags, the p-value is only 0.11 using five-year lags, suggesting that congestion may have a weakening effect over the longer term. The results suggest that urban agglomeration and access benefits inextricably linked with congested places are initially strong but may be weakened at higher levels at which congestion functions as a drag.

Results suggest that once a particular congestion threshold is met, additional congestion is associated with a decreasing rate of employment growth (not just a diminishing rate of increase). I estimate the thresholds at which one would expect higher congestion to be associated with slower employment growth rate (the *congestion diseconomy threshold*) to be approximately 39 hours ($q = 3$ -year lags) or 57 hours ($q = 5$ -year lags) of delay per auto commuter per year. Thus, all else being equal, according to the three-year lag model one would expect an annual job growth rate of 1.11% annually for an MSA with 39 annual hours of travel delay per auto commuter, but one would expect an annual job growth rate of 0.98% annually for an MSA with 85 annual hours of delay (the maximum

observed value between 1993 and 2008). Many of the study cities have historically exceeded these thresholds at least once: 27 cities have exceeded the 39-hour threshold. Only six MSAs have ever exceeded the 57-hour threshold (Atlanta, Chicago, Houston, Los Angeles, San Francisco, and Washington, DC), while three additional MSAs have met the threshold (Baltimore, Boston, and San Jose).

There is no theoretical reason why congestion would directly act as an input to better economic outcomes, so the effect of congestion at those levels at which it is associated with higher employment growth should be interpreted as capturing positive additional correlates of congestion (e.g. aspects of agglomeration benefits), thereby highlighting the relative trade-off between congestion's drag and urban access. Nevertheless, the same challenge remains when using instrumental variables (see Appendix E on page 202), an econometric technique which can sometimes isolate predictive influences despite endogeneity and dual causal processes – in this case, big-cities leading to economic agglomeration benefits and big cities simultaneously leading to congested road conditions which potentially impede the economy. Using instrumental variables, parameter estimates are very similar in shape and magnitude to those using OLS. Therefore, interpreting congestion as directly causing increased economic growth for the initial levels at which parameters suggest a positive link (below the congestion diseconomy threshold) remains challenging regardless of whether TSLS or OLS regression is used.

Estimates consistently suggest that existing MSAs continue to function while exposed to levels of congestion sufficient enough to predict slowing employment growth rates. In fact, among the 27 cities which exceed the 39-hour threshold, only Detroit has sustained job losses during any period between 1993 and 2008. But while Detroit's shrinking economy is largely a function of other factors unrelated to congestion (deindustrialization and a failing auto industry), other highly-congested MSAs continue to grow despite traffic because of individual competitive advantages and relative congestion-resilience in planning policies (the topics of Chapters 6 and 7)

In Figure 2, I display predicted employment growth rates using estimates from Table 2 (page 85) when holding all explanatory variables constant at their means (a hypothetical "All-American City"), thereby focusing on expected changes in annual employment growth rates with respect to different levels of congestion. Results suggest that congestion's drag on employment growth is strongest over the shorter-term (three-year lags) and weaker over the longer-term (five-year lags). Hymel (2009) similarly finds congestion's drag to be stronger over the shorter term, likewise providing evidence of adaptation to congestion through policy or innate firm-level or individual adjustments. I turn to the questions of adaptation through congestion resilience in Chapter 6 and 7.

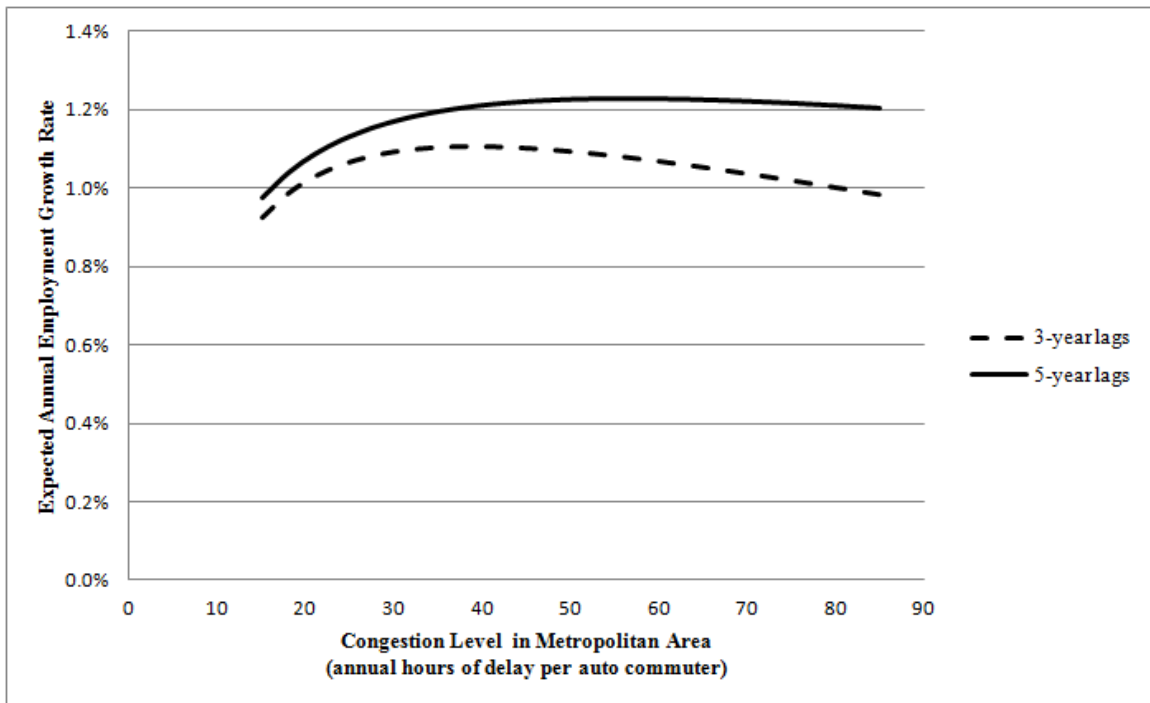


Figure 2. Congestion's Predicted Association with Expected Annual MSA Employment Growth Rates (using results in Table 2 on p. 85; all other explanatory variables are held at their means)

These congestion diseconomy threshold estimates should not be viewed as unbending: they suggest that when accounting for many of the other predictor variables, the relatively higher levels of traffic congestion are associated with expected slower employment growth rates. These threshold estimates likely vary by MSA and represent order-of-magnitudes and not absolute limits. Empirically, there remains substantial variance in employment growth rates (R-squared values for the three and five-year lag models are 0.45 and 0.56, respectively) which remains unexplained by the model. There are theoretical reasons to believe that congestion's drag would vary by MSA. For example,

given enough other competitive advantages and alternate travel options, congestion may be a relatively unimportant regional drag. But in the absence of other regional competitive advantages, moderate congestion may be a significant deterrent for incremental growth. Given sufficient data quality with enough observations across a significant timeframe, one could test for inter-MSA variation in several of the estimated model effects, including the estimated economic drag of congestion. But such an analysis remains beyond the scope of this research and this dataset.

But results suggest that – at least for a hypothetical “average” metropolitan area, as assumed in Figure 2 – road gridlock would not lead to regional stagnation, as indicated in news media, research, or policy documents. Without other competitive disadvantages, congestion levels within the observed range of values are not sufficiently high to stop job growth. In fact, when extrapolating the trend in Figure 2, one might expect job growth in this hypothetical city to cease at 410 annual hours of commuter delay (100 minutes per workday) over the shorter term or 1050 annual hours (250 minutes per workday) over the longer-term. These magnitudes of delay are longer than almost all average two-way commuting times in MSAs and are more than five times higher than the maximum congestion levels currently observed. Moreover, given potential variability in the estimate of congestion’s drag – particularly beyond the range of observed values - the thresholds above which one might expect job growth to cease are highly imprecise. Instead, evidence suggests that higher levels of congestion can be associated with slower

job growth rates, that large MSAs with dense CBDs and expansive suburbs face challenges in maintaining high job growth rates, but that congestion alone is not expected to cease job growth without other competitive disadvantages.

5.2. Productivity Growth Model Results

Next, I explore whether congestion also hinders the economic productivity of workers. If congestion is only a drag on employment growth, the extent to which congestion is a problem depends on local policy preferences and market trends which shape population and employment growth. But, if congestion inhibits individuals' capacities to be productive in their daily activities, this represents a drag not only on potential future residents, but also on current citizens and voters. In this section, I use methods discussed in Chapter 4 to explore the influence of traffic congestion on productivity growth.

First, I estimate Equation 4 (page 56) using OLS regression to explore predictors of growth in average (across all industries) worker productivity. I apply two-year ($q=2$) and three-year ($q=3$) lag structures because requisite productivity data is only available between 2001 and 2008. Growth in productivity is measured as the ratio of productivity in the later year divided by productivity in the initial year (see Equation 2, page 53).

Goodness of fit tests suggest that the explanatory power of the productivity growth models (R-squares between 0.309 and 0.533) are less than those of the employment growth models, although some of the variation is partially due to the differences in the number of observations and differences in the lag structures (see Table 3). All variables

are mean-centered, facilitating interpretation of the intercept (as the natural logged mean q -year lag productivity growth rate during the initial year – for example from 2001 to 2004), and quadratic terms are included, as appropriate.

Table 3. Productivity Growth Results with Ordinary Least Squares (Equation 4)

Dependent Variable: Productivity Growth (ln) (Equation 2)	2-Year Lags		3-Year Lags	
	Initial Year = 2001	Initial Year = 2002	Initial Year = 2001	Initial Year = 2002
Variable	Estimate	Estimate	Estimate	Estimate
Intercept	0.030 ***	0.029 ***	0.045 ***	0.037 ***
Congestion	-0.005	0.001	-0.003	0.003
Congestion Squared	-0.002	0.000	-0.001	0.001
Median MSA Age	-0.058 **	-0.045 *	-0.059	-0.047
Education (BS Per Capita)	0.027 ***	0.026 ***	0.034 **	0.040 ***
Race (Blacks Per Capita.)	0.001	-0.003	0.001	-0.006 *
Road-Stock (Per Area)	0.003	0.002	0.006	0.008
Transit Stock (Per Area)	-0.006	-0.003	-0.011 **	-0.006
Crime Rate Per 100,000 Residents	-0.017 ***	-0.012 **	-0.027 ***	-0.024 ***
Regional Governance	0.004	0.007	0.013	0.016
Municipalities Per Capita	-0.001	-0.001	-0.001	-0.001
Special Districts	0.000	-0.001	-0.001	-0.002
Public Sector Unionization Rate	0.011 *	0.007	0.023 ***	0.009
Public Sector Union Rate Squared	0.000	0.001	0.006	-0.002
Industry Specialization (Maximum)	-0.002	-0.002	-0.010	0.003
CBD Job Density	0.001	-0.001	0.000	-0.003
Job Density Grade/Concentration	-0.039	-0.027	-0.051	-0.026
Area (square miles)	0.001	-0.001	0.000	0.002
Job Subcenters (p95 method)	0.002	0.001	0.003	0.002
Job-Housing balance (w/in 30 mls.)	0.054	0.046	0.082	0.084 *
Job-Housing Balance Squared	0.057	0.091	0.083	0.240
Weather (mean January Temp.)	0.018 **	0.018 **	0.030 ***	0.024 ***
Observations (N)	255	255	167	165
Adjusted R-Squared	0.309	0.440	0.403	0.533

* Statistical significance at the $p=0.10$ level.

** Statistical significance at the $p=0.05$ level.

*** Statistical significance at the $p=0.01$ level.

Year fixed effects are included but not shown.
All continuous variables are natural logged and parameter estimates represent elasticities.
Explanatory variables are mean-centered.

Results suggest that education, crime, and weather (the Sunbelt premium) are, by far, the most important predictors of productivity growth, regardless of lag structure. For example, using the two-year lag models, the elasticity of productivity growth with respect to education is approximately 0.026 or 0.027, depending on the initial year used in the panel dataset (an annual elasticity of approximately 0.013). The parameter estimates using two-year lags for crime (-0.012 to -0.017) and weather (0.018) are statistically significant in each model, indicating the importance of low-crime and warmer climates in predicting productivity growth (annual elasticities of -0.006 to -0.009 for crime and 0.009 for weather). Year fixed effects are included, but are not shown in the table.

Neither congestion nor congestion-squared is statistically significant in any of the models (see Table 3). The shape, the magnitude, and the significance of the congestion parameter estimates are inconsistent with the employment growth model (see Table 2, page 85). Thus, evidence suggests that congestion does not impede productivity growth. Results in Chapters 6 and 7 address the question of how MSAs may adapt and compensate for the potential drag – leading to this evidence indicating that higher congestion is not associated with slower productivity growth.

5.3. Discussion

Results from this chapter broadly suggest four important conclusions. First, higher levels of congestion appear to be associated with decreasing employment growth rates (not just a diminishing rate of increase), but there is no evidence of congestion as a drag on

productivity growth. Second, the threshold at which higher levels of congestion are associated with slower employment growth – to which I refer as the *congestion diseconomy threshold* – appears to be approximately 39 hours of delay per auto commuter per year using three-year lags (the shorter-term) in the preferred OLS regression models, and approximately 57 hours of delay per auto commuter when using five-year lags (the longer-term). This result differs from Hymel (2009), in which the author found a constant elasticity estimate for congestion's drag on job growth. This is likely because Hymel (2009) employs MSA-specific fixed effects which account for unobserved MSA-specific characteristics (including urban benefits and diseconomies), and because the congestion parameter estimates from this dissertation account for the sum trade-off between urban benefits and congestion diseconomies, while Hymel's parameter estimates are more tightly constrained to congestion's drag. But consistent with Hymel (2009), results from this dissertation suggest that congestion's drag may be stronger over the shorter-term than over the longer-term (parameter estimates for congestion squared were only significant at the 0.11-level using the five-year lag model). Third, questions remain about the extent of congestion's endogeneity in the economy, and, therefore, congestion's precise drag will likely remain a topic of debate for the foreseeable future. Nevertheless, the best estimates of congestion's drag must still be interpreted as the sum trade-off between congestion's drag and other urban agglomeration benefits which will continue to remain challenging to disentangle from general traffic congestion. Fourth, results suggest that it is more challenging for big cities

with dense downtowns, expansive suburbs, and high traffic congestion levels to maintain high job growth rates. Each of these big-city characteristics are strong predictors of slowing employment growth. Nevertheless large and congested MSAs have used other economic competitive advantages to overcome these potential growth limits. Detroit is the only MSA exceeding the shorter-term congestion diseconomy threshold (39 annual hours per year) which also has sustained job losses – a function of deindustrialization and a failing auto industry. In the next chapters, I turn to explanations why some cities may be strategically better positioned to adapt to congestion and enable high function despite congestion's potential drag.

CHAPTER 6. CONTRIBUTORS TO CONGESTION RESILIENCE

As many urban areas continue to grow despite congestion's potential diseconomy, I first empirically test firm-level adaptations to congestion and second, explore planning policies which can enable regions to thrive despite traffic congestion. To identify more or less effective means of enabling adaptation to congestion, I explore means of growing an economy (both productivity and employment) at a relatively lower cost of congestion growth – *congestion resilience*. High-functioning urban places are inherently congested, so identifying means of growing an economy by adapting to traffic congestion becomes a critical means through which transportation and urban planning policies can advance opportunities for individuals and regional economies.

6.1. Endogenous Congestion Adaptation by Firms

One potential means through which economies adapt to congestion's potential economy is through firm or industry location decisions according to their trade-offs between urban benefits and urban diseconomies such as congestion. I test for industry-variant sensitivity to congestion's drag using Equation 6 (page 69) with three-year lags (see Table 4, page 101) and five-year lags (see Table 5, page 106) for five chief economic industries: *construction; finance, insurance, and real estate (FIRE); manufacturing, retail trade, and wholesale trade*. Industries are defined according to SIC two-digit definitions and converted between SIC (before 2000) and NAICS (after 2000) using standard definitions by the United States Office of Management and Budget. In total, these five industry

categories account for less than half of all jobs in MSAs, so there are potential variations between other industries, by which firms and job self-sort into MSAs according to their relative benefits from urban access and diseconomies from negative externalities, such as congestion. Research methods are described in more detail in Chapter 4, see page 68.

Results using the three-year lags suggest that congestion's diseconomy is most strong in the retail trade and wholesale industries (see Table 4). The parameter estimates using a quadratic specification (congestion and congestion-squared) are consistent with the average effects discussed in Chapter 5, but evidence suggests variation between industries. Results suggest a congestion drag on the retail and wholesale industries above thresholds, respectively, of 28 and 33 annual hours of delay per auto commuter (see Figure 3). These results are significant at the 0.01-level. Results on the manufacturing sector provide weaker evidence that congestion is a diseconomy (significant at 0.10-level) above a threshold of 32 annual hours of delay per auto commuter. Finally, the construction and FIRE industries appear to be only weakly impacted by congestion's diseconomy – neither parameter estimates are significantly different from zero (0.10-level).

Table 4. Industry Employment Growth Model Results Using Three-Year Lags (Equation 6)

Dependent Variable: Employment Growth Rate (ln) (Equation 5)					
Initial Year = 1993 (<i>t</i>) and 3-Year Lags					
Industry	Construct- ion	FIRE	Manufactu- ring	Retail	Wholesale
Variable	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept	0.094 ***	0.096 ***	0.041 ***	0.108 ***	0.087 ***
Congestion	0.039	-0.003	0.004	-0.001	0.005
Congestion Squared	-0.008	-0.008	-0.015 **	-0.020 ***	-0.017 ***
Median MSA Age	0.031	0.055 *	0.003	-0.025	-0.013
Education (BS Per Capita)	0.002 **	0.000	0.002	-0.015	-0.004
Race (Blacks Per Capita.)	-0.012 **	-0.009 **	-0.005	-0.010 ***	-0.006
Road-Stock (Per Area)	0.031	0.016 *	-0.012	0.004	0.009
Transit Stock (Per Area)	-0.009	-0.006	-0.001	0.001	-0.006
Crime Rate Per 100,000 Residents	-0.020	-0.024 **	-0.006	-0.014 *	-0.012
Regional Governance	0.005	-0.041 *	0.011	-0.027 *	-0.054 **
Municipalities Per Capita	0.002	0.000	0.003	0.002	0.001
Public Sector Unionization Rate	-0.041	-0.035 ***	-0.008	-0.018 **	0.013
Public Sector Unionization Rate Squared	0.003	0.005	-0.023	0.009	0.033 ***
CBD Job Density	-0.014	-0.008	-0.005	-0.011 ***	-0.011 *
Job Density Gradient (Spatial Concentration)	0.058	0.061 ***	0.014	0.088 **	0.133 **
Area (square miles)	0.037 ***	0.019	0.018 **	0.021 ***	0.025 ***
Job Subcenters (p95 method)	-0.003	-0.009	-0.005	0.002	-0.007
Job-Housing balance (w/in 30 mls.)	-0.140	0.023	0.025	0.023	-0.044
Job-Housing Balance Squared	0.152	0.050	0.134	0.078	-0.055
Weather (mean January Temp.)	0.040 **	0.031 **	0.026 *	0.023 ***	0.040 ***
Adjusted R-Squared	0.280	0.252	0.349	0.535	0.228
Observations (N)	418	432	341	349	330

* Statistical significance at the $p=0.10$ level.
 ** Statistical significance at the $p=0.05$ level.
 *** Statistical significance at the $p=0.01$ level.

*Year fixed effects are included but not shown.
 All continuous variables are natural logged and
 parameter estimates represent elasticities.
 Explanatory variables are mean-centered.*

Estimates of goodness of fit suggest significant variation among the industry models: adjusted R-squared values for construction and FIRE industries (0.280 and 0.252, respectively) are lower than those for manufacturing, retail trade, and wholesale trade (0.349, 0.535, and 0.228). Each industry model has a different number of observations (leading to differences in R-squared values) partially due to challenges in converting SIC to NAICS industry classifications between 2000 and 2001.

Next, I estimate industry-variant sensitivities to congestion's drag using five-year lags, indicating industries' relatively longer-term responses to congestion's diseconomy. Results are broadly consistent with those using the three-year lags. Estimates of model goodness of fit similarly indicate comparable model performance for construction, FIRE, manufacturing, and wholesale industries, while a greater proportion of variance in retail growth rates is explained by the seasonal nature of retail - captured in the model using year fixed effects which are not shown in Table 5.

Using five-year lags, results suggest that congestion is a drag on the retail and wholesale industries, but not on the construction, FIRE, and manufacturing industries. There are several potential explanations for these differences. The retail and wholesale industries may be more sensitive to congestion because they depend more on the local market. They are significantly more "basic" because they support other economic activities such as world-class finance, information technology, or manufacturing – each of which is generally exported beyond the local market. Thus, the unique characteristics of large and

congested cities may not significantly benefit basic industries (such as wholesaling and retail) beyond the constraints of local demand, while export-oriented industries benefit more from returns to scale and knowledge-sharing in big and congested cities with better access to global markets.

But while the retail and wholesale industries are both more subject to local market conditions, I expect that congestion may influence wholesale industries chiefly on the supply-side, while I expect retail to be influenced both on the supply and demand-sides. First, I expect congestion to increase the unreliability and cost of travel and the cost of wholesaling services while it simultaneously raises the wages of wholesaling employees who are compensated for exposure to inconvenient and unreliable supply chains. Thus, one may expect wholesalers to relocate adjacent to large MSAs or within relatively less congested MSAs in trading off between access within the national wholesaling supply chain and inflated wages and high travel costs. Second, in interpreting the link between congestion and retail industry job growth, I expect congestion's potential drag to be a function of both higher wage compensation for exposure to traffic congestion during the work commute and the increased likelihood of non-place based retail purchasing (such as online buying) due to congestion-induced daily scheduling constraints. But while one might expect wage compensation for exposure to congested commuting conditions, basic industries such as retailing and wholesaling are likely more vulnerable to incremental increases in wages due to the already-low profit margins and the potential for

comparatively fewer competitive advantages for these industries within large and congested regions (compared to, for example, global finance).

While the results for congestion's drag on manufacturing had been weak (according to statistical significance) using the three-year panel data, the evidence is even weaker using longer five-year time-frames. Manufacturing firms and jobs are less mobile than other industries due to relatively stationary capital inputs (machinery and leaseholds) and higher, less-mobile manufacturing wage rates due to unions. So, contrary to model results, one might expect manufacturing employment growth to be less sensitive over the short-term than over the long-term. However, in contrast to this expectation, results indicate higher sensitivity by the manufacturing industry over the short-term than over the long-term. This difference may reflect not the responsiveness of firms in leaving a congested MSA over the short-term (as had been expected), but the difficulty in the regional economy absorbing replacement manufacturing firms or jobs in short time periods. Congestion and congestion squared parameter estimates that are insignificant over the longer-term ($q=5$) but significant over the shorter-term ($q=3$) suggest that the equilibrium of self-selection and filtering congestion resilient manufacturing firms into congested MSAs and congestion sensitive manufacturing firms into uncongested MSAs may require more time (for example, to build expensive manufacturing facilities). Thus, the manufacturing sector of the economy may often be "out" of equilibrium over the

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short-term in response to congestion's drag because entering a market is relatively more difficult for manufacturing firms with high capital costs than for other industries.

Table 5. Industry Employment Growth Model Results Using Five-Year Lags (Equation 6)

Dependent Variable: Employment Growth Rate (ln) (Equation 5)					
Initial Year = 1993 (<i>i</i>) and 5-Year Lags					
Industry	Construct- ion	FIRE	Manufactu- ring	Retail	Wholesale
Variable	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept	0.260 ***	0.178 ***	0.067 ***	0.135 ***	0.135 ***
Congestion	0.003	0.011	0.019	-0.004	0.012
Congestion Squared	-0.013	0.000	-0.015	-0.032 ***	-0.026 **
Median MSA Age	0.057	0.111	0.055	0.012	0.060
Education (BS Per Capita)	-0.005	-0.007	0.012	-0.024	0.021
Race (Blacks Per Capita.)	-0.019 **	-0.019 **	-0.014	-0.016 ***	-0.018 **
Road-Stock (Per Area)	0.005	0.017	-0.019	0.000	0.011
Transit Stock (Per Area)	0.009	-0.012	0.002	0.008	-0.013
Crime Rate Per 100,000 Residents	-0.009	-0.043 *	-0.009	-0.024 *	-0.015
Regional Governance	0.018	-0.036	0.009	-0.050 *	-0.088 *
Municipalities Per Capita	0.009	-0.007	0.006	0.002	0.000
Public Sector Unionization Rate	-0.030	-0.053 **	-0.006	-0.053 ***	-0.002
Public Sector Unionization Rate Squared	0.000	-0.020	0.000	0.002	0.046 *
CBD Job Density	-0.018	-0.018	-0.006	-0.014 **	0.000
Job Density Gradient (Spatial Concentration)	0.120	0.128	0.152	0.117 *	0.130
Area (square miles)	0.026 *	0.030 **	0.033 **	0.029 ***	0.030 **
Job Subcenters (p95 method)	0.003	0.001	-0.011	0.003	-0.015
Job-Housing balance (w/in 30 mls.)	-0.019	0.129	0.125	0.017	-0.055
Job-Housing Balance Squared	0.005	0.323	0.378	0.128	-0.158
Weather (mean January Temp.)	0.073 **	0.078 ***	0.048 *	0.023	0.051 **
Adjusted R-Squared	0.270	0.349	0.380	0.578	0.272
Observations (N)	247	161	171	172	157

* Statistical significance at the $p=0.10$ level.
 ** Statistical significance at the $p=0.05$ level.
 *** Statistical significance at the $p=0.01$ level.

*Year fixed effects are included but not shown.
 All continuous variables are natural logged and
 parameter estimates represent elasticities.
 Explanatory variables are mean-centered.*

Figure 3 illustrates the expected changes in industry-variant annual job growth rates depending on MSA congestion levels within the range of observed values. Only results are shown which are statistically significant according to Table 4 and Table 5, as non-significant parameter estimates imply an association indistinguishable from zero. Regardless of congestion level, expected job growth rates are higher in wholesale industries than in retail industries, while manufacturing jobs are expected to decline. Figure 3 indicates that higher levels of congestion are most strongly associated with lower rates of job growth in the retail sector. As all other variables are held at their mean values, results indicate that one would expect manufacturing jobs to decline, but one would expect relatively more rapid decline in MSAs as congestion exceeds 32 annual hours of delay per auto commuter.

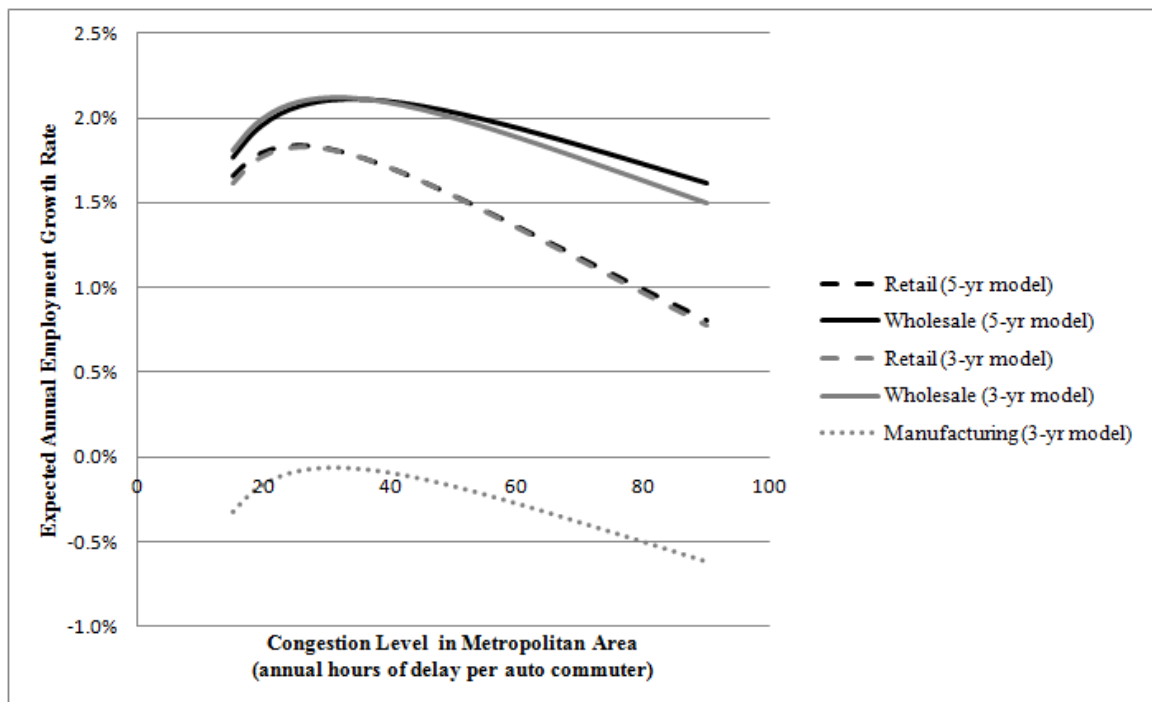


Figure 3. Industry Variance Among Retail, Wholesale, and Manufacturing Industries in Congestion's Predicted Association with Expected Annual MSA Employment Growth Rates (using results in Table 4 and Table 5 on pages 101 and 106; all other explanatory variables are held at their means)

6.2. Policy Sources of Congestion Resilience

Next, I estimate potential policy contributions to better regional adaptation to congestion through congestion resilience. As discussed in Chapter 4, I measure congestion resilience as the capacity of an economy to grow at a relatively lower cost in terms of congestion growth (see Equation 8 on page 71 and Equation 9 on page 71).

6.2.1. Congestion Resilience in Employment Growth Results

Using panel data with three- and five-year lag structures with 1993 as the initial year, I estimate predictors of congestion resilience in employment growth (see Equation 10, page 73). Results are shown in Table 6. Models include all 88 MSAs in the study dataset, thereby testing for policies which are associated with congestion resilience regardless of the level of regional congestion experienced at any given time. Results generally suggest that congestion resilient employment growth is most strongly a function of MSA population characteristics (age and education) and weakly a function of urban spatial structure. Surprisingly, evidence indicates that road and transit stock are not associated with congestion resilience in employment growth when assessed according to average trends across all 88 MSAs.

Table 6. Predictors of Congestion Resilient Employment Growth (see Equation 10)

Dependent Variable: Congestion Resilience in Employment Growth (Employment Growth per Congestion Growth, see Equation 8) Initial Year = 1993		
	3-Year Lags	5-Year Lags
Variable	Estimate	Estimate
Intercept	-0.074 ***	-0.077 **
Median MSA Age	0.155 *	0.272 **
Education (Bachelors Degrees Per Capita)	0.043	0.132 **
Race (Blacks Per Capita.)	0.001	0.009
Road-Stock (Per Area)	0.002	0.015
Transit Stock (Per Area)	-0.005	-0.010
Crime Rate Per 100,000 Residents	-0.002	0.003
Regional Governance	-0.038	-0.027
Municipalities Per Capita	0.016	0.021
Public Sector Unionization Rate	0.025	0.003
Public Sector Union Rate Squared	0.029	-0.042
Industry Specialization (Maximum)	-0.060	0.002
CBD Job Density	-0.003	-0.012
Job Density Gradient (Spatial Concentration)	0.224 *	0.272
Area (square miles)	0.020	0.032
Job Subcenters (p95 method)	-0.005	-0.019
Job-Housing balance (within 30 miles)	0.119	0.103
Job-Housing Balance Squared	0.413	0.554
Weather (mean January Temperature)	0.035	0.028
Observations (N)	408	245
Adjusted R-Squared	0.373	0.441

* Denotes statistical significance at the $p=0.10$ level.

** Denotes statistical significance at the $p=0.05$ level.

*** Denotes statistical significance at the $p=0.01$ level.

Year fixed effects are included in each model but not shown in the table. All continuous variables are natural logged and parameter estimates represent elasticities. Explanatory variables are mean-centered.

Among regional economic demand variables, median age and average education levels appear to be a strong predictors of congestion resilience in employment growth. If the

median age in a MSA is ten-percent higher, one would expect congestion resilience in employment growth to be 1.5 percent higher over three years and 2.7 percent higher over five years (both are significant at the 0.10-level or better). In comparison, evidence of education's contribution to congestion resilience is weaker using three-year lags, but using five-year lags, results suggest that a ten percent increase in the percent of people with Bachelor's degrees or higher would increase congestion resilience in employment growth by 1.3 percent over five years – or when adjusted to reflect annual elasticities, 0.03 percent over one year. In fact, when observing a scatter plot illustrating the potential link between average MSA education level and congestion resilience in job growth, as shown in Figure 4 using five-year lags, this illustrates a strong and positive relationship between the two, as demonstrated in the model results.

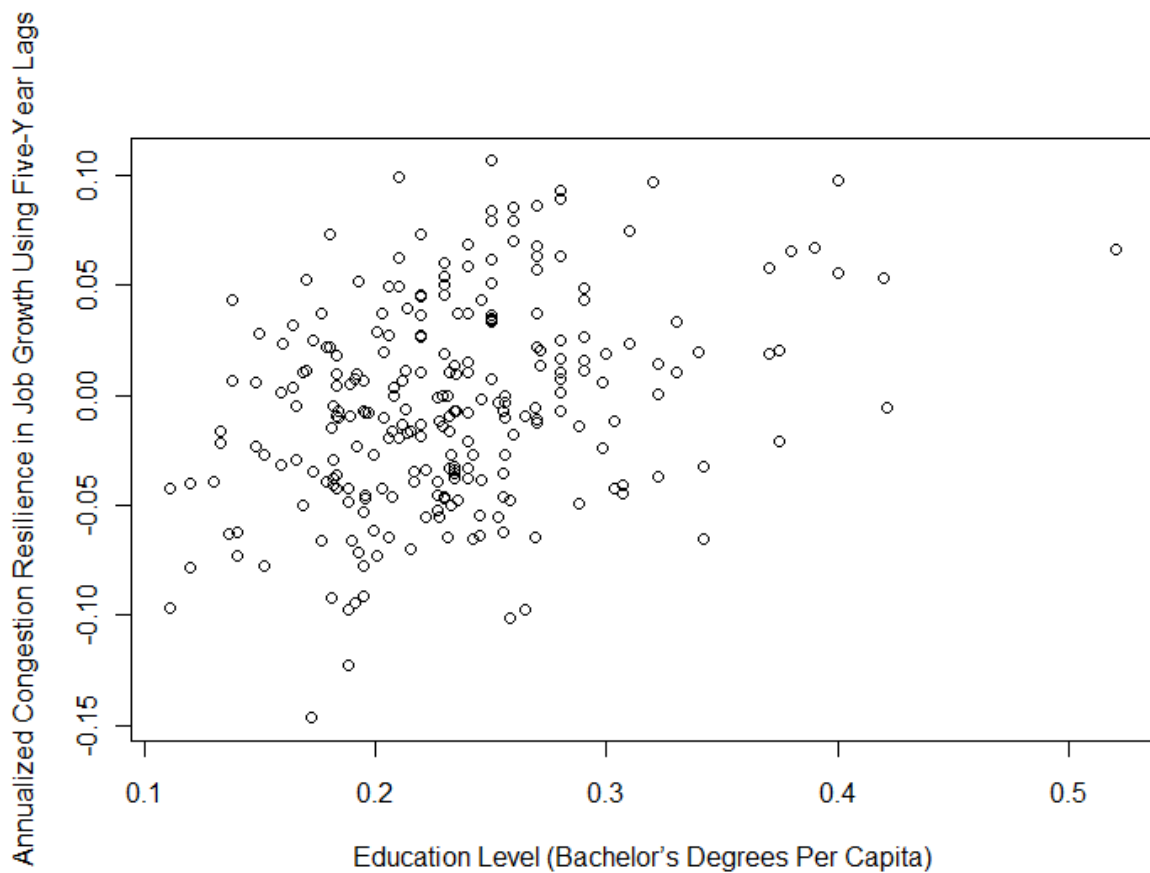


Figure 4. Scatter Plot of MSA Education Level (Bachelor's Degrees Per Capita) and Annualized Congestion Resilience in Job Growth (Five-Year Lags)

Interpreting the meaning of these results, one observes that age is only weakly (but positively) linked with employment growth (see Chapter 5), but is negatively linked with congestion growth (see Table 13 in Appendix G, page 215). Therefore, the effect of age on congestion resilience in employment growth appears to be largely because MSAs with older populations have slower congestion growth (perhaps because of lower trip making rates) and only secondarily to be a function of employment growth in response to age. Likewise, the effect of education on employment growth appears to be indistinguishable

from zero (see Chapter 5). Instead, MSAs with more educated populations appear to exhibit slower congestion growth – perhaps because growth in mobility among already highly-mobile educated workers has slowed or stagnated more rapidly than mobility growth among the general population.

There is only very weak evidence of spatial structure contributing to congestion resilience using three-year lags, while the five-year lag model provides no such evidence. Results using three-year lags (but not the five-year lags) suggest that more concentrated spatial arrangements (steeper job density gradient) are linked with congestion resilience in employment growth. Although only weakly significant (0.10-level), the parameter estimate implies that a ten percent steeper job density gradient (for example, by increasing central density relative to the suburbs) would be associated with 2.24 percent increase in congestion resilience over three years, an annualized elasticity of $0.070 = (1.224^{1/3} - 1)$. Spatial concentration is associated with congestion resilient employment growth because it is a predictor of faster employment growth (see Table 2, page 85) but is not meaningfully linked with congestion growth (see Table 13, page 215). These findings are in direct contrast with many of the debates between smart growth advocates (Ewing, 1997) and defenders of suburbanization (Gordon & Richardson, 1997) who justify particular types of urban form on the basis of congestion-related travel efficiencies.

Finally, perhaps the largest surprise is that neither transportation nor transit infrastructure appear to contribute to congestion resilience in employment growth. As both of these transportation policy metrics are relatively blunt, I test other models (not shown) with finer metrics of transportation infrastructure. I distinguish infrastructure stock by roadway classification type and transit mode type and I test metrics of roadway and transit capital and maintenance expenditures (not shown), but alternate transportation infrastructure metrics do not perform better and the fundamental finding remains. Thus, results suggest that if transportation and transit infrastructure contribute to congestion resilience, their contributions are not most important, on average, across MSAs of all sizes and congestion levels. Instead, their contributions may be either most important for MSAs functioning at or above the congestion diseconomy threshold (the topic of Chapter 7) or they may be most critical for congestion resilience in quality of life, not congestion resilience in the economy.

6.2.2. Congestion Resilience in Productivity Growth Results

Next, I explore predictors of congestion resilience in productivity growth. Equation 11 (page 74) models are estimated with two and three-year lag structures for initial years of 2001 and 2002 (see Table 7, page 119). Other lag structures and initial years are tested, but these models are preferred based on a trade-off between degrees of freedom (which are sacrificed when using longer lags) and avoiding models of noise (which occur for

models with shorter lags). Nevertheless, R-squared goodness-of-fit metrics vary from 0.073 to 0.385 depending on the initial year and lag structures.

Results between the models with an initial year of 2001 and two or three-year lags (henceforth called the 2001 models) differ from the models with an initial year of 2002 and two or three-year lags (henceforth called the 2002 models) in terms of the estimated impacts of key explanatory variables. The chief difference between the 2001 and 2002 models are due to the slowing national economy between 2007 and 2008. Figure 5 illustrates the rapid drop in congestion associated with slowing economic activity between 2007 and 2008 in select large MSAs, resulting in different congestion resilience outcomes between the 2001 (including observations between 2001 and 2007) and 2002 models (including observations between 2002 and 2008). In order not to identify regions as relatively more congestion resilient in cases when congestion shrank more rapidly than the economy (see Equation 8, page 71 or Equation 9, page 71), observations are included in the models of congestion resilience only in cases when the economy grows. The slowing national economy is most strongly reflected in lower productivity per worker and less reflected in metropolitan job losses (the topic of the previous section). Thus, 2001 model results capture general economic growth patterns while 2002 model results are more constrained to growing regions and illustrate the conditions under which MSAs can become more productive at a lower congestion-cost despite a national economic slowdown. Returning to congestion resilience in job growth, only 18 MSAs experienced

employment losses between 2007 and 2008, resulting in only five MSAs having job losses according to the three-year lag period between 2005 and 2008 (Dayton, OH; Detroit, MI; New Orleans, LA; Bradenton, FL; and Toledo, OH) and only four MSAs having job losses during the five-year lag period between 2003 and 2008 (Dayton, OH; Detroit, MI; New Orleans, LA; and Toledo, OH). In contrast, productivity per worker (the topic of this analysis) dropped more significantly during the national economic slowdown beginning in 2007. As a result, the 2002 models (which include observations covering 2007 to 2008) capture effects of the national slowdown more than the 2001 models of congestion resilience in productivity growth. In fact, of 88 MSAs, 52 had declining productivity between 2007 and 2008, resulting in 40 MSAs having productivity losses according to the previous two-year lag period between 2006 and 2008, while 28 MSAs had declining productivity according to the previous three-year lag period between 2005 and 2008. In contrast, productivity decreased in 20 MSAs during the final two-year lag period in the 2001 models (2005 to 2007) while productivity decreased in only 11 MSAs during the final three-year lag period in the 2001 models (2004 to 2007).

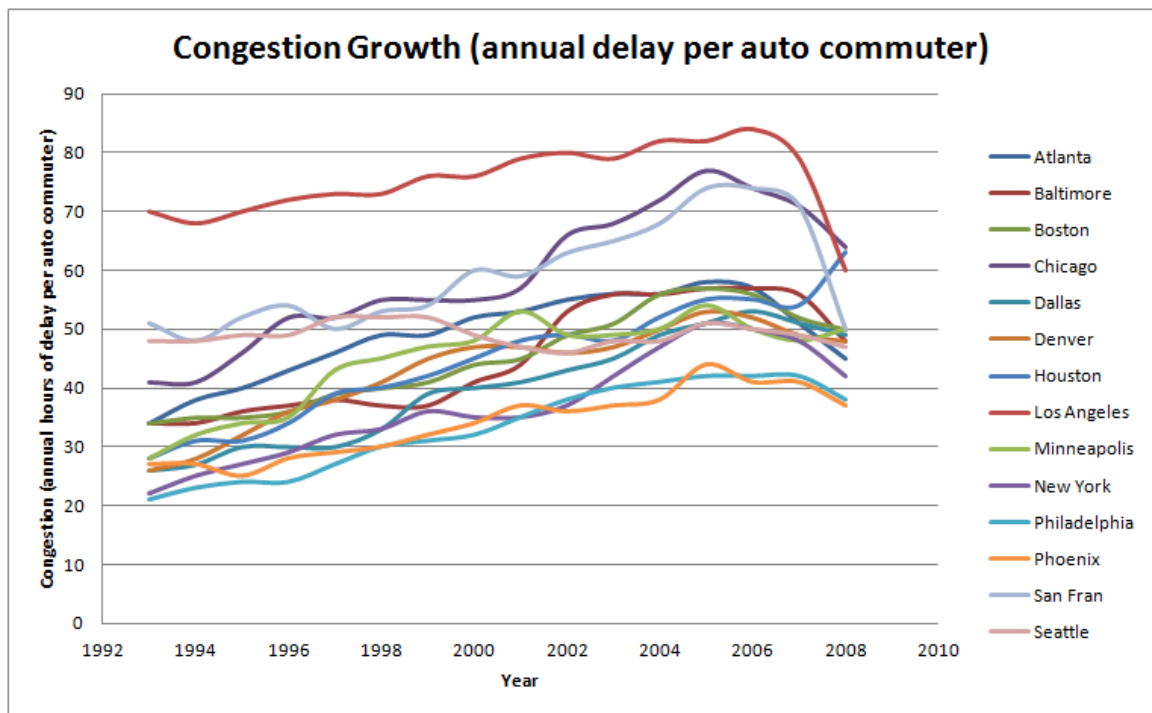


Figure 5. Congestion Growth Among Select Large Metropolitan Areas (1993 to 2008); data source is (Schrank, Lomax, & Turner, 2010)

Demographic characteristics –principally education levels, but secondarily racial demographics – are predictors of congestion resilience in productivity growth according to both 2001 and 2002 models. While both models indicate that regional education levels (percentage of the population with Bachelor’s degrees or higher) are positively associated with congestion resilience in productivity growth, the parameter is statistically significant in the 2002 model but not in the 2001 model. According to the 2002 model, one would expect a ten percent increase in the share of Bachelor’s degrees to be associated with a 1.07 percent increase in congestion resilience in productivity growth over three years (0.35 percent annualized). As education is a strong predictor of productivity growth, but

is only weakly linked with congestion, this suggests that the productivity-generating attributes of having a more educated labor force outweigh their potential contributions to congested road conditions – particularly in enabling a more productive economy despite a national economic slowdown (the 2002 models). In comparison, the 2001 models also suggest a positive but more modest (and statistically insignificant) predicted association between education and congestion resilience in productivity growth. Evidence is more ambiguous on the links between racial demographic characteristics and congestion resilience in productivity growth. While the 2001 model with three-year lags indicates that racial demographic characteristics are negatively associated (and marginally significant) with congestion resilience in productivity growth, results from both the 2001 model with two-year lags and the 2002 models suggest statistical insignificance and an unclear sign in the link.

Table 7. Predictors of Congestion Resilient Productivity Growth (see Equation 11)

Dependent Variable: Congestion's Economic Returns (Productivity Growth Rate per Congestion Growth Rate, see Equation 9)				
	Initial Year = 2001		Initial Year = 2002	
Lag Structure	3 Years	2 Years	3 Years	2 Years
Variable	Estimate	Estimate	Estimate	Estimate
Intercept	-0.042	-0.009	-0.011	-0.023
Median MSA Age	-0.175	-0.044	-0.146	-0.065
Education (Bachelors Degrees Per Capita)	0.046	0.028	0.107 *	0.080 **
Race (Blacks Per Capita.)	-0.023 *	-0.011	0.011	0.004
Road-Stock (Per Area)	0.052 *	0.007	0.024	0.022
Transit Stock (Per Area)	-0.031	-0.002	-0.020	-0.023
Crime Rate Per 100,000 Residents	-0.011	-0.012	-0.036	-0.031
Regional Governance	-0.032	-0.067	-0.104	-0.053
Municipalities Per Capita	0.000	-0.012	-0.001	0.004
Public Sector Unionization Rate	-0.037	-0.042	-0.029	-0.010
Public Sector Union Rate Squared	-0.033	-0.064 *	-0.112 **	-0.023 **
Industry Specialization (Maximum)	-0.011	0.035	-0.047	-0.030
CBD Job Density	0.016	0.014	0.015	0.009
Job Density Gradient (Spatial Concentration)	-0.020	0.038	0.081	-0.068
Area (square miles)	0.013	0.000	0.000	0.014
Job Subcenters (p95 method)	-0.023	-0.013	-0.028	-0.012
Job-Housing balance (within 30 miles)	0.147	-0.033	-0.100	0.031
Job-Housing Balance Squared	-0.261	-0.660	-1.033	-0.736
Weather (mean January Temperature)	-0.053	-0.020	-0.023	-0.018
Observations (N)	124	188	114	161
Adjusted R-Squared	0.103	0.073	0.385	0.325

* Statistical significance at the $p=0.10$ level.

** Statistical significance at the $p=0.05$ level.

*** Statistical significance at the $p=0.01$ level.

Year fixed effects are included but not shown.

All continuous variables are natural logged and parameter estimates represent elasticities.

Explanatory variables are mean-centered.

Second, the unionization rates squared – a metric of municipal efficiency – are highly significant in the 2002 models and the 2001 model with two-year lags (albeit of the same signs). Unionization is entered in the model as a quadratic specification (both a linear and a squared term), thereby enabling a changing magnitude or direction of association across the range of public sector unionization rates. Results suggest that higher public sector unionization rates (interpreted as the relative cost to value of public services) are associated with lower rates of congestion resilience.

Finally, there is some limited evidence that dense road networks are important predictors of congestion resilience in productivity growth according to the 2001 model with three-year lags. Results from both the 2002 models and the 2001 model with two-year lags indicate that the estimated impact is insignificant and of a lower magnitude (but of the same sign). Thus, of the four models, only one indicates that road network density is a strong predictor of congestion resilience in productivity growth. The 2001 model implies that for every ten percent increase in road network density – measured as road-miles per square mile of land area – one would expect congestion resilience in productivity growth to increase by 0.52 percent over three years (0.2 percent annually). This finding provides some support for the assertion that road building by increasing network density can potentially be an important means of enhancing economic productivity – and in this case, at a lower cost of congestion growth. This suggests that – consistent with the findings of other – productivity growth benefits from new roads and road use (Melo, Graham, & Canavan, 2012) may outweigh the congestion growth from induced demand as a

consequence of new road construction (Duranton & Turner, 2011; Winston & Langer, 2006).

None of the other explanatory variables are significant (marginally or otherwise). Even parameter estimates for transit infrastructure suggest that denser transit systems are unlikely to be a chief source of congestion resilience for MSAs across all congestion levels.

6.3. Discussion

I explore two types of adaptations through which metropolitan regions can become congestion resilient: adaptations by firms and adaptation through policy. First, evidence suggests that adaptations by firms allow intra- and inter-industry sorting by congestion resilient industries into congested MSAs and vice-versa (Hypothesis 2). Tests for firm responses to congestion's diseconomy suggest that the retail and wholesale industries are particularly sensitive to congestion's drag above congestion diseconomy thresholds of approximately 27 or 28 hours of delay for the retail industry and 32 or 33 annual hours of delay for the wholesale industry, depending on whether three or five-year lags are used. Therefore, evidence is strong that firm relocation and growth decisions are important means by which congestion resilient firms self-select into congested regions and adapt with little or no need for policy intervention. These results are consistent with the findings of Graham (2007), according to whom industries' sensitivities to congestion's drag vary. More congestion resilient industries (construction and FIRE) appear to gain

competitive advantages in congested MSAs compared to less congestion resilient industries (retail and wholesale). But sorting also appears to occur within industries. For example, while employment growth among manufacturing jobs appear to be subject to congestion's drag over the shorter-term (three years), marginally longer timeframes (five years) appear to enable new manufacturing firms or new jobs within existing firms to replace those which fled the congested regions. In summary, while self-selection between economic industries into MSAs appears to be an important means for endogenous adaptation, self-selection among firms or economic opportunities within the same industries appears to also be important.

Second, I find potential roles for planners and other policymakers to make MSAs strategically better positioned to grow despite traffic congestion and become congestion resilient (Hypothesis 3). But the policies most strongly linked with congestion resilience across MSAs with different congestion levels appear to parallel "good" economic policy more generally and particularly a highly-educated labor force and more cost effective municipal governance (lower public sector unionization). These results support literature in economics and geography which identify highly-educated individuals as drivers of future economic growth, particularly at the scale of MSAs (Knudsen, Florida, Stolarick, & Gates, 2008; Inman, 2009; Glaeser, 2011). Only limited evidence supports a role for transportation policy – in this case, road network density- in supporting congestion resilience.

CHAPTER 7. CASE DISCUSSIONS IN CONGESTION RESILIENCE

In this chapter I explore the link between congestion experience and congestion resilience and focus on potential explanations for congestion resilience among those MSAs with the highest congestion levels. First, I explore whether one might simply expect MSAs to “naturally” become more congestion resilient as they have more experience with high congestion levels and become more adept at enabled continued economic growth at diminishing marginal congestion costs. Descriptive analyses in this chapter and inferential statistical tests in Chapter 6 suggest that this is not the case. All MSAs exceeding the congestion diseconomy thresholds estimated in Chapter 5 continue to grow and implicitly adapt, but some MSAs are more congestion resilient than others.

Second, I focus on the role of specific planning policies in congestion resilience for four large and severely congested MSAs. Chapter 5 results suggest that one may expect job growth rates to slow in large and congested MSAs in the absence of other regional competitive advantages. Chicago, Houston, Los Angeles, and Washington, DC have beaten the odds. They are large, are among the most-congested MSAs in the U.S., and by 2008, each had reached the long-term congestion diseconomy threshold estimated in Chapter 5 at least once (57-annual hours of delay per auto commuter). Nevertheless, while Los Angeles and Washington, DC have adapted in highly congestion resilient manners (in both employment and productivity growth), Chicago and Houston have been congestion unresilient. For convenience, I henceforth refer to congestion resilient MSAs

as “CR” MSAs and congestion-unresilient MSAs as “CUR” MSAs. In the cases of these four MSAs, one would expect congestion’s drag to be more important, so identifying how each adapts can provide guidance in adopting policies which foster congestion resilience.

7.1. Congestion Experience and Congestion Resilience

To initially identify means of becoming congestion resilient, I explore differences in economic outcomes and congestion resilience across MSAs according to their experience with congestion. If MSAs simply become more congestion resilient as they have more experience with congestion, adapting to congestion may only be a matter of time and policy interventions may be comparatively unimportant. Instead, there are significant variations in MSA congestion resilience along the congestion-experience continuum, indicating competitive advantages for some. To test for systematic increases in congestion resilience linked to congestion-experience, I subdivide MSAs into six groups according to *congestion experience bands* determined by their maximum congestion levels experienced during any one year between 1993 and 2008 (in annual hours of delay per auto commuter):

- 10-19 annual hours of delay per auto commuter (N=13)
- 20-29 annual hours of delay per auto commuter (N=22)
- 30-39 annual hours of delay per auto commuter (N=23)
- 40-49 annual hours of delay per auto commuter (N=9)

- 50-59 annual hours of delay per auto commuter (N=11)
- greater than 60 annual hours of delay per auto commuter (N=6)

The average annual employment and productivity (per worker) growth rates vary significantly according to regional congestion levels. Figure 6 illustrates that employment growth rates are comparatively lower among MSAs with less than 30 annual hours of delay. While MSAs are expected to experience congestion's short-term diseconomy (using three-year lags) above 39 annual hours of delay, employment growth rates are highest in the bands on either side of this threshold. Employment growth rates decrease in each band above 30-39 annual hours of delay, providing supporting evidence that congestion's diseconomy may be associated with lower long-term employment growth rates. Nevertheless, even the six highest-congestion MSAs retain employment growth rates higher than the lowest-congestion MSAs with less than 30 annual hours of delay.

Differences in productivity growth rates according to MSAs' congestion experience do not appear to be systematic, providing supporting evidence that congestion's drag on productivity growth is very weak (see Chapter 5). In fact, among the MSAs, those in the two highest bands (50-59 and 60-85 annual hours of delay) of congestion experience narrowly have the highest productivity growth rates among all MSAs.

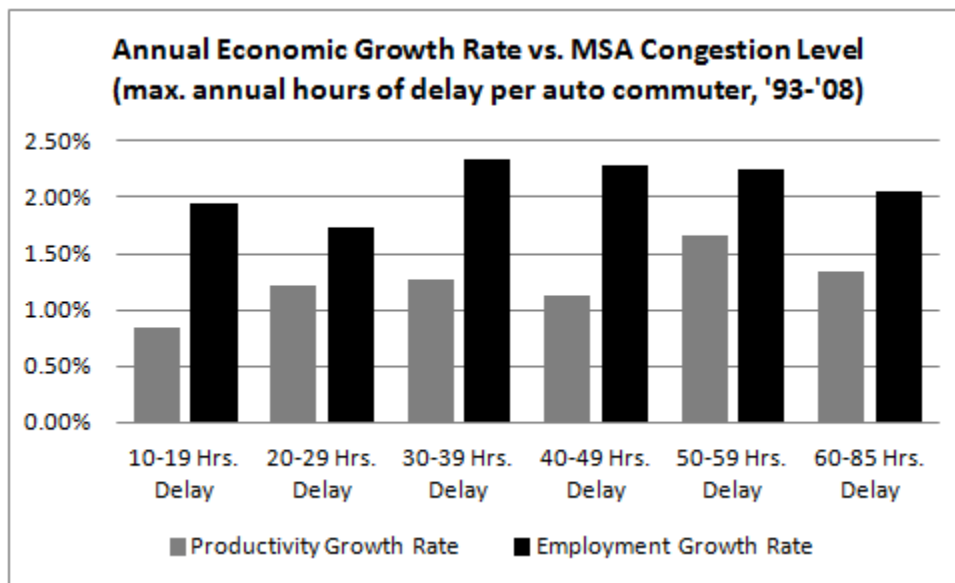


Figure 6. MSA Congestion Experience and Economic Growth

There are significant differences in congestion resilience in productivity or employment growth among the six congestion-experience bands, as shown in Figure 7. But evidence is weak for quasi-linear adaptation through time, as would be implied by increasing levels of congestion resilience as congestion experience increases. In fact the strongest evidence for linear adaptation indicates that congestion resilience in productivity growth increases up to the congestion experience band of 40-49 annual hours of delay and subsequently decreases. In contrast, no linear patterns are evident in congestion resilience in employment growth. One would expect high incentives for MSAs exceeding the congestion diseconomy threshold (39 annual hours of delay over the shorter-term or 57 hours of delay over the longer-term) to become more congestion resilient in employment growth. But only MSAs with congestion levels approaching or

exceeding the longer-term congestion diseconomy threshold estimate (57 annual hours of delay) exhibit higher congestion resilience in employment growth.

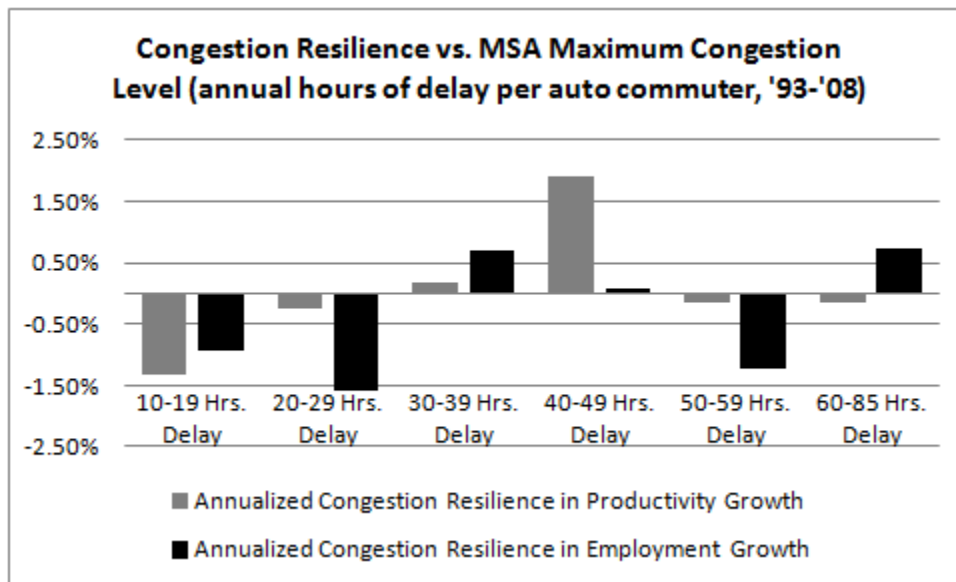


Figure 7. Comparing Congestion Resilience and MSA Congestion Experience

* Note that productivity (per worker) growth rates are for 2002 to 2008 while employment growth rates are for 1993 to 2008.

7.2. Congestion Resilient MSAs

Maintaining compounding employment growth rates beyond the congestion diseconomy threshold is challenging (see Chapter 5). While all 27 of the cities exceeding either the short-term (39 annual hours of delay) or long-term (57 annual hours of delay) congestion diseconomy thresholds host substantial economic growth in the study years, there are significant differences in congestion resilience as a source of MSA competitive

advantage. In this next section, I compare the performance of MSAs with congestion experience at some point between 1993 and 2008 above the long-term congestion diseconomy threshold, *above-threshold MSAs*, with those experiencing congestion between the short-term and long-term thresholds (39 to 57 annual hours of delay), the *at-threshold MSAs*. Using these comparisons, I discuss why the experiences of Chicago, Houston, Los Angeles, and Washington, DC can inform planners in advancing congestion resilience.

If one expects decreasing marginal productivity when adding workers, one would expect high-employment growth rate MSAs to have relatively lower productivity growth rates and vice-versa. Figure 8 generally supports the diminishing marginal productivity of additional employees, but there are some exceptions.

Chapter 5 results suggest that higher levels of congestion are associated with slowing employment growth rates, but each of the nine above-threshold MSAs continues to grow. Among above-threshold MSAs, employment growth rates in Houston, Atlanta, and Washington, DC are higher than average, while other above-threshold MSA job growth rates are slower than average. There is significant variation in productivity growth among the above-threshold MSAs, generally consistent with the diminishing marginal productivity of additional employees. In fact, Los Angeles, San Jose, and Washington, DC productivity growth rates are among the highest within the sample of MSAs (see bold in Figure 8). Atlanta stands out for rapid job growth rate of almost three percent annually

and slower productivity growth per worker (consistent with decreasing marginal productivity of additional workers). Only Chicago's employment and productivity growth rates are both less than average.

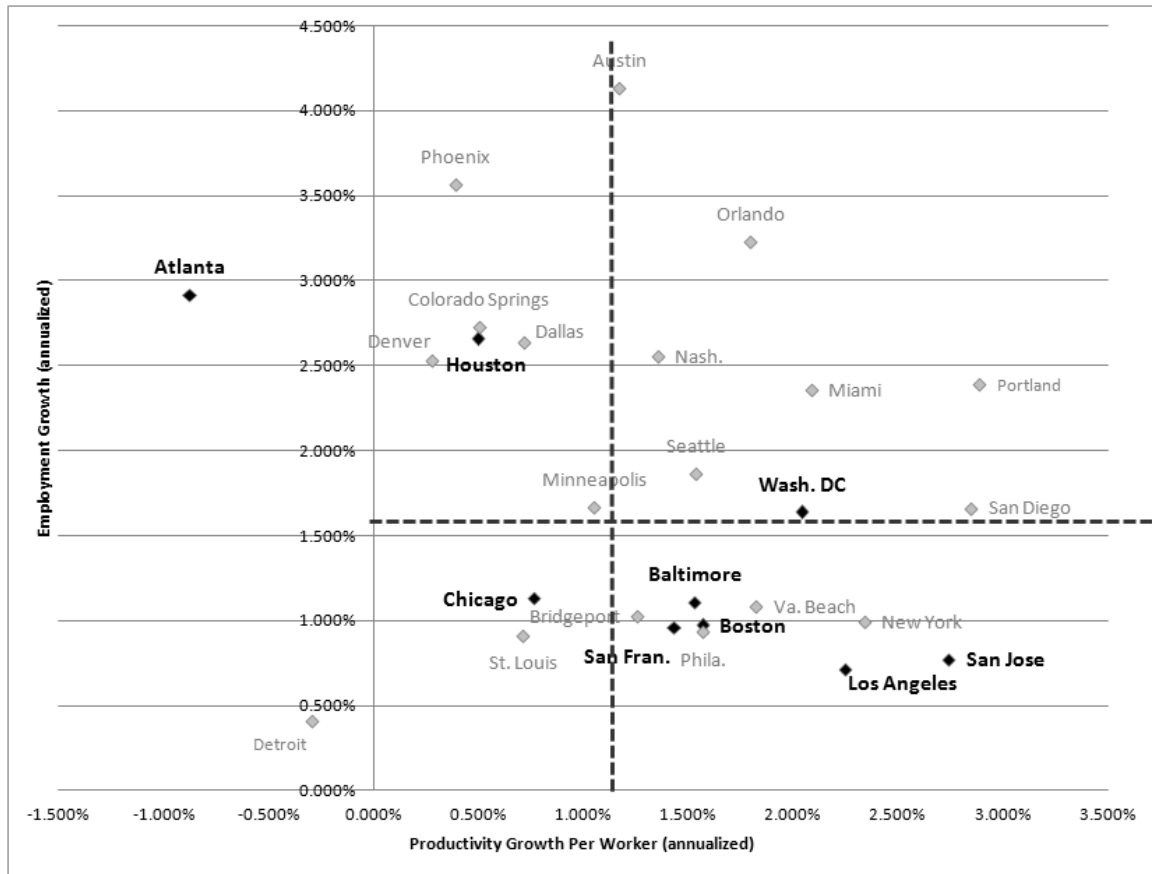


Figure 8. Comparing Productivity (per worker) Growth and Employment Growth (MSAs with >39 annual hours of delay per auto commuter at one or more times; MSAs with ≥ 57 hours of delay in bold; average shown by dotted line)

There are also significant differences in congestion resilience among the at-threshold and above-threshold MSAs (see Figure 9): while congestion resilience is more modest for at-threshold MSAs, above-threshold MSAs are either highly congestion resilient or highly

congestion-unresilient. Overall, very few MSAs are significantly congestion resilient in both employment and in productivity growth. There are exceptions – particularly among above-threshold MSAs. Only four MSAs exhibit congestion resilience (see Equation 8 on page 71 or Equation 9 on page 71) of greater than 1 percent in employment growth and 2 percent in productivity growth: Orlando and three above-threshold MSAs: Los Angeles, Washington, DC, and San Jose.

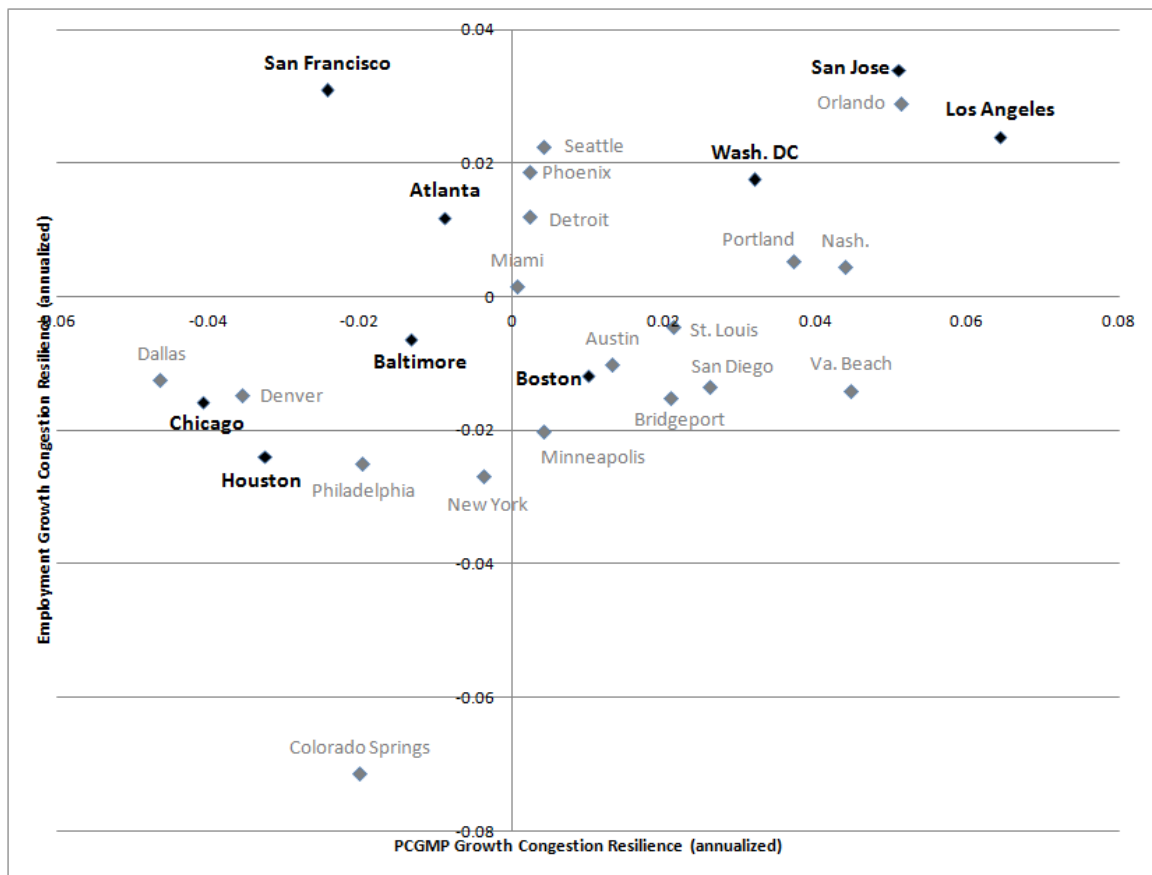


Figure 9. Comparing Congestion Resilience in Productivity (per worker) Growth and Employment Growth (MSAs with >39 annual hours of delay per auto commuter at one or more times; MSAs with ≥ 57 hours of delay in bold)

Likewise relatively few MSAs are congestion unresilient in both productivity and employment growth. Six MSAs have congestion resilience of less than -1 percent in employment growth and -2 percent in productivity growth (see Figure 9): Colorado Springs, Dallas, Denver, Philadelphia, and two above-threshold MSAs: Chicago and Houston.

Differences between the highly-congestion resilient (CR) and highly congestion-unresilient (CUR) MSAs are stark when exploring the meaning of their respective congestion resilience metrics. For CR MSAs at or above the one-percent/two-percent job growth/productivity growth CR thresholds, even without any congestion growth whatsoever, one would expect employment to grow by 1.0 percent or greater ($= 1 * 1.01 - 1$) and per capita productivity to grow by 2.0 percent or greater ($= 1 * 1.02 - 1$) annually. The entire economy (the product of job growth and per worker productivity growth) would grow by 3.02 percent or greater ($= 1 * 1.01 * 1.02 - 1 = 3.02$ percent). But if congestion increased by five percent, one would expect employment to grow by 6.05 percent ($= 1.05 * 1.01 - 1 = 6.05$ percent), productivity to grow by 7.1 percent ($= 1.05 * 1.02 - 1 = 7.1$ percent) and the entire economy to grow by 13.5 percent [$= (1.05 * 1.01) * (1.05 * 1.02) - 1 = 13.6$ percent]. In contrast, one would expect much slower economic growth in congestion unresilient MSAs through a five-percent increase in congestion. For example, if an MSA's congestion resilience were -1 percent in employment growth and -2 percent in productivity growth, one would expect a 4.0

percent employment increase ($=0.99*1.05-1=4.0$ percent), a 2.9 percent productivity increase ($=0.98*1.05-1=2.9$ percent), and a 7.0 percent total economic growth rate ($=(0.99*1.05)*(0.98*1.05)-1=7.0$ percent) in response to a five percent increase in traffic congestion. Thus, the difference between the highly congestion resilient (+1 percent / +2 percent CR in job/productivity growth) and highly congestion-unresilient (-1 percent / -2 percent CR in job/productivity growth) represents an annual economic growth rate difference of 6.6 percent or higher: 2.1 percent employment growth and 4.2 percent productivity growth.

Nevertheless, among above-threshold MSAs, the reasons for differences in congestion resilience remain unclear. Three above-threshold MSAs are highly congestion resilient (see Figure 9), of which I focus on Washington, DC and Los Angeles. I do not focus on San Jose even though it is also highly-congestion resilient. San Jose's regional planning is highly-related to its larger neighbor, San Francisco. The Metropolitan Transportation Commission serves as the Metropolitan Planning Organization for the larger Bay Area (including San Francisco and San Jose), thereby reducing the strength of making policy conclusions about San Jose's without also exploring San Francisco. But as San Francisco, also an above-threshold MSA, is unresilient in productivity growth but resilient in employment growth, similarly leading to less clear policy conclusions; I jointly omit San Francisco and San Jose from in-depth case studies. Two above-threshold MSAs are unresilient to congestion (see Figure 9), of which one is growing

substantially in employment (Houston), while the other is growing comparatively slowly (Chicago) and are therefore included in case studies. But while Atlanta, Baltimore, and Boston exceed the long-term congestion diseconomy threshold, they are less clear examples of congestion resilience in productivity and employment growth and are therefore omitted from in-depth case studies. Baltimore and Atlanta are comparatively more resilient in job growth but are unresilient in productivity growth, while Boston is only moderately congestion resilient in both.

7.3. Case Studies

I explore industry make-up and policies which distinguish congestion resilient (CR) from congestion unresilient (CUR) MSAs among four high-congestion regions: CR Los Angeles and Washington, DC and CUR Chicago and Houston. While not proving causality, important differences in industry make-up and available transportation planning policies and spatial structure can suggest means of becoming congestion resilient and accommodating economic growth at a relatively lower “cost” in congestion growth. Based on results from Chapter 5, these MSAs are among those most vulnerable to congestion’s drag, so lessons on how these particular regions adapt to congestion can have important broader applications for planners in other congested regions.

Although each of the four MSAs added between 1.25 and 2.0 million residents between 1990 and 2008 (see Table 8, page 137), Houston and Washington, DC had fewer residents to begin with and therefore grew at faster rates. So the extent to which

employment growth is slower in Los Angeles and Chicago depends on the exponential growth expectation within this research and widely adopted within urban economics.

Houston and Washington, DC are smaller both in absolute sizes and in terms of population density per unit area, thereby hosting more potential developable land.

Chapter 5 results suggests that congestion's economic drag is most strongly linked with employment growth, so this stratification by CR/low employment growth rate (Los Angeles), CR/high employment growth rate (Washington, DC), CUR/low employment growth rate (Chicago), and CUR/high employment growth rate (Houston) is useful to explore explanations of the two effects independently.

In contrast, differences in productivity growth rates do not mirror those of employment growth and instead mirror distinctions by congestion resilience. Per capita gross metropolitan productivity grew faster in the two CR MSAs than in the two CUR MSAs. The independent contributions to congestion resilience or high-productivity growth are more challenging to separate using a case study approach. Thus, while the following discussion focuses explicitly on the CR/CUR differences, factors influencing productivity growth are likely mediating this distinction.

I begin by highlighting differences in base characteristics (metropolitan size, education, demographics, and commuting), I then focus on differences in industry make-up between the four MSAs, and then I focus on 1) road transportation policy, 2) transit policy, and 3) spatial structure within each MSA as the potential distinguishing factors between CR and

CUR MSAs. Results suggest that each of the MSAs' routes towards congestion resilience or unresilience is relatively unique. But common distinctions emerge which had played a relatively more dormant or unimportant role across the 88 MSAs of all congestion levels, as explored in Chapter 6. Particularly, descriptive comparisons suggest that important ingredients for congestion resilience among the highest-congestion regions include: lower shares of congestion-sensitive industries, road network density and redundancy, the critical role of freeways, the importance of improving transit services, and a polycentric spatial structure.

7.3.1. Background Comparisons

These four MSAs are significantly different from the other metropolitan areas in the dataset and from other U.S. cities generally, as shown in Table 8 (page 137). While there are some background differences between CR and CUR MSAs, the largest differences are between these four above-threshold MSAs and other U.S. metropolitan areas among the 88 in the dataset. The four study MSAs are more populous, have higher population densities (except Houston), are generally larger in terms of land area (except Los Angeles), are more diverse and rapidly becoming even more diverse than other cities, the commutes are less frequently by car (except Houston), average commute times are longer, and residents are more educated (particularly Washington, DC).

Each of the four MSAs has unique competitive advantages over others: Chicago's is the urban hub of the Midwest; Houston's has abundant land and sunshine and is relatively

less dense; Los Angeles's is the center of the entertainment industry, is diverse, and has sunshine; and Washington, DC's is relatively less dense, houses the federal government, and has an extraordinarily well-educated workforce. In fact, many of these characteristics are confirmed as competitive advantages in results from inferential statistical models in Chapters 5 and 6 (land, sunshine, and education are linked with better economic outcomes).

But based on background MSA characteristics, there are only modest differences between the two CR and two CUR MSAs: land area and demographics. Both of the CUR MSAs have significantly more land area, but the CR MSAs are somewhat more diverse. The proportion of whites is lower in CR MSAs and shrinks faster over time – with the exception of Houston, which overtakes Washington, DC in terms of the share of non-whites. Research indicates that immigrants and diversity lead to public transit use and transportation system efficiency (Blumenberg, 2009; Blumenberg & Norton, 2010) and that sprawl (insofar that a greater MSA area implies sprawl) leads to auto dependence (Cervero, 1986), but these differences are unlikely to explain the CR/CUR distinction. Moreover, contrary to the Chapter 6 findings that MSAs with older residents are linked with more congestion resilience, median age does not seem to distinguish CR from CUR MSAs and does not distinguish these four regions from others in the dataset (median ages are between 32 and 35 years in 1990 or 2000).

Table 8. Basic Characteristics of Chicago, Houston, Los Angeles, Washington, DC, and average MSA in study dataset

	Congestion Unresilient MSAs		Congestion Resilient MSAs		
	Chicago	Houston	Los Angeles	Washington, DC	Average (N=88)
Area (sq. ml.)	7,212	8,928	4,850	5,948	4,829
Population Density (/sqml)	1,135 (+127)	422 (+106)	2324 (+225)	693 (+126)	470 (+56)
Population	8,182,076 (+916,240) [+1,333,560]	3,767,335 (+948,072) [+1,959,370]	11,273,720 (+1,091,907) [+1,494,675]	4,122,914 (+749,174) [+1,255,022]	1,716,210 (+253,656) [+443,377]
DEMOGRAPHICS					
Whites	72% (-5%)	67.9% (-5.2%)	61.6% (-9.3%)	66.9% (-7.1%)	80.2% (-5.2%)
Blacks	18.9% (-0.9%)	17.8% (-1%)	9.2% (-1.4%)	25.8% (+0.2%)	11.5% (+0.3%)
Asians	3.1% (+0.9%)	3.5% (+1.3%)	10.7% (+1.6%)	4.9% (+1.7%)	3.1% (+0.5%)
Hispanic	10.7% (+5.3%)	20.3% (+8.4%)	34.3% (+7.1%)	5.4% (+3.4%)	10.9% (+3.5%)
Median Age	32 (+2)	34 (-2)	34 (-2)	32 (+3)	32 (+3)
COMMUTING					
Single-occupancy Vehicle	59.6% (+3.4%)	73.4% (+1.6%)	67.9% (+0.1%)	56.1% (+4.9%)	73.1% (+1.3%)
Transit	11.7% (-1.7%)	3.5% (-0.5%)	5.2% (-0.2%)	11.4% (-1.4%)	3.3% (-0.2%)
Mean Commute Time (min.)	33.5 (+8.9)	31 (+5.9)	31.1 (+6.2)	35.5 (+9.4)	26.7 (+5.6)
EDUCATION					
Bachelors (%)	23.4% (+5.6%)	24% (+2.0%)	23.5% (+2.5%)	37.5% (+4.5)	21.8% (+4.4%)
Masters (%)	8.4% (+2.6%)	7.6% (+1.4%)	8.1% (+0.9%)	16% (+3%)	7.6% (+1.8%)

*Values show as following: 1990 (change from 1990 to 2000) [change from 1990 to 2008, when applicable] data from U.S. Census Bureau

7.3.2. Industry Comparisons

Results from Chapter 6 suggest that some industries are more sensitive to congestion's drag (retail, wholesale, and partially manufacturing) than others (construction, finance, and real estate), and case study comparisons provide supporting evidence that these

relative industry sensitivities contribute to the difference between CR and CUR MSAs. If industries which are more sensitive to congestion represent a smaller share of regional jobs in CR MSAs compared to CUR MSAs (or vice versa), this would provide supporting evidence that regional industry makeup contributes to congestion resilience. Not all industries and less than half of all jobs are included here and those five which I discuss represent Standard Industrial Classification (SIC) codes for their respective two-digit categories.

On average, between 1993 and 2008, the two congestion resilient regions have a lower proportion of retail industry jobs (15.0 and 13.9 compared to 15.3 and 15.7 percent, see Table 9), indicating that a relatively lower proportion of jobs in this congestion-sensitive industry may contribute to congestion resilience. But while the retail share of jobs remained relatively stable in CR Los Angeles (see Figure 12), retail jobs decreased moderately as a share of total employment in each of the other MSAs (see Figure 10, Figure 11, and Figure 13). A relatively more rapid decrease in retail jobs within these high-congestion regions are to be expected based on Chapter 6 results which suggest that retailing is comparatively more sensitive to congestion's drag. Therefore both the relatively lower share of retail jobs among CR regions initially in 1993 and Los Angeles's comparatively stable retailing industry over time (implying a comparatively more congestion-resilient retail industry in Los Angeles, see Figure 12) potentially contribute to the relative differences between CR and CUR MSAs.

Table 9. Average Industry Employment Composition in Chicago, Houston, Los Angeles, and Washington, DC (1993 to 2008)

Industry	Chicago	Houston	Los Angeles	Washington, DC	Congestion Resilient Industry
Construction	5.1%	8.0%	4.3%	5.7%	Yes
Manufacturing	12.3%	8.9%	12.0%	3.3%	Short-Term No; Long-Term Yes
Wholesale	5.8%	5.5%	5.9%	2.3%	No
Retail	15.3%	15.7%	15.0%	13.9%	No
Finance, Insurance, and Real Estate	9.9%	8.1%	9.6%	7.6%	Yes
Congestion Resilient Region	No	No	Yes	Yes	

On average between 1993 and 2008, congestion resilient Washington, DC appears to have less than half the share of wholesaling jobs and manufacturing jobs as the other three MSAs (see Table 9). While the manufacturing and wholesaling industries in Chicago, Houston, and Los Angeles respectively make up more than 8.9 and 5.5 percent of regional jobs, Washington, DC's manufacturing and wholesaling sectors respectively make up approximately 3.3 and 2.3 percent of regional jobs on average, between 1993 and 2008. Thus, a smaller share of Washington, DC's economy is comprised of the comparatively more congestion-sensitive retailing and wholesaling industries. As shown in Figure 13, manufacturing job shares are only shown in Washington, DC between 1993 and 1998 due to data quality, but the manufacturing industry nevertheless represents a significantly smaller share of regional jobs compared to the other three MSAs. Most industry types are shown in Table 9 (as the component industries do not sum to 100 percent), so one potential additional explanation for Washington, DC's congestion

resilience is the comparatively stronger regional role of other industries, including the federal government. Government jobs comprise on average 21.8 percent of regional jobs between 1993 and 2008, while government jobs make up 14.6% of jobs across all 88 MSAs. Nevertheless, the share of government jobs declines from 25.0 percent of the Washington, DC economy in 1993 to 19.1 percent in 2008. In fact, with the exception of a drop in government jobs in the mid-1990s and a return to early 1990s hiring levels by the late 2000s, government jobs are relatively stable in absolute terms in Washington, DC. Instead, incremental economic growth in the Washington, DC region has been in non-government industries.

However, neither differences in construction or FIRE industries' regional job shares nor changes in these industries' relative make-ups distinguish CR from CUR industries. Both CR and CUR industries increase the share of construction and FIRE jobs between 1993 and 2008. Unsurprisingly, the construction share of regional jobs is highest in the two highest-growth MSAs (Houston and Washington, DC). While construction makes up 8.0 and 5.7 percent of jobs in Houston and Washington, DC, it represents 5.1 and 4.3 percent of jobs in Chicago and Los Angeles. In comparison, the highest share of FIRE (finance, insurance, and real estate) industries are in lower-growth and the absolutely larger MSAs of Chicago and Los Angeles, respectively with 9.9 and 9.6 percent of jobs, while the Houston and Washington, DC FIRE industries respectively represent 8.1 and 7.6 percent of jobs.

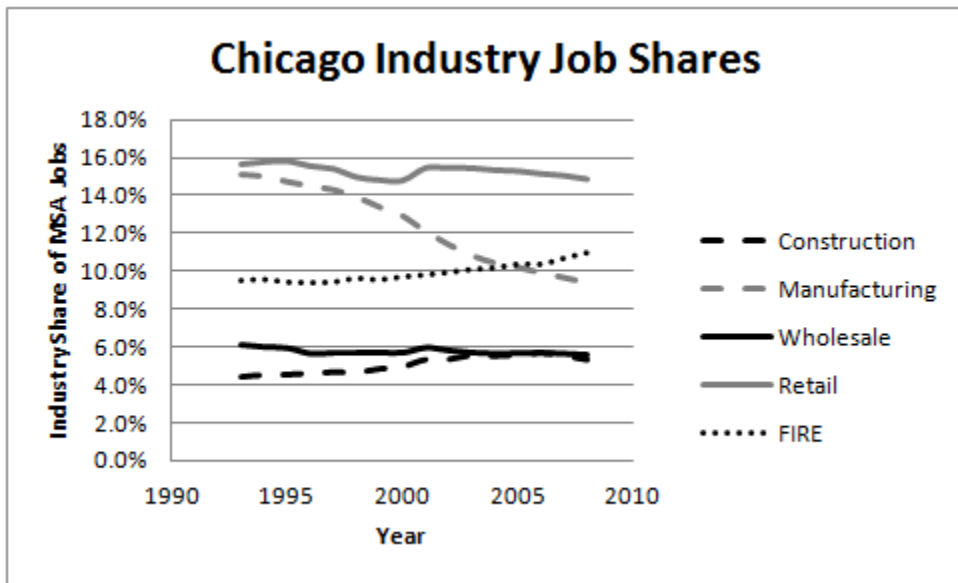


Figure 10. Chicago, IL Industry Job Shares (1993 to 2008)

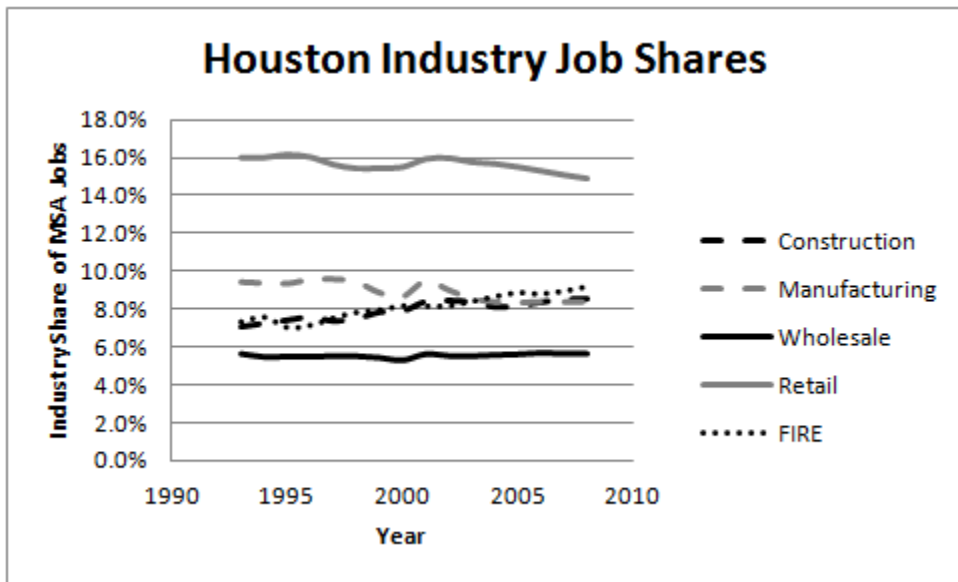


Figure 11. Houston, TX Industry Job Shares (1993 to 2008)

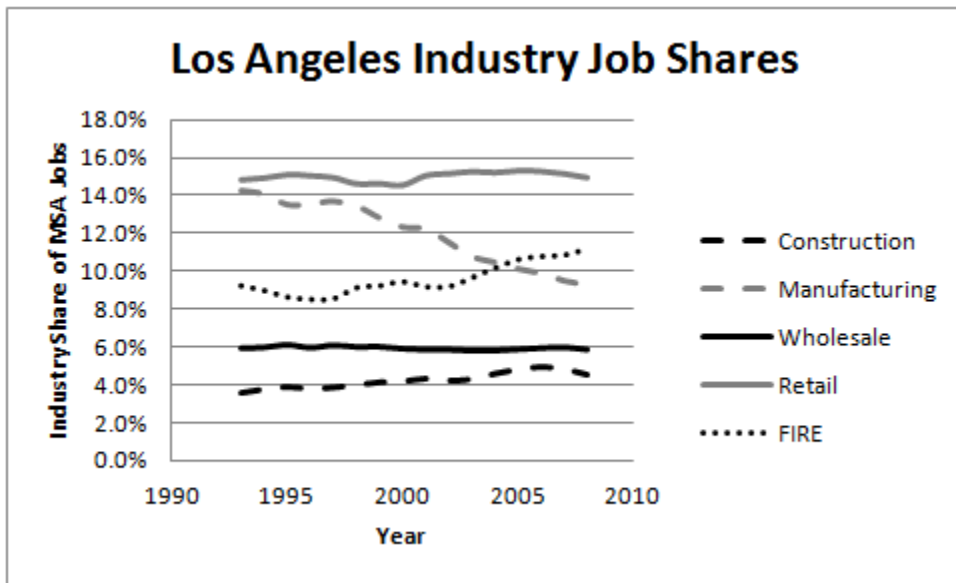


Figure 12. Los Angeles, CA Industry Job Shares (1993 to 2008)

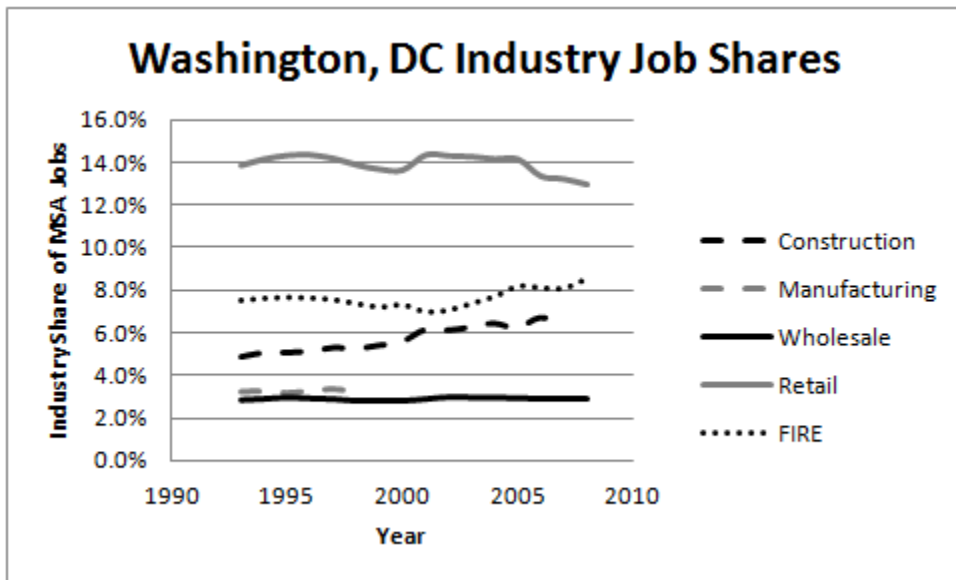


Figure 13. Washington, DC Industry Job Shares (1993 to 2008)

7.3.3. Road Transportation Policy

Next, I turn to differences in road infrastructure, services, and use which may be important distinguishing factors between CR Los Angeles and Washington, DC and CUR Chicago and Houston. Results suggest that network density, freeway services, and road use patterns each are important differentiating characteristics between CR and CUR MSAs. Moreover, network load density, a metric of relatively higher travel demand relative to network supply, suggests that CUR MSAs are relatively more congested than one would expect based simply on the relative balance of supply and demand. In contrast, higher network load densities in CR MSAs indicate high travel demand relative to road supply, implying that CR MSAs may be relatively less subject to congestion caused by inefficient spatial patterns, network designs, or transit systems.

Network Density

First, the availability of roads appears to be important in distinguishing CR from CUR MSAs, but some of the potential explanations appear to be counterintuitive. Higher network load density (more residents per road-mile), a metric of the relative balance of travel demand with road supply, appears to be important. More potential road users per unit of road, indicators of congestion because of the relative balance of supply and demand, appear to be linked with congestion resilience (see Figure 14). Los Angeles has, on average, 480 residents per road mile across all study years, while Washington, DC has 357, Chicago has 334, and Houston has 174. Changes in network load density over time

are less pronounced because the road network is generally expanded at a similar rate to background population and employment growth.

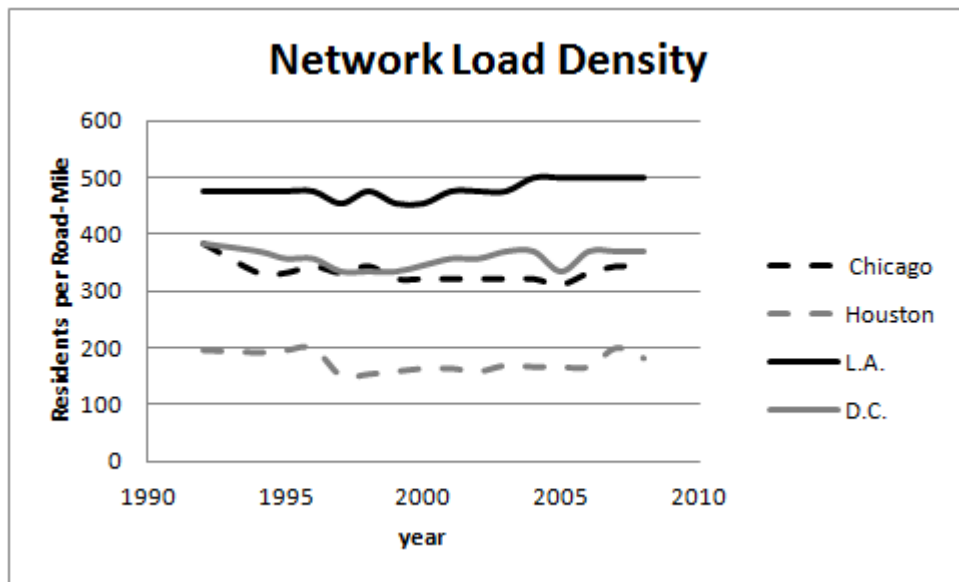


Figure 14. Road Network Load Density (residents per road-mile)

There are two (perhaps complementary) explanations why high network load density may lead to congestion resilience: one related to road service inefficiency and one related to the potential for more efficient transit service provision. Higher network load density leads to slower road travel speeds as a consequence of congestion (Chatman, 2008): if demand for road travel is higher than road supply, there is likely to be more congestion, all else being equal. Thus, to the extent that network load density is an indicator of “efficient” congestion which is not easily-avoided, a higher network load density suggests more efficient travel per unit of congestion. First, if congestion is caused by other factors unrelated to the relative balance of supply and demand (here captured as

network load density), this may indicate inefficient operations (not directly tested here), less efficient network structure, less efficient spatial structure, or dependence on and vulnerability to services on a limited set of roadways. Second, high network load density may indicate the potential to integrate higher-capacity public transit to absorb auto trips – a topic discussed in more detail in the next section.

The availability of a spatially dense road network also appears to contribute to congestion resilience. Higher network densities per unit land area appear to give Los Angeles a competitive advantage in congestion resilience, most likely by enabling substantial redundancy in the transportation system. Across study years, Los Angeles has on average 12.0 miles of roads per square mile of land, while the other MSAs have fewer: Chicago has 8.4, Houston has 10.1, and Washington, DC has 9.7. With more redundancy in the road network, this could enable system users more route choices in response to high levels of congestion on particular links and thereby allow more opportunities to adapt to congestion in order to retain high access.

But while the FHWA data indicates that Los Angeles has a significantly denser road network than the other three MSAs, differences between Chicago, Houston, and Washington are less clear due to changes in geographic boundary definitions. Between 1992 and 2008, Los Angeles has, on average, over 12 miles of roads per square mile of land area, while road densities in Houston, Washington, DC, and Chicago are 20 percent less dense or more, on average.

Freeways

Dense freeway networks also distinguish CR from CUR MSAs. Los Angeles and Washington, DC have 2.5 and 1.8 miles of freeway lane-miles per square mile of land area, while Chicago and Houston have 0.9 and 1.6 freeway lane-miles per square mile, on average between 1992 and 2008 (see Figure 15). While it appears that Washington, DC's freeway network density decreases to the level of Houston, this is largely a result of changes in the urbanized area boundary definition (see Figure 15). Freeway network densities (see Figure 15) reflect overall road network densities.

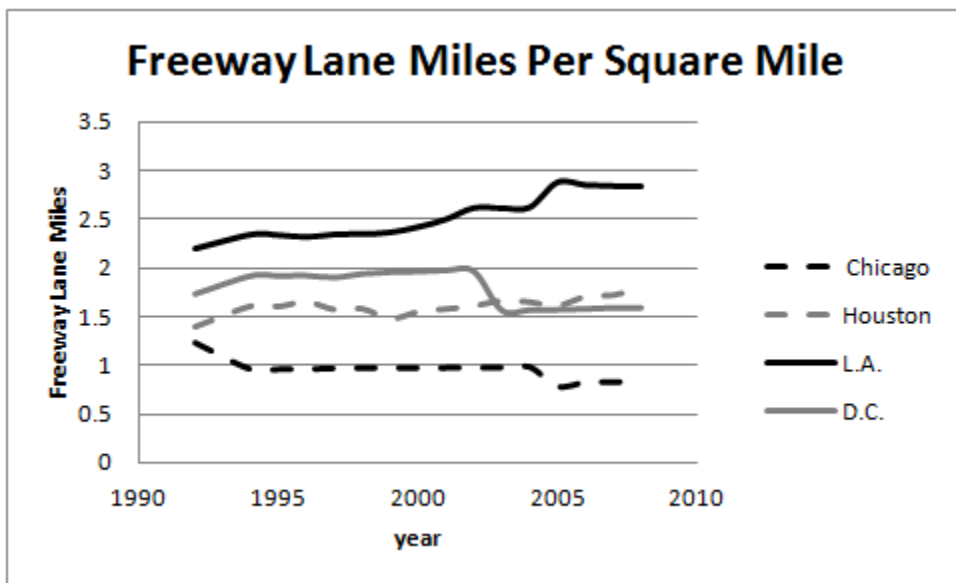


Figure 15. Freeway Lane-Miles Per Square Mile of Land Area

On average, freeways make up a higher proportion of total roadway stock in CR MSAs than in CUR MSAs. Freeways represent 2.6 percent and 3.0 percent of total road-miles in Los Angeles and Washington, DC and 2.0 percent and 2.4 percent of total road-miles

in Chicago and Houston, on average, between 1992 and 2008 (see Figure 16). Although Los Angeles is well-known for its spatially-dense freeway and general road networks, freeways actually make up a higher proportion of the total road network in Washington, DC. Both of the CR MSAs have dense freeway networks. Houston's freeway share increases substantially in 2008 – partly a consequence of new freeway construction and expansion (e.g. the Katy Freeway expansion) and partly as a result of changing urbanized area boundaries.

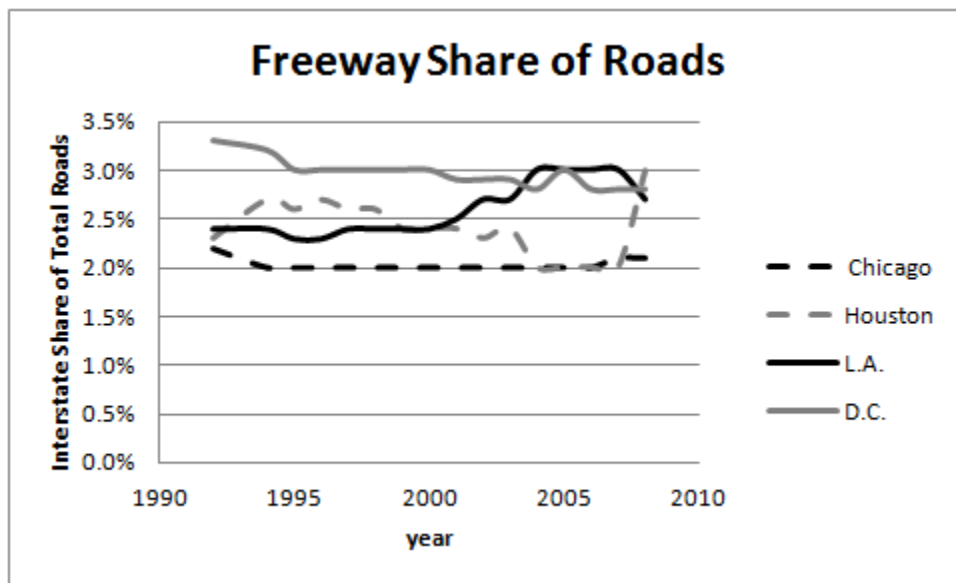


Figure 16. Share of Total Road Miles Made Up By Freeways

There are two plausible explanations why dense freeway networks may lead to congestion resilience: one related to measuring congestion and another related to road capacity. First, the Texas Transportation Institute's Urban Mobility Report uses delay relative to free-flow speeds to measure congestion. But this metric does not represent

mobility, road services, or access in a more absolute sense. Thus, since freeway free-flow speeds are much higher than arterials or collectors, one could have significantly higher levels of road delay on freeways despite similar travel services. For example, if one is traveling 30 miles per hour, on average, on either a freeway or an arterial, metrics of delay would be much higher for the freeway although the average speeds would suggest much more comparable absolute service levels. This would suggest that congestion resilience is partly a matter of focusing on absolute service levels and not on less-realistic free-flow service expectations.

Second, compared to other road classes, freeways (and higher functional classes, generally) carry more vehicular capacity even on a per-lane basis. For example, according to the 2000 Highway Capacity Manual, the base capacity (unadjusted by lane widths, speeds, demographic, or environmental assumptions) is 2,400 vehicles per lane per hour for freeways, 2,200 vehicles per lane per hour for highways, and 1,900 vehicles per lane per hour for arterials (Transportation Research Board, 2000). Freeways and arterial networks and lanes may both be congested, but the value of freeways in sheer travel capacity may enable more activity and function – all else being equal. In this case, the advantage for CR MSAs would accrue through higher road capacities and service capacities despite spatial and network constraints within the urban environment.

Houston, a CUR MSA, also has a relatively dense freeway network (see Figure 15, page 146) – particularly on a per capita basis (see Figure 17). Houston policymakers invest

substantially in new freeways, add road capacity, and use pricing or carpooling incentives to manage travel lanes (Burris & Stockton, 2004). Houston has almost twice as many freeway lane miles per capita as any of the other three MSAs. On average, Houston has 0.92 freeway lane-miles per 1,000 residents, while Chicago, Los Angeles, and Washington, DC each have 0.34, 0.44, and 0.52 freeway lane-miles per 1,000 residents, on average, between 1992 and 2008 (see Figure 17).

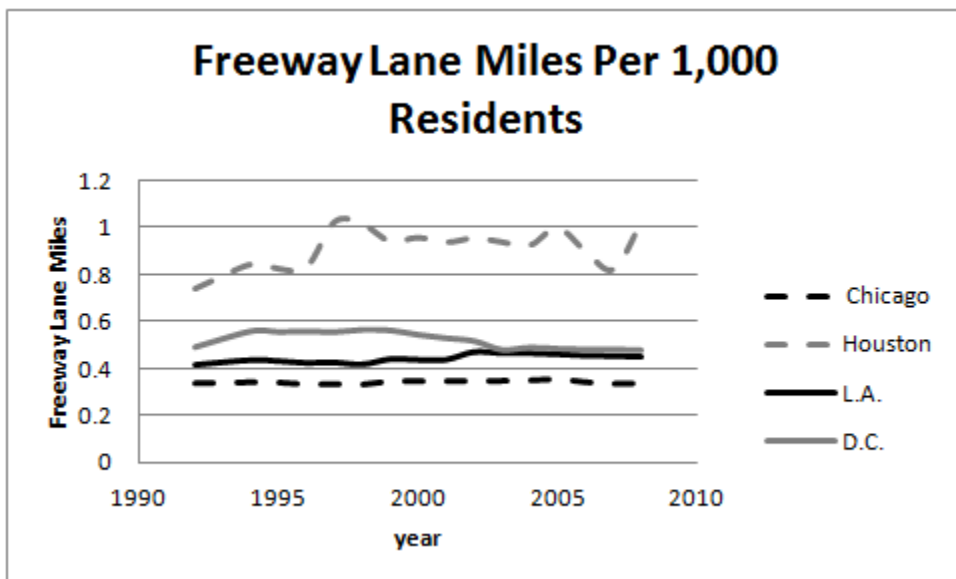


Figure 17. Freeway Lane-Miles Per Capita (per 1000 residents)

But there are several reasons why, despite its freeways, Houston may not share the same freeway advantages as Los Angeles and Washington, DC. Based on the available data, there is some question about the extent to which Houston's freeway network density per

unit area actually caught up with Washington, DC (see Figure 15, page 146). The definitions of Houston's urbanized area boundary changed several times between 1992 and 2008, while Washington's expanded by over 40 percent (leading to lower metrics of roads per area) in 2004. These effects cannot be separated with the available data.

Significant Houston freeway expansions are finished in 2003, 2006, and in 2008 with the Katy Freeway expansion. Therefore, the largest increases in the spatial density of the freeway network (measured as freeway lane-miles per square mile) and the implicit network benefits likely do not accrue until very late in (or after) the study timeframe.

Houston's freeway network is substantially more expansive than those of the other MSAs on a per capita basis (see Figure 17), but as the network is not as spatially dense and general population densities are significantly lower across the region, there may not be sufficient network redundancy to enable additional choice and adaptation by road system users. This is perhaps why Houston has historically turned to managed lanes using high-occupancy/toll (HOT), high-occupancy vehicle (HOV), or bus rapid transit (BRT) systems (Burriss & Stockton, 2004; Burriss, Konduru, & Swenson, 2004) to enable service choice on the freeway even if other road or transit alternatives are less competitive. In fact, an extensive and spatially-dispersed freeway network may lead residents to become relatively dependent on high-capacity freeways with relatively few alternatively competitive travel routes and travel options to accommodate additional productivity and employment growth.

Road Use

Road use patterns also distinguish CR from CUR MSAs. The two CR MSAs have spatially denser travel demand (see Figure 18), indicating “normal” sources of congestion (more travel per unit of land area or per unit of road supply). Thus, although these four MSAs may have relatively comparable congestion levels, road use (and implicitly congestion) is more geographically constrained in the cases of Los Angeles and Washington, DC. As discussed above in the context of network load potential (see page 143), fewer roads per capita or per unit land area directly translate into the root cause of congestion: high travel demand despite geographic and road capacity limits. Thus, spatially dense road use among CR MSAs implies that other spatial structure inefficiencies or network inefficiencies are comparatively less important in causing congestion.

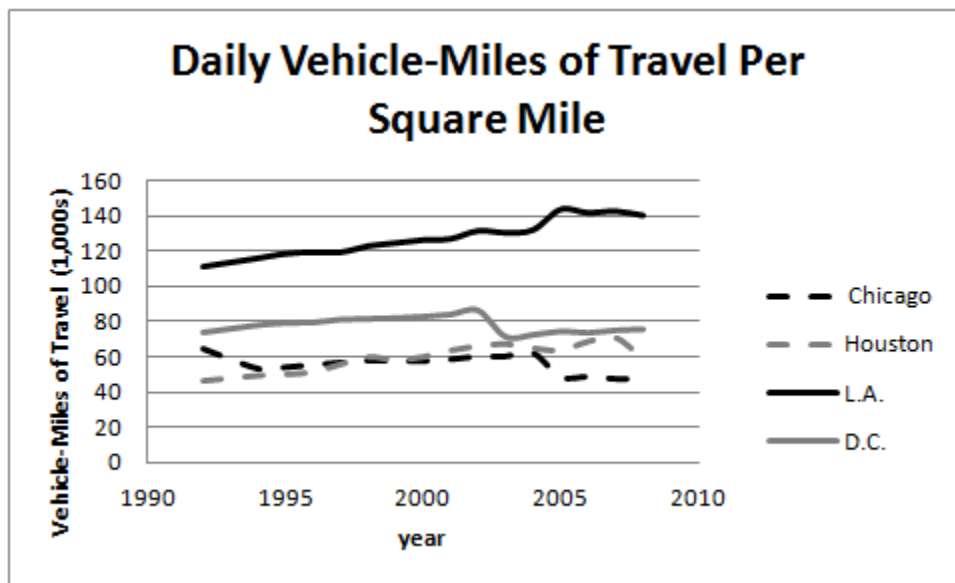


Figure 18. Daily Vehicle-Miles of Travel per Square Mile

Road use patterns unique to Houston and Los Angeles also contribute to these two MSA's respective congestion unresilience or resilience. Houston residents depend heavily on freeways and automobility. Houstonians travel by automobile approximately 50 percent further per capita (see Figure 19) and use freeways 50 percent more than the other three MSAs (see Figure 20), while the freeway-share of total road travel is comparably high to only Los Angeles (see Figure 21). As already shown in Table 8 (page 137), Houstonians are significantly more likely to commute to work by car. In sum, more auto use and higher driving intensity among Houston travelers likely lead this MSA to be significantly more vulnerable to traffic congestion. Passenger and freight system users can adapt by switching departure times and by consolidating activities in

other manners, but, relative lack of network redundancy and less efficient automobile-dependent spatial arrangements may leave Houston travelers with fewer choices and potential means to adapt to congestion.

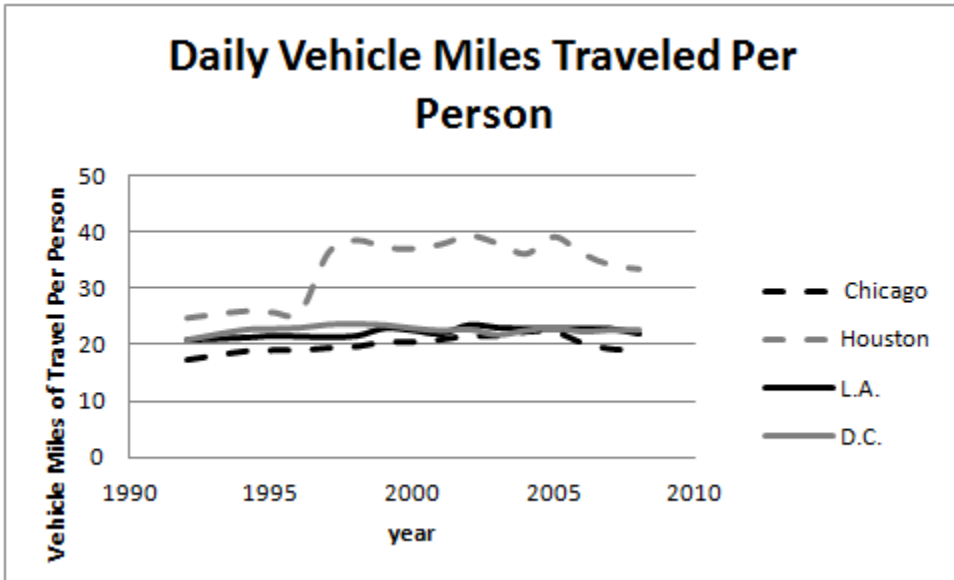


Figure 19. Daily Vehicle Miles of Travel (DVMT) Per Person

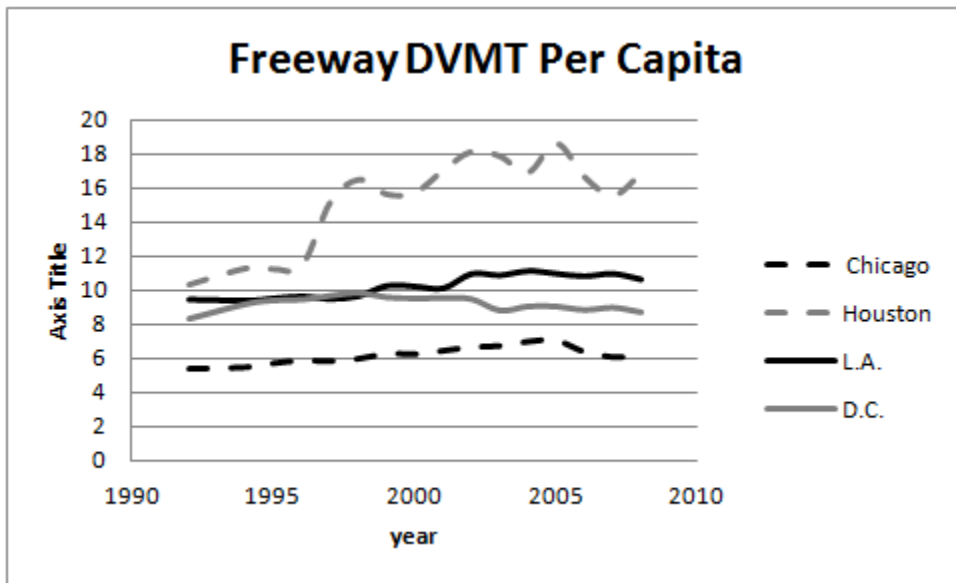


Figure 20. Freeway Daily Vehicle Miles of Travel (DVMT) Per Person

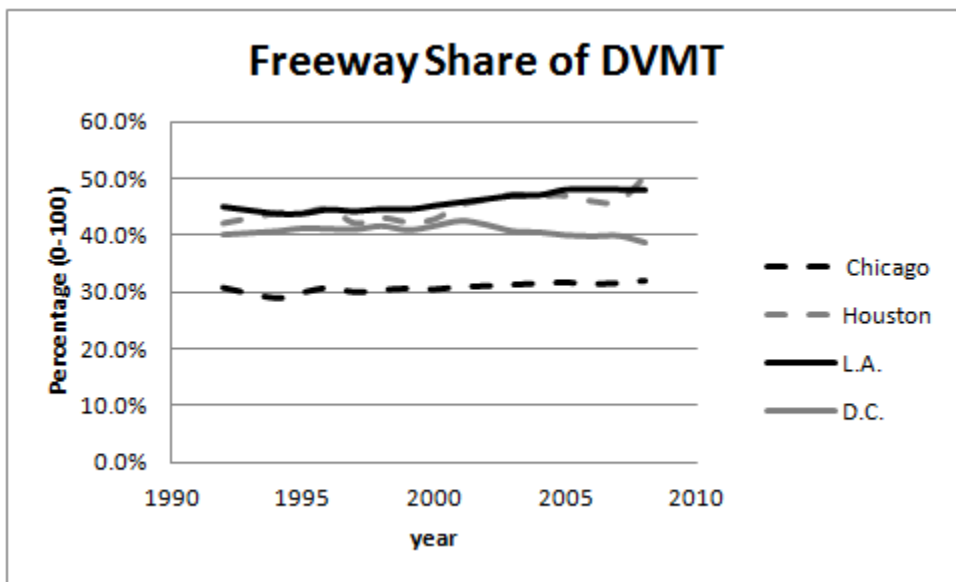


Figure 21. Freeway Share of Total Daily Vehicle Miles Traveled (DVMT)

In contrast, while Los Angeles transportation system users also depend heavily on freeways (see Figure 21), they are served by a highly-dense and redundant network which

is approximately 30 percent more productive on a per-lane basis than in any of the other MSAs (see Figure 22). Average daily traffic (ADT) on Los Angeles's freeway network is over 23,000 vehicles per lane-mile, while ADT in Chicago, Houston, and Washington, respectively are 18,300, 16,700, and 17,800 vehicles per lane-mile.

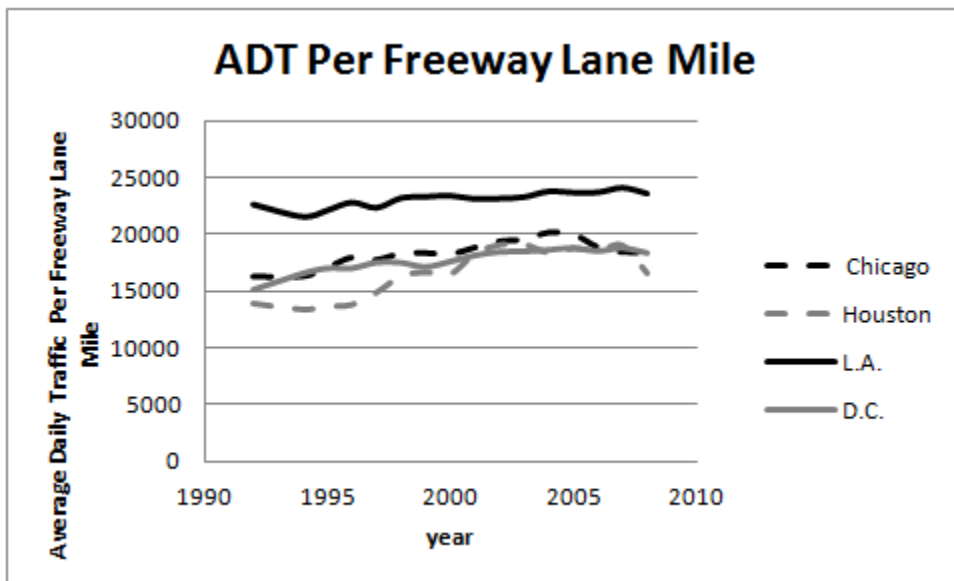


Figure 22. Freeway Productivity: Average Daily Traffic (ADT) Per Freeway Lane Mile

The significantly more productive Los Angeles freeways suggest congestion resilience through aggregate travel demand shifts towards non-peak hours and across all network links. Nevertheless, it is unclear whether unique conditions to Los Angeles have enabled these adaptations and high levels of road productivity. In fact, it is conceivable that by providing alternate travel modes (including transit or walkability) before congestion is sufficiently chronic and thereby avoiding a transportation culture engrained in road congestion experience, other MSAs may never realize Los Angeles's road productivity

benefits. On the other hand, to the extent that a driving culture based in congestion-experience may be personally undesirable to some, the efficiency benefits of highly-productive roads must be weighed against considerations for quality of life.

7.3.4. Transit Policy

Improving transit mobility services and increasing transit use are also distinguishing factors between CR and CUR MSAs. The share of total mobility provided by transit use increased for CR MSAs, while it declined or remained flat for the two CUR MSAs. Los Angeles and Washington, DC, respectively increased the transit share of motorized mobility by 0.8 percent and 0.6 percent between 1992 and 2008, while Chicago remained flat and Houston decreased the transit share of motorized mobility by 0.4 percent (see Figure 23). Three key distinguishing sub-factors appear to be the most important in transit service provision: improving and expanding transit services over time, establishing highly-competitive transit services, and attracting riders.

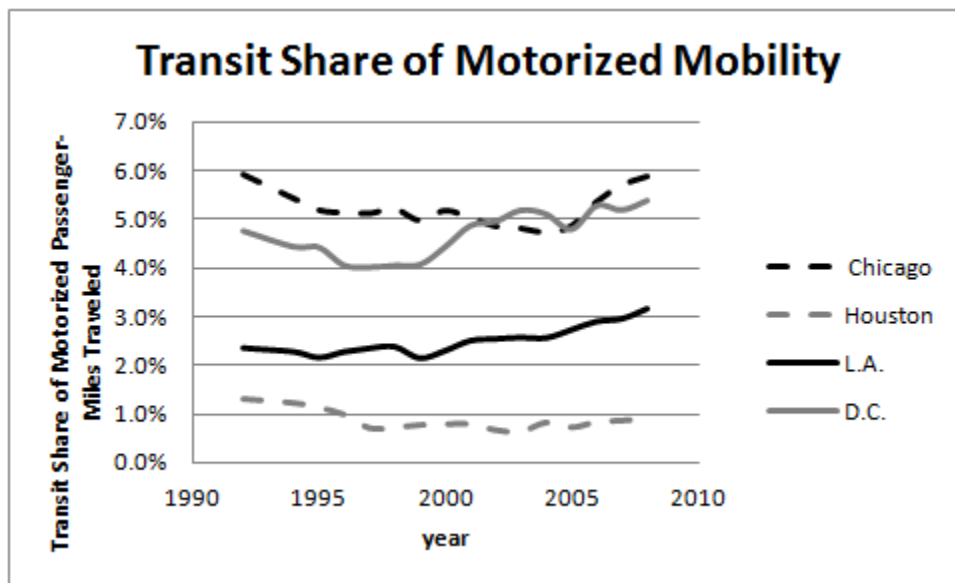


Figure 23. Transit Share of Motorized Mobility (miles of travel)

Expanding Transit Services

Both Los Angeles and Washington, DC substantially expand their rail and bus networks and improve transit services. In comparison, Chicago and Houston expand rail services modestly bus services grow more slowly than background population growth, thereby reducing transit service competitiveness. Although Chicago provides substantial transit services throughout the study timeframe, service providers in Washington, DC and Los Angeles significantly expand, providing additional alternatives to auto use for incremental travel demand. Houston expands its rail transit services but does not expand the overall capacity of its system on a per-person basis, leaving transit serving a relatively small traveler market with high travel times and long trip distances.

On a per capita basis, the total transit service expansions (all modes) are much more rapid in Los Angeles and Washington, DC between 1991 and 2008 than in Chicago and Houston, the two CUR MSAs. The two CR MSAs do not have the highest transit services, but vehicle operation increases more rapidly (see Figure 24). Chicago provides more vehicles operated in the maximum service (VOMS) period per MSA resident than the other MSAs between 1991 and 2008 largely because of the significantly higher levels of rail capacity (over 2 vehicles per 10,000 residents, as shown in Figure 25). However, as shown in Figure 26, the growth in VOMS per capita is highest for Los Angeles and Washington, DC primarily because of growth in bus services (0.64 and 0.11 additional vehicles per 10,000 MSA residents), as opposed to shrinking services in Chicago and Houston (0.31 and 0.52 fewer vehicles). Rail VOMS in Los Angeles and Washington, DC also increase more rapidly (0.23 and 0.48 additional vehicles per 10,000 MSA residents) than in Chicago and Houston (0.09 and 0.03 additional vehicles), as shown in see Figure 25.

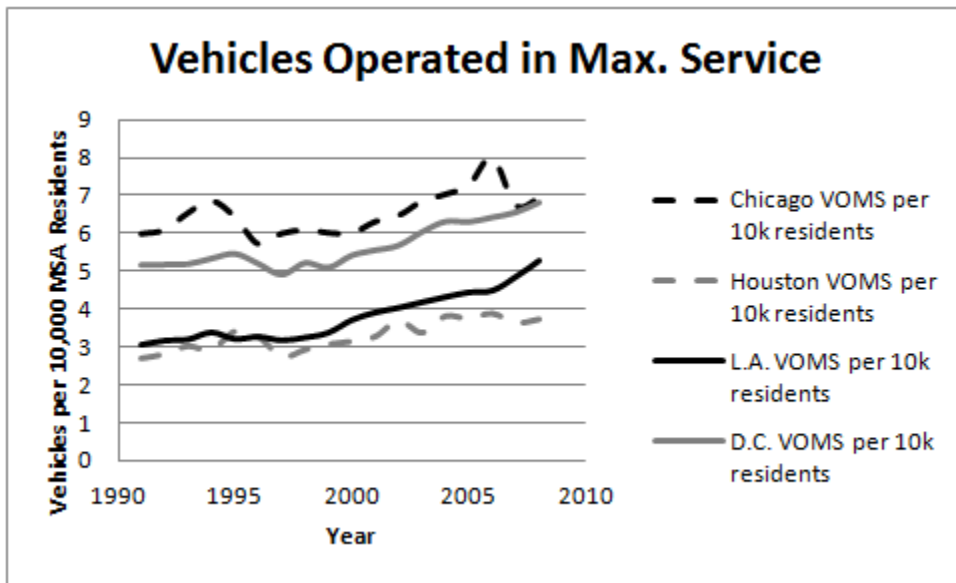


Figure 24. Transit Vehicles Operated in Maximum Service Period

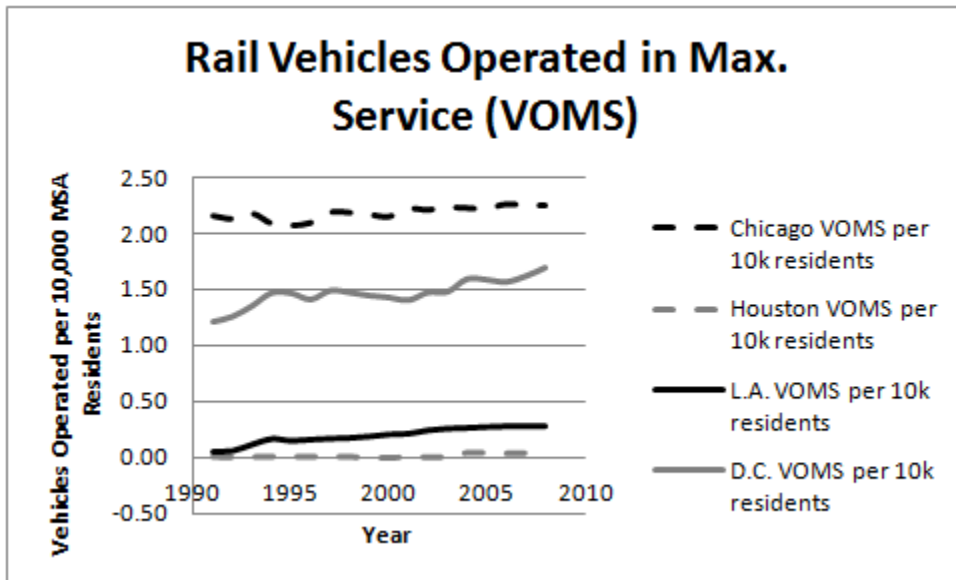


Figure 25. Rail Transit Vehicles Operated in Maximum Service Period

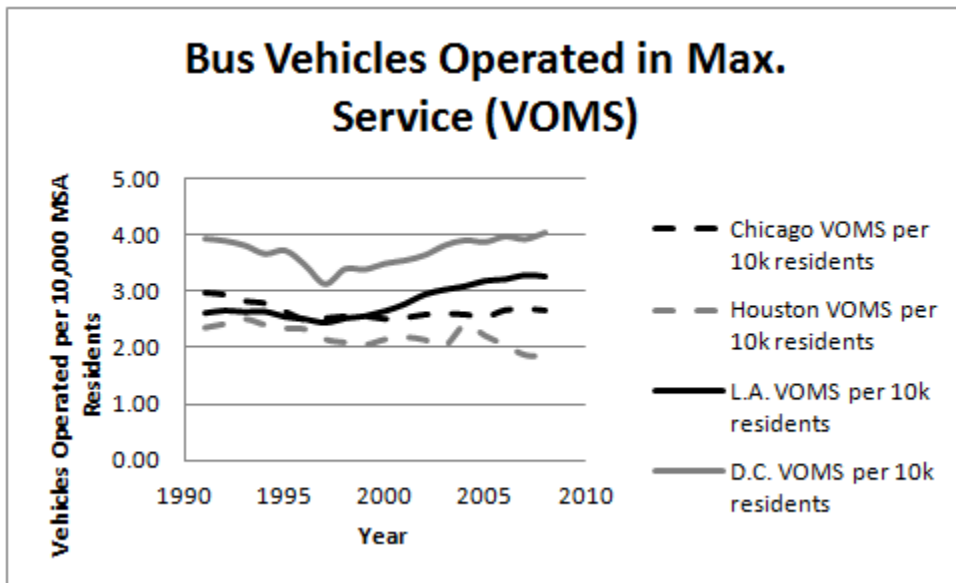


Figure 26. Bus Transit Vehicles Operated in Maximum Service Period

Likewise, Los Angeles and Washington, DC have significant growth in vehicle revenue-miles (VRM) of service per MSA resident per year (7.6 and 10.5 additional VRM per capita), while Chicago and Houston remained relatively flat (2.5 and 1.7 additional VRM), as shown in Figure 27. Measures of VRM per capita provide an indication of the quantity of transit mobility services provided within a region. In fact, by 1999 and 2003 Washington, DC overtakes Chicago in providing more total and more rail VRM per resident. Bus service expansions are the primary reason for the CR/CUR disparity in VRM growth. By 1997, Los Angeles and Washington, DC overtake Chicago and provide more bus VRM per resident. The CR MSAs each increase bus services by 2.0 VRM per resident between 1991 and 2008, while Chicago and Houston decrease bus services by 1.5 and 1.7 VRM per resident. In the case of Chicago, this reduction is a function of both more residents and bus service cuts, while in Houston, services increased at a

significantly slower rate than population growth. But Los Angeles and Washington, DC also expand rail services faster (1.8 and 4.7 additional VRM per capita) than Chicago and Houston (1.2 and 0.2 additional VRM).

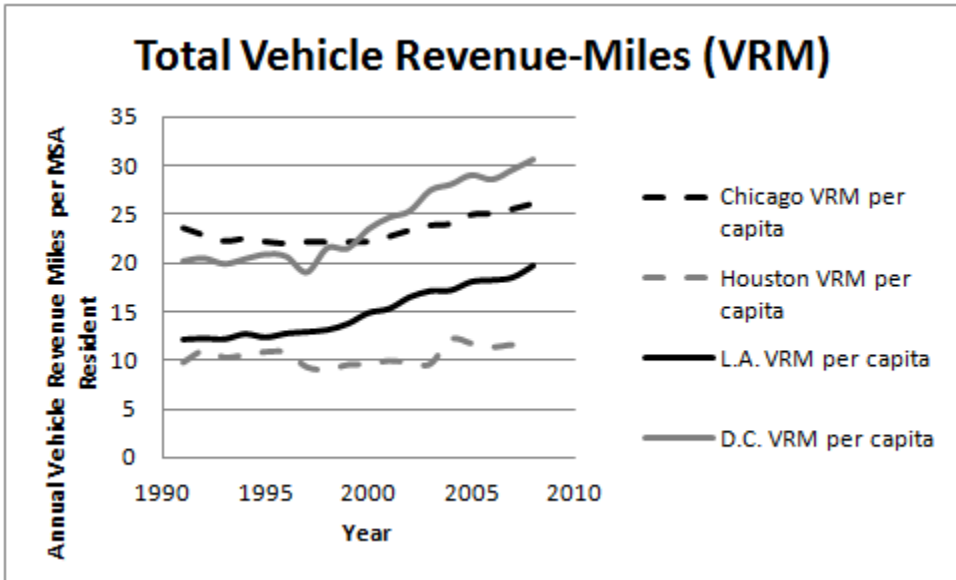


Figure 27. Transit Vehicle Revenue Miles Per MSA Resident

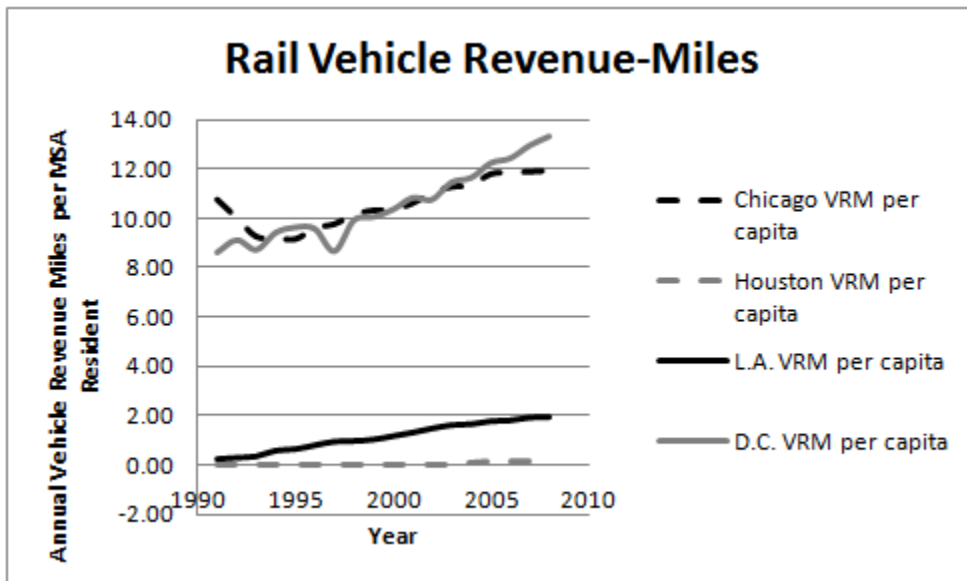


Figure 28. Rail Transit Vehicle Revenue Miles Per MSA Resident

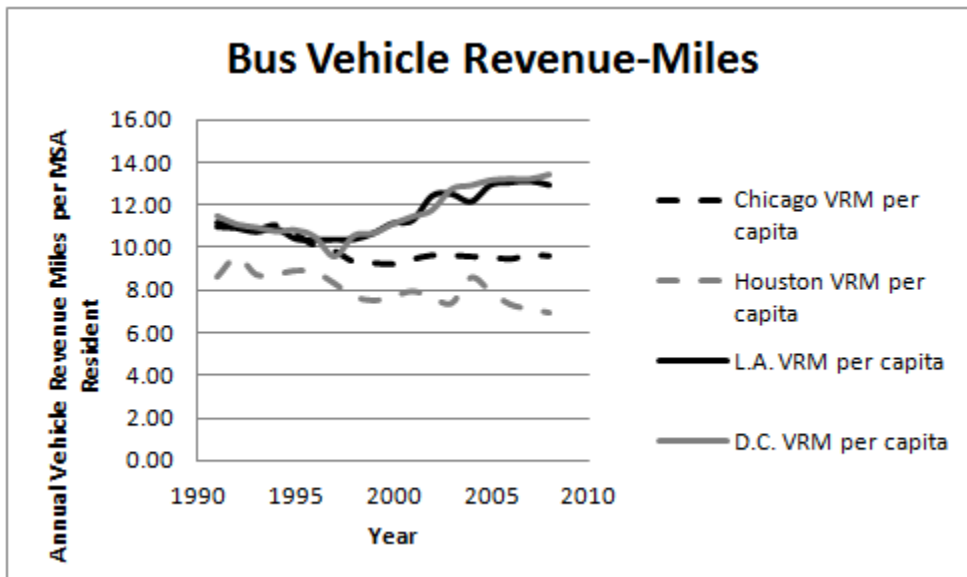


Figure 29. Bus Transit Vehicle Revenue Miles Per MSA Resident

Improving Transit Service Competitiveness

Improvements in transit speed and travel times are also distinguishing factors between CR and CUR MSAs. But while bus speeds and travel times remain relatively stable

across all regions, rail service improvements in CR MSAs are most pronounced. The transit expansion and changes in vehicle fleet composition in Los Angeles and Washington, DC leave these two CRMSAs with the fastest average rail transit services (see Figure 30) and the shortest average transit travel times for unlinked trips (see Figure 32). Although Chicago and Washington, DC share the competitive advantage in rapid rail service in the early 1990s, average speeds in Chicago deteriorate, while Washington, DC speeds remain stable and Los Angeles speeds improve (see Figure 30). Houston's rail services, on the other hand, are very slow (less than 15 miles per hour, on average) and less competitive. Bus service speeds do not change noticeably between 1991 and 2008 for any of the MSAs (see Figure 31). In fact, Houston consistently provides the fastest bus service partly due to its comparatively extensive system of Bus Rapid Transit (Burriss & Stockton, 2004; Cervero, 1998).

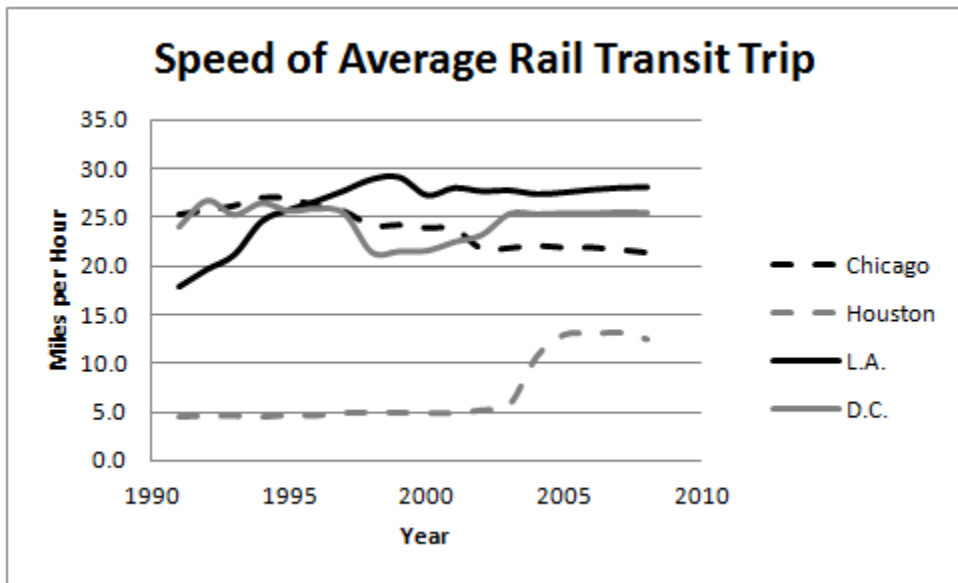


Figure 30. Rail Transit Average Speeds

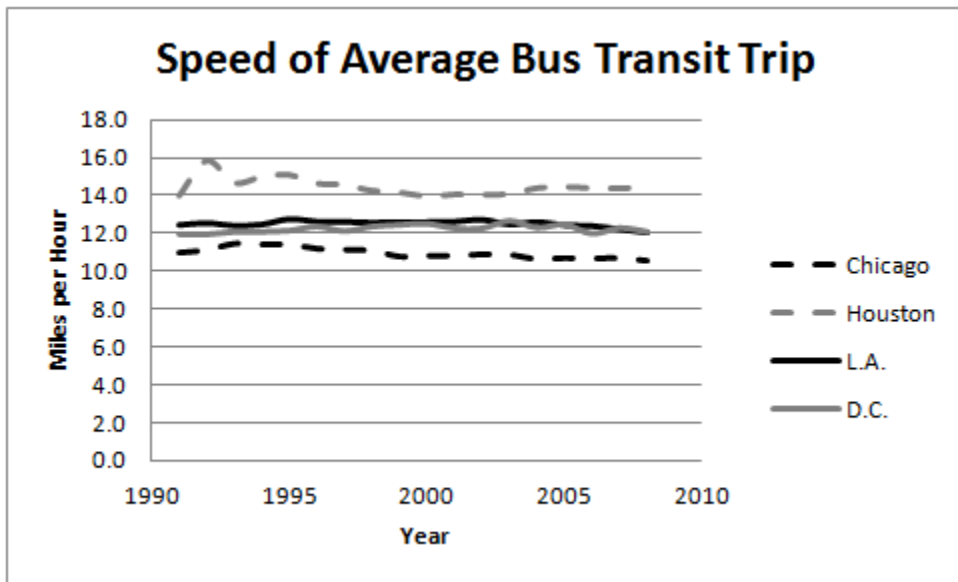


Figure 31. Bus Transit Average Speeds

Likewise, there are differences between CR and CUR MSAs in public transit travel times. Across all transit modes, Los Angeles and Washington, DC average travel times

for unlinked trips are approximately 20 minutes by 2008, while in Chicago and Houston, average travel times are slightly higher at 22 and 25 minutes, respectively (see Figure 32) – largely because of longer trip lengths. But while Chicago’s travel times Unlinked trip travel times do not directly measure total travel times, which would also include access, egress, and transfers. Instead they are broad indicators of travel time services, particularly if transfer rates and station access are comparable across MSAs.

Average travel times are the shortest across all modes for the two CR regions (see Figure 32), but differences across mode persist. Chicago rail travel times are very long, while Houston’s rail travel times decrease dramatically over the study timeframe. Houston rail services remain just over half the speed of any of the three other MSAs, but its travel times are competitive (at least for its limited market) because of relatively shorter trip distances. Because of short unlinked trips, bus travel times are lowest in Chicago in spite of the slowest speeds, while in spite of the fastest bus service, Houston’s bus travel times for unlinked trips are significantly higher (see Figure 34) due to longer trip distances. Nevertheless, some of these comparisons are imperfect. For example, Houston’s Bus Rapid Transit system is more comparable to commuter rail in other regions (longer times at faster speeds) than to traditional urban bus systems.

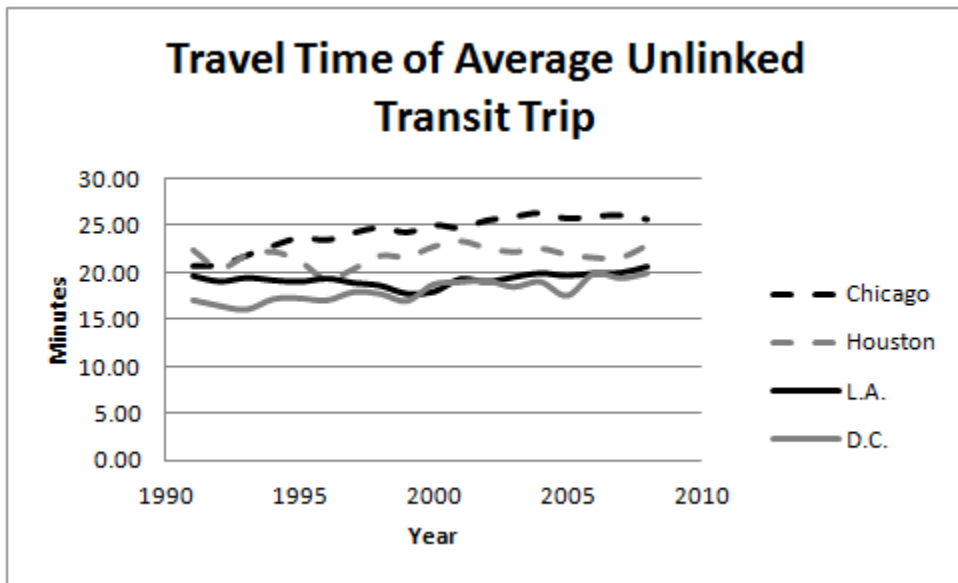


Figure 32. Travel Times of Average Unlinked Transit Trip

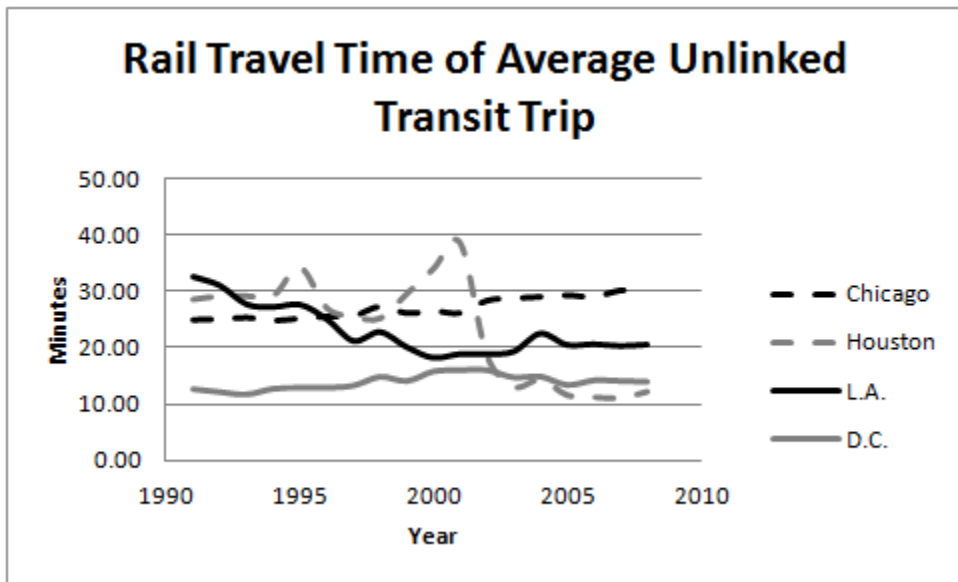


Figure 33. Travel Times of Average Unlinked Rail Transit Trip

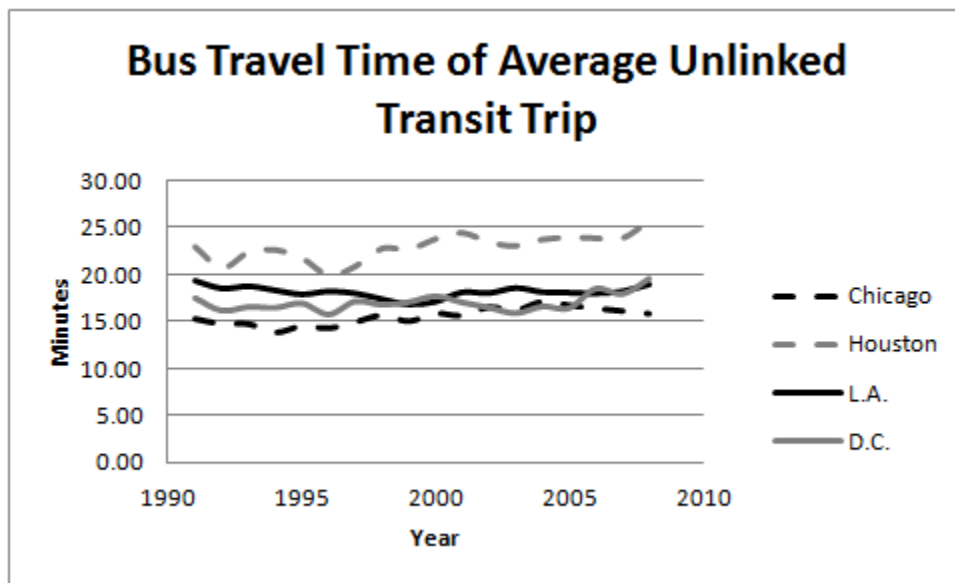


Figure 34. Travel Times of Average Unlinked Bus Transit Trip

Transit Use

Los Angeles and Washington, DC's significant transit service improvements also translate into higher rates of transit mobility consumption per capita and in absolute terms. Total transit passenger miles of travel (PMT) increase in Los Angeles and Washington, DC (by 56.6 and 56.4 percent), while total PMT growth is more modest in Chicago and Houston between 1991 and 2009 (13.7 and 28.4 percent), as shown in Figure 35). Growth in total unlinked passenger trips (UPT) is also higher in Los Angeles and Washington, DC (30.4 and 29.8 percent) than in Chicago (2.6 percent decrease) and Houston (3.4 percent growth).

In absolute terms, these increases in transit use between 1991 and 2009 translate into significantly faster growth in rail use within CR MSAs and stability in bus use in CR

MSAs compared to shrinking bus use in CUR MSAs. Los Angeles and Washington rail PMT grow faster (901 and 811 million additional annual miles) than in Chicago and Houston (702 and 27 million miles), as shown in Figure 36. Los Angeles and Washington rail UPT also grow faster (97 and 112 million additional trips) than in Chicago and Houston (64 and 12 million trips). In contrast, bus use grows more in Los Angeles and Washington, DC (175.3 and 95.1 million annual PMT) than in Chicago (274 million fewer miles) and Houston (19.4 million additional miles), as shown in Figure 37. Bus trip making in Los Angeles (61.8 million additional UPT) and Washington, DC (0.7 million fewer UPT) is also more stable than in Chicago and Houston (84.0 and 12.3 million fewer UPT).

The changes in transit mode use patterns represent shifts among all four MSAs from bus to rail transit on a per capita basis (see Figure 37), but not on an absolute basis, as noted in the previous paragraph. Total transit PMT per person increase more in Los Angeles and Washington, DC (69 and 80 additional miles annually) than in Chicago (14 additional miles annually), or Houston (8 fewer miles annually). Rail PMT grow faster in Los Angeles and Washington, DC (69 and 95 additional miles annually per resident) than in Chicago and Houston (48 and 5 additional miles). Bus PMT per resident decrease in all of the MSAs, but shrink more slowly in Los Angeles and Washington (11 and 22 fewer miles per resident) than in Chicago and Houston (40 and 26 fewer miles per resident).

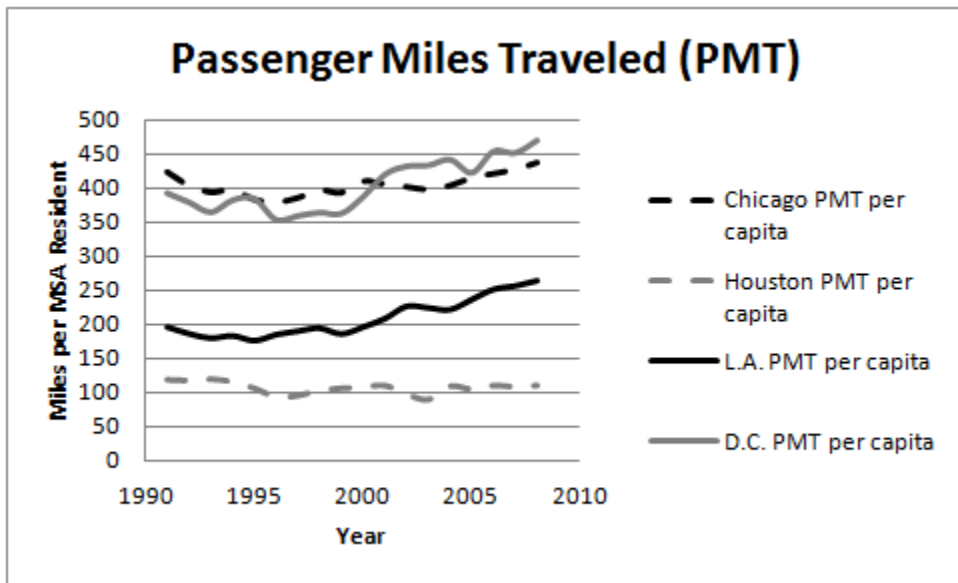


Figure 35. Transit Passenger Miles Traveled Per MSA Resident

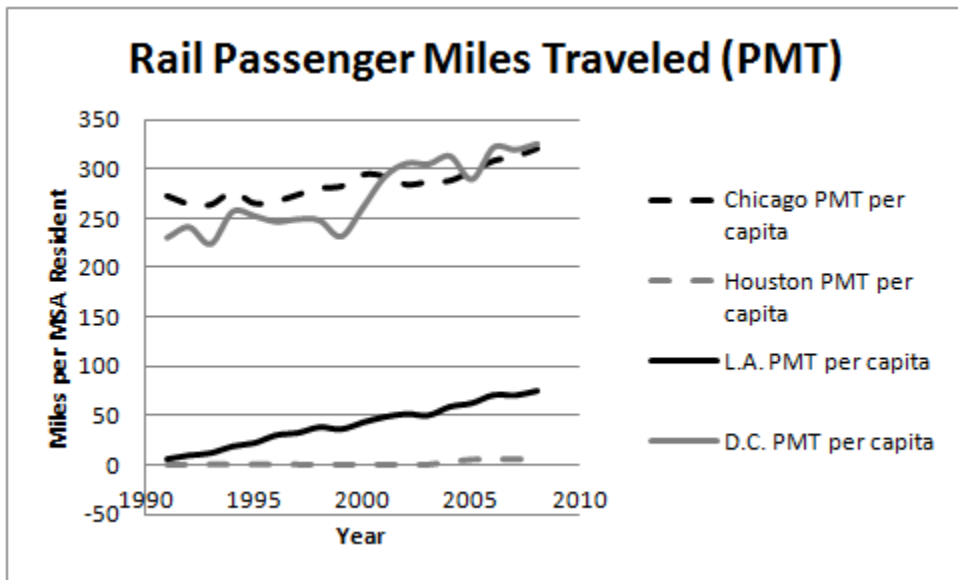


Figure 36. Rail Transit Passenger Miles Traveled Per MSA Resident

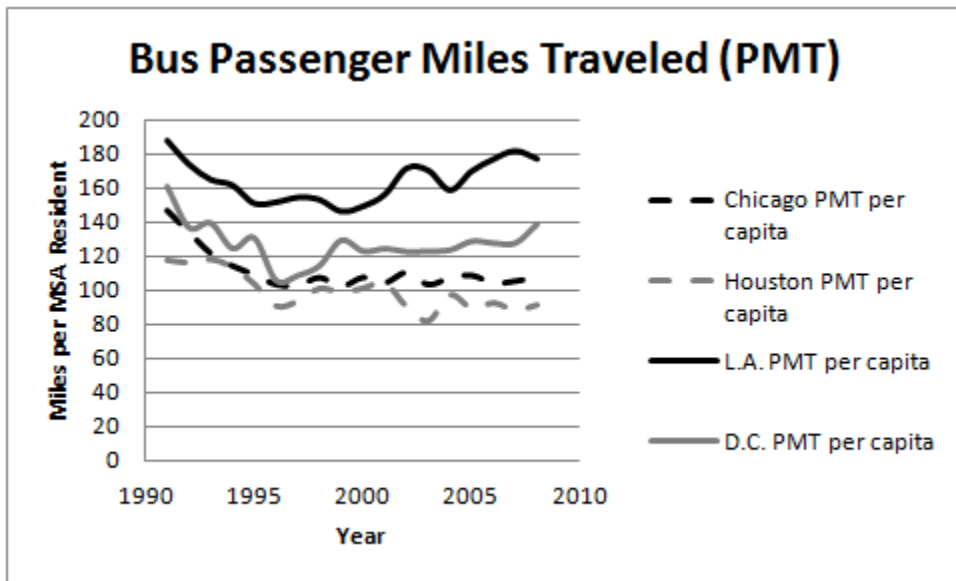


Figure 37. Bus Transit Passenger Miles Traveled Per MSA Resident

It is challenging to separate the independent influences of bus service improvements and use from rail service improvements and use as means of fostering congestion resilience. Absolute comparisons of bus and rail use suggest that most new transit use is by rail, while bus use grows either moderately (Los Angeles and Washington, DC), remains stable (Houston), or shrinks (Chicago). Congestion resilient MSAs expand bus services significantly more, but service expansions appear to yield only modest ridership growth. In contrast, CR MSAs expand rail services more than CUR MSAs, leading to significant ridership increases.

7.3.5. MSA Spatial Structure

Road and transit policy and services appear to distinguish CR from CUR MSAs among those with high regional congestion, but spatial structure and supporting land use patterns are also important. What spatial form is more efficient for congestion resilience? The answer depends on the level of regional congestion. Results from Chapter 6 suggest that when pooling the 88 study MSAs of varying congestion levels, job-housing balance and spatial concentration are predictors of regional congestion resilience. But when exploring spatial structure distinctions between CR and CUR MSAs among four with among the highest regional congestion levels, the key difference is polycentricity.

Each of the four MSAs is relatively more polycentric than most others, but the CR MSAs have more employment subcenters (particularly on a per capita basis) which cumulatively make up a larger share of the region's total employment. Thus, agglomeration benefits do not only appear to be realized near the central business district (CBD), but also at other urban and suburban employment centers. I explore differences between the CR and CUR MSAs, focusing on the spatial structure of each MSA in 1990 according to both monocentric and polycentric model expectations of spatial arrangement.

Monocentric Models of Spatial Structure

First, comparisons of monocentric job-density and population-density model estimates for each MSA indicate substantial differences⁵. The monocentric model estimates both the expected job or employment density at the city center (the CBD) and the rate of density decrease as a function of distance from the center. Together the CBD density and density gradient provide a density profile for urban areas, assuming that the center is the most important node of activity. Actual CBD job densities are significantly higher than the model estimates (see Table 10) because the monocentric model fit is not only based on central density, but also on surrounding areas and the density gradient. Los Angeles has the densest CBD, with over a million workers per square mile at the center, Chicago is second densest with almost half a million workers per square mile, while Houston and Washington, DC CBD densities are each just under 200,000 jobs per square mile. While Los Angeles is highly-dense and has a relatively flat job density gradient, Chicago is also very dense but has a much steeper job density gradient. In comparison, Washington, DC and Houston have relatively less dense CBDs, while their job density gradients are relatively similar. For three metropolitan areas, one would expect job density to decrease by approximately 13 percent to 16 percent for each one-mile distance from the CBD. In

⁵ Results from the monocentric job-density and population-density models are explained in Appendix D and estimate the density at the center and the predicted density decline as distance from the center increases.

contrast, Los Angeles has much denser suburbs and a flatter density gradient: one would expect only an 8.9 percent decrease in job density for each one-mile incremental distance from the CBD. These monocentric job model results are broadly consistent with comparable studies (Song, 1992; McMillen, 2003).

Table 10. Job and Resident Densities based on Monocentric Model and Observed Densities

	Chicago MSA	Houston MSA	Los Angeles MSA	Washington, DC MSA
Observed CBD Job Density	410,600	173,400	1,116,500	199,800
CBD Job Density Estimate	3,600	1,800	9,000	1,800
Job Density Gradient	-0.151	-0.129	-0.089	-0.157
CBD Worker Density Estimate	2,300	700	5,400	1,200
Worker Density Gradient	-0.102	-0.059	-0.078	-0.076
MSA Total Area (square miles)	7,212	8,928	4,850	5,948

** Models are estimated with Equation 16 (page 198) using Census Transportation Planning Package data for 1990.*

According to monocentric density estimates, the distribution of residents (workers) varies somewhat from those of workers. But in each case, the CBD job density is between 50 percent and 70 percent higher than the population density, with the exception of Houston, where the expected CBD job density is 170 percent higher than the population density. In contrast, the density gradients for the population and job models vary even more: the job density gradient is between 14 percent and 120 percent steeper than the population

density gradient. These differences are shown graphically in Figure 38 and demonstrate how much more dense Los Angeles is than any of the other three MSAs.

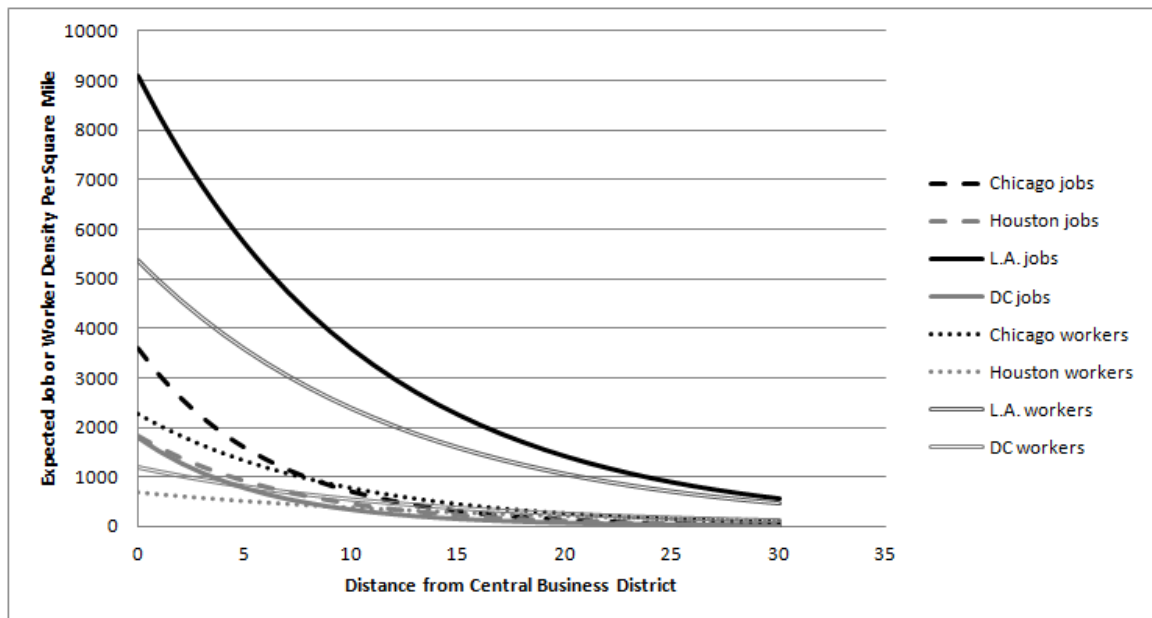


Figure 38. Estimated Job and Worker Density Profiles for Case MSAs

The monocentric expectations for spatial distributions of jobs and workers' residences do not distinguish CR from CUR MSAs. While Los Angeles and Chicago are much denser, the two MSAs which had the highest employment growth rates, Houston and Washington, DC are the two least dense in 1990. The relatively lower densities of Houston and Washington, DC are consistent with explanations of employment growth from Chapter 5, but the spatial structures in CR MSAs (particularly Los Angeles) are not consistent with regional predictors of congestion resilient employment growth from Chapter 6. While Chapter 6 had suggested that highly concentrated MSAs (steep job-

density gradients) were more likely to be congestion resilient in employment growth, Los Angeles, a CR MSA, has among the flattest job-density gradients among all study MSAs.

Subcenters in Polycentric Spatial Structure

In contrast to the regionally-scaled differences in monocentric spatial structure, clear differences emerge in terms of the numbers of employment subcenters in the two CR MSAs. According to McDonald (1987), employment subcenters are localized job clusters which impact land values and densities. The monocentric model depicts urban areas as having only one center, the CBD, but polycentric models of urban form account for additional job centers which provide alternate localized agglomeration economies that support regional function. In Table 11, I present results when estimating subcenters using definitions based on absolute density (>10 jobs per acre) and total employment thresholds (>10,000 jobs in contiguous zones). I discuss additional relativistic methods which I employ to identify subcenters in the Appendix D (see page 199); and in the research methods discussion (see page 81), I explain why I prefer these metrics for this analysis.

The CR MSAs have more employment subcenters. Los Angeles's CBD and 40 job subcenters are approximately twice as many as any other MSA in the entire dataset except New York, which has 41 subcenters in addition to its CBD. These estimates are very close to those of McMillen (2003), using similar absolute thresholds for 1990 CTPP data: Chicago (15 subcenters), Houston (8 subcenters), Los Angeles (46 subcenters), New

York (38 subcenters), and Washington, DC (10 subcenters). Differences between my findings and those of McMillen (2003) are due to the higher thresholds employed by McMillen (2003) (15 jobs per acre and 10,000 total workers) than mine (10 jobs per acre and 10,000 total workers)⁶⁶ and somewhat different boundaries – leaving my estimates somewhat higher but of comparable relative magnitudes.

Table 11. Employment Subcenter Counts and Shares of Regional Employment

	<i>Number of Subcenters</i>	<i>Subcenter Share of Regional Jobs</i>	<i>CBD Share of Regional Jobs</i>	<i>CBD and Subcenter Share of Regional Jobs</i>
Chicago	19	11%	22%	33%
Houston	7	16%	9%	25%
Los Angeles	40	34%	9%	43%
Washington, DC	20	24%	25%	50%

** These job subcenter estimates are based on density thresholds of 10 jobs per acre and total employment thresholds of 10,000 jobs in contiguous zones. Percentages do not sum because of rounding.*

A much higher proportion of regional jobs is located in the job centers (CBD and subcenters) in Los Angeles (43 percent) and Washington, DC (50 percent) than in the two CUR regions, Chicago (33 percent) and Houston (25 percent). The strongest CBD anchors are in Washington, DC and Chicago, respectively representing 25 percent (740,000 jobs) and 22 percent (1.04 million jobs) of total jobs, while Los Angeles and Houston CBDs each account for only nine percent (620,000 and 190,000 jobs) of

⁶⁶ There are infinite potential job density thresholds, but I apply a threshold of 10 jobs per acre, as it has virtually become an industry standard since the publication of Giuliano and Small (1991).

regional jobs in 1990. Subcenters (excluding the CBD) account for larger shares of total employment in CR MSAs, representing 34 percent of jobs in Los Angeles, 24 percent in Washington, DC, 16 percent in Houston, and 11 percent in Chicago. The role of the employment centers – and subcenters, particularly – appears to be much more important for CR MSAs. In fact, these differences would lead one to believe that Chicago may rely on CBD agglomeration benefits too heavily and not enough from subcenters, while Houston's dispersed spatial structure may be more conducive to congestion resilience with more concentrated employment in both the CBD and in subcenters.

Subcenters make up a larger share of the regional labor market in CR MSAs because they are more numerous. Average subcenter sizes, excluding the CBD, are comparable between Chicago (26,000), Houston (49,000), Los Angeles (58,000), and Washington, DC (35,000). Instead, CR MSAs have significantly more subcenters per person. Los Angeles and Washington, DC have on average one subcenter for every 275,000 and 200,000 people, while Chicago and Houston have one subcenter for every 400,000 and 475,000 people, on average. This indicates that on a per capita basis, there is a much greater opportunity for Los Angeles or Washington, DC residents and firms to access localized agglomeration economies than for residents and firms in Chicago or Houston.

Other studies have independently validated the potential for subcenters to generate transportation, economic, and population growth efficiencies. McMillen and Smith (2003) have empirically validated the theoretical urban economic expectation that

subcenters develop in response to population growth and increased commuting costs (congestion). Other studies indicate numerous potential benefits from employment subcenters. They are potentially conducive to transit use, and enable choices among suburban, urban, and downtown localized sources of economic agglomeration and access. Moreover, they can establish the potential to match suburban workers with increasingly suburbanizing jobs while retaining urban agglomeration benefits (McMillen, 2003; McMillen & Smith, 2003).

7.4. Discussion

Although many MSAs grow and adapt to congestion despite its potential economic drag, some gain competitive advantages by doing so in a more congestion resilient manner. I find no evidence among 88 of the largest U.S. MSAs that regions simply become more congestion resilient as a natural response to congestion experience. This is not to say that individuals and firms do not adapt in order to enable regions to continue being highly-productive centers of economic growth despite congestion; evidence suggests that they do. Instead, both firm-level adaptations and planning policies appear to be key ingredients in enabling some regions to be highly congestion resilient by more easily adapting to traffic congestion and realizing economic growth at a relatively lower “cost” in congestion growth.

Differences in industry make-up and the relative sensitivities of industries appear to distinguish congestion resilient Los Angeles and Washington, DC from congestion

unresilient Chicago and Houston. Both congestion resilient regions have relatively lower shares of total employment in retail industries, and Washington, DC appears to have significantly lower shares of employment in each of the congestion-sensitive industries (retail, wholesale, and partially manufacturing). Thus, for these high-congestion regions, “natural” adaptations to congestion through firm and worker location decisions appear to contribute to congestion resilience.

Potential policy ingredients for adapting to congestion include 1) driving more and having a greater proportion of residents bearing road gridlock (Houston), 2) using transit more frequently despite the generally-higher transit travel times (Los Angeles and Washington, DC), 3) using infrastructure more efficiently by spreading road network use throughout the day (Los Angeles), or 4) building a highly-redundant road network with which one can easily alter destinations to a variety of activity centers (Washington, DC and Los Angeles). Case comparisons suggest that in high-congestion regions, the last three of these are most conducive to better adaptation through congestion resilience – increasing the economic function of regions at a lower congestion cost.

But while these case studies suggest that transportation services and urban spatial structure are important for congestion resilient regions, these four MSAs are each stories of successful regional economies. The four MSAs’ cumulative share of U.S. employment is approximately 11 percent between 1990 and 2008. Chapter 5 evidence suggests that MSA job growth may slow in large and congested regions, but absolute

growth has not stopped in these MSAs. Each region is highly successful and attracts between 1.25 and 2.0 million jobs between 1990 and 2008. They cumulatively add 6.0 million jobs over this 18-year period, more than the entire population of Denmark. In fact, their roles in the U.S. economy are more important and not less. Their share of U.S. jobs increases over time, representing 11.3 percent of new jobs between 1990 and 2000 and 11.8 percent of new jobs between 2000 and 2008. The story of congestion resilience is thus not about whether an economy can grow despite congestion, but the qualitative function of places planners have helped create once congestion invariably follows urbanization.

CHAPTER 8. CONCLUSION

The *congestion alleviation model*, according to which congestion alleviation is a core policy objective, has long informed expensive public sector transportation programs even though existing policy portfolios have been unsuccessful at alleviating congestion (Winston & Langer, 2006). But existing research on congestion has largely ignored the link between congestion and more fundamental second-order objectives and outcomes, including economic activities, opportunity, and equity. My research contributes to filling this gap by using the *accessibility planning model* – according to which transportation services and policy should support social needs – as a guide in estimating congestion’s impact on economic outcomes and the capacity for policy to mediate congestion’s potential drag. This dissertation estimates the conditions under which congestion is a drag on the economy (Chapter 5), explores potential policies which can contribute to *congestion resilience* (better adaptation by enabling more economic growth at a relatively lower “cost” in congestion growth) across MSAs with different levels of congestion (Chapter 6), and highlights industry make-ups and planning policies which, for high-congestion regions, are the most important distinguishing features between congestion resilient and congestion unresilient MSAs (Chapter 7). Results suggest that regional economies are highly adaptive to congestion’s potential drag, but that both industry make-up and planning policy can contribute to metropolitan competitive advantages in congestion resilience.

Congestion's Drag

Evidence suggests that higher congestion is not associated with slower productivity growth, but is associated with slower job growth rates above congestion levels of 39 annual hours of delay per auto commuter (shorter-term) or above 57 hours of delay (longer-term) (Chapter 5). This is not to say that large and highly-congested MSAs are not growing. Of 88 study MSAs, 27 meet or exceed 39 annual hours of delay per commuter at any given time between 1993 and 2008. These congestion threshold estimates are not unmoving; in fact, I expect that they shift over time and vary by region and should thus be interpreted as order of magnitudes. But in estimating congestion's drag, the larger theoretical issue of endogeneity is palpable: large cities have bigger economies and have more congestion, so separating that congestion which is a function of large regional economies from that which represents an economic drag remains conceptually challenging. Results from this dissertation imply that higher congestion is associated with slower job growth rates above particular thresholds, but explicitly separating this interpretation according to congestion's exclusive influence and the positive influences of its correlates (broadly, urbanity) is intractable. Instead, I interpret these estimates of congestion's drag to represent trade-offs between congestion's diseconomy and urban access benefits.

Although evidence suggests that large and congested MSAs' employment growth rates are expected to slow, the economic success and importance of large and highly-congested

regions in the national economy is rising and not waning. In fact, Chicago, Houston, Los Angeles, and Washington, DC, among the most congested MSAs and four of those exceeding the longer-term congestion diseconomy threshold, account for approximately 11 percent of all U.S. jobs and their share of jobs nationally has increased over the last 20 years. So planners' skills in using policy to foster high-functioning places despite congestion will become more important and not less.

Contributors to Congestion Resilience: All MSA Types

This dissertation suggests that planning policies have enabled some MSAs to gain competitive advantages in becoming resilient to congestion's potential drag (Chapter 6). Using panel data on 88 large MSAs but with varying congestion levels, I estimate predictors of higher economic growth per unit growth in congestion to explore policies which contribute to "better" adaptation. Dissertation results suggest that for most MSAs, policies which contribute to congestion resilience parallel "good" economic policy more generally. Evidence indicates that among MSAs across the spectrum of congestion levels, planners can advance congestion resilience primarily by advancing education and secondarily by controlling unionization rates (interpreted as a metric of the relative costs of public services). These findings support those of others in planning and economics which emphasize efficient governance and educated knowledge workers as the engines of future economic growth (Knudsen, Florida, Stolarick, & Gates, 2008; Inman, 2009; Glaeser, 2011). Results weakly suggest that a concentrated urban spatial structure is

associated with congestion resilience in employment growth. Likewise, there is weak evidence that spatially dense road networks are associated with congestion resilience in productivity growth.

This research also suggests that regions partially adapt to congestion “naturally” through firm location decisions, leading to a reshuffling in regional industry makeup, thereby retaining high-functioning regions despite congestion (Chapter 6). Firms and industries appear to choose MSAs according to their specific trade-offs between urban benefits and congestion’s diseconomy, among other factors. While industries that implicitly thrive in large, congested MSAs appear to exhibit little slowing in job growth in response to congestion (finance, insurance, real estate, and construction industries), higher MSA congestion levels are more strongly associated with slowing employment growth rates in other congestion-sensitive industries (retail and wholesale industries).

Contributors to Congestion Resilience: Cases of Large, High-Congestion MSAs

But when focusing on those MSAs with the most severe congestion and exceeding the long-term congestion diseconomy threshold (57 annual hours of commuter delay per year), results indicate that road transportation policy, transit policy, and urban spatial structure distinguish congestion resilient from congestion unresilient MSAs (Chapter 7). Descriptive analyses suggest that MSAs do not simply become more congestion resilient as they have more experience with congestion. While all MSAs adapt, some appear to have competitive advantages in being more resilient to congestion’s potential drag.

Using case studies of four high-congestion MSAs, I focus on industry makeup, transportation policy, and spatial structure characteristics which distinguish congestion-resilient Los Angeles and Washington, DC from congestion-unresilient Chicago and Houston. The retail industry (a congestion-sensitive industry according to Chapter 6 results) appears to comprise a smaller share of regional jobs in the two congestion resilient regions, while congestion resilient Washington, DC has a lower share of jobs in each congestion-sensitive industry (retail, wholesale, and partially manufacturing). This implies that “normal” adjustments through firm and worker location decisions contribute to congestion resilience among these high-congestion regions. In roadway planning, dense road and freeway networks appear to contribute towards resilience because of network redundancy benefits and superior freeway mobility services. In transit planning, significant rail and bus service expansion, improved service competitiveness, and growing transit use are linked with congestion resilience because of the availability of competitive mobility services with less vulnerability to road congestion. Finally, urban spatial patterns in congestion resilient Los Angeles and Washington, DC are significantly more polycentric than monocentric Chicago and dispersed Houston. Polycentricity establishes conditions for localized (as well as regional) agglomeration benefits, a more diverse market in suburban and urban activity centers, and the potential for land use patterns to support travel efficiencies.

Lessons from Chicago, Houston, Los Angeles, and Washington, DC apply to other MSAs to varying degrees. They illustrate potential means of becoming congestion resilient for other large and severely congested MSAs which approach or exceed the congestion diseconomy threshold. In contrast to large and highly-congested metropolitan areas, smaller, less dense, and less congested MSAs are unlikely to benefit significantly through improved congestion resilience from expensive public transit infrastructure and dense, polynucleated spatial structures. In contrast, dense (and implicitly redundant) road networks per unit land area appear to be associated with congestion resilience for both smaller and larger MSAs (both Chapter 6 and 7) – although even here, the evidence is comparatively weaker in the case of Chapter 6 and smaller MSAs. In fact, applying lessons from these four large MSAs to small cities may actually decrease their congestion resilience if such policies are advanced at the expense of more transformative interventions which focus on advancing the economy, and principally on developing, attracting, and retaining knowledge workers. For example, findings from Chapter 6 suggest that policies which foster congestion resilience for MSAs across the entire spectrum of regional congestion levels generally parallel “good” economic policy (principally education), while transportation (particularly transit) and land use policy are likely most critical for congestion resilience in MSAs with the most severe congestion.

Future Research

Research remains sparse on how to foster high-functioning places despite congestion.

Three principal issues remain: exploring congestion's impact on different types of outcomes, addressing the endogeneity issue, and exploring differences across varying types of MSAs in what policies are the most important contributors to congestion resilience and congestion adaptation. First, this dissertation only focuses on economic activities and does not identify how planning can address congestion's potential drag in advancing other social outcomes, most notably equity and quality of life. Second, within the literature on congestion's economic drag, the issue of endogeneity remains important. Identifying and acknowledging the endogeneity problem will be critical to enable researchers and practitioners to compare evidence on the congestion-economy link between different studies using different research designs. Third, additional research is necessary to identify transportation planning policies which facilitate adaptation to congestion for different types of MSAs. The results of this dissertation suggest that context matters considerably, but additional research is necessary when focusing on variations within specific MSAs. Evidence indicates that policies which contribute to congestion resilience are different for the 88 MSAs when pooled across the entire spectrum of congestion levels, compared to the case studies of four of the most congested MSAs in the U.S. Dense road networks appear to be associated with congestion resilience both across the 88 study MSAs (although confidence in parameter estimates are weak in one of the models) (Chapter 6) and for high-congestion MSAs (Chapter 7).

However, using descriptive case studies, polycentric spatial structure and expanding transit services also appear to be important sources of congestion resilience for high-congestion MSAs (Chapter 7), but not according to inferential statistical models in which all 88 MSAs of varying congestion levels are pooled (Chapter 6).

APPENDICES

Appendix A. Key to Model Variables

Following is a consolidated list of variables used throughout this dissertation.

Indexing

- m indexes MSAs

- i indexes industry type according to SIC two-digit classification schemes.

- t indexes time periods

- $t-1$ indexes time periods at least one year before t

- $t-1a$ indexes decennial census data, for which $t-1$ values before 2000 correspond to the 1990 U.S. Census Bureau data and $t-1$ values after 2000 correspond to the 2000 U.S. Census Bureau data.

- $t, t-1, q$ reflects growth or changes between year $t-1$ and t and q indexes lag structures. For example, if $q=3$, this represents three year intervals for each value for $t-1$ and t .

Dependent Variables

While the following means of indexing independent and dependent are not the only ones employed, they illustrate the most widespread use.

$y_{1mt,t-1,q}$ indicates the employment growth in metropolitan area m between times $t-1$ and t according to a q -year lag structure;

$y_{2mt,t-1,q}$ indicates the productivity growth (see Equation 2) in metropolitan area m between times $t-1$ and t according to a q -year lag structure ranging from two to three;

y_{1m} represents the employment in MSA m ;

$y_{2m,t}$ represents the productivity at time t in MSA m ;

Independent Variables

T_{t-1} represents a series of dummy variables for each year ($t-1$) in the given lag structure. For example, if the initial year is 1993 and five year lags ($q=5$) are employed, $t-1$ equals 1998 or 2003, while the first value of $t-1$ (1993) is omitted and the beta coefficient for 1993 is represented by the intercept, β_0 .

$A_{m,t-1}$ indicates a vector of regional economic demand characteristics which apply to metropolitan area m at time $t-1$;

$X_{m,t-1}$ indicates a vector of transportation infrastructure characteristics in metropolitan area m at time $t-1$;

$\Phi_{m,t-1a}$ indicates a vector of municipal governance characteristics in metropolitan area m in either 1990 or 2000, depending on whether or not year $t-1$ is before 2000;

$\Gamma_{m,1990}$ indicates a vector of spatial structure metrics for metropolitan area m in 1990;

H_m indicates the average weather of metropolitan area m between 1971 and 2000;

$\mathfrak{G}_{m,t-1}$ indicates the congestion level in metropolitan area m at time $t-1$ plus a constant one in order to allow natural logging.

B indicate vectors of beta coefficients estimated using ordinary least squares (OLS) for each vector of explanatory variables;

β represent a beta coefficient estimated using OLS for a specific variable;

$\varepsilon_{mt,t-1}$ represents the error term, which is assumed to be independently and identically distributed across observations.

M_m indicates a vector of instrumental variables corresponding to metropolitan area m , but which are not year-specific.

N_{mt} indicates a vector of instrumental variables corresponding to metropolitan area m , but which are specific to year t .

\hat{C}_{m-t} corresponds to the estimated congestion in MSA m at time $t-1$ using instrumental variables.

Appendix B. Measuring Metropolitan Area Industry Specialization

Metrics of industry specialization are constructed in two manners: one based on the share of individual industry employment as a portion of the MSA economy, and one based on the over- or under-representation of particular industry employment in a regional economy compared to average expectations (location quotient). I begin by estimating industry shares of regional employment as follows:

Equation 12. Industry Share of Regional Employment

$$\zeta_{itm} = \frac{y_{litm}}{y_{lmt}}$$

y_{litm} represents the total employment in industry i at time t within metropolitan area m ; and

y_{lmt} represents the total employment at time t in metropolitan area m .

To extrapolate to the metropolitan-area level, I identify the maximum level of ζ_{itm} for each metropolitan area to capture the effects of industries with very high proportions of regional jobs.

Next, I explore differences in employment shares which deviate from local expectations. Particular industries regularly represent larger shares of the regional economies.

Following are the average job shares between 1990 and 2008 for principal industries as a portion of the regional economy:

- Construction (5.3% of jobs)
- Manufacturing (9.7% of jobs)
- Wholesale (4.6% of jobs)
- Retail (13.6% of jobs)
- Finance, Insurance, and Real Estate (FIRE) (9.2% of jobs)
- Government (13.3% of jobs)

Retail and government jobs represent the largest shares of average jobs, while wholesale and construction are the least. Even if the retail or government industries make up a somewhat higher share of local jobs (for example, 15% of jobs), this may not be indicative of a high regional dependence on one of these industries. But if 12% of a region's jobs were in the wholesale sector, 2.6 times the average wholesale employment share, this is likely to be a more important source of industry specialization within a MSA.

To account for differences in an industry's employment share from average expectations, I estimate the relative concentration of jobs in particular industries in particular MSAs using a location quotient. First, I estimate the overall industry employment share across all metropolitan areas as follows:

Equation 13. Total Sample Industry Employment Share

$$\zeta_{it} = \frac{y_{lit}}{y_{lt}},$$

y_{lit} represents the total employment in industry i at time t ; and

y_{lt} represents the total employment at time t .

Next, I estimate the location quotient comparing the metropolitan share of an industry with the industry share across all metropolitan areas as follows:

Equation 14. Measuring Industry Specialization using the Location Quotient

$$\zeta_{litm} = \frac{\zeta_{itm}}{\zeta_{it}},$$

where ζ_{itm} and ζ_{it} are already defined above.

Appendix C. Measuring Municipal Regionalization

To measure municipal regionalization, I calculate a variation of the Gini coefficient. The Gini coefficient ranges from 0, equal employment distribution among observations, to a theoretical high of 1, according to which one municipality would have all residents and others would have none. I identify the relative concentration of residents among municipalities in each of the 88 major U.S. metropolitan areas. If all municipalities are of roughly equal size, this would be indicative of a relatively low level of regionalized governance, and would be demonstrated through a low Gini coefficient (close to 0). In comparison, if most residents are concentrated in one or very few municipalities, this would signify high degree of regionalization and have a high Gini coefficient.

Fundamentally, municipal regionalization metrics should capture the degree to which a given municipality is dominant among all municipalities in a region, so I apply the Gini coefficient as follows:

Equation 15. Measuring Regional Governance Using a Gini Coefficient

$$\Omega_{mt} = \frac{\sum_{i=1}^n \sum_{j=1}^n |x_{imt} - x_{jmt}|}{2n_{imt}^2 \bar{x}_{imt}}$$

Where Ω_{mt} represents the regional Gini coefficient for metro area m at time period t ;

$\sum_{i=1}^n \sum_{j=1}^n |x_{imt} - x_{jmt}|$ represents the sum of the average difference between the population intensity for each pair of municipalities (i and j) for metro m in period t ; n_{imt}^2 represents

the squared count of municipalities for each metro m and period t ; and \bar{x}_{imt} represents the mean population total across municipalities for metro m and period t . As sufficiently detailed data is only available for the U.S. Census of Municipalities in 1992 and 1997, the time period index t only refers to one of these two years.

Appendix D. Measuring Spatial Structure

I estimate metropolitan spatial structure using several methods.

Monocentric Spatial Structure

First, I estimate a monocentric job density model for the 85 of the 88 MSAs for which 1990 Census Transportation Planning Package data is available. Only Portland, Eugene, and Salem Oregon are not included due to restrictions by Oregon State on using employment data aggregated to smaller zones of analysis ⁷. Using the job density model, I can estimate the degree of central agglomeration (the intercept estimate) and the degree of employment containment (the steepness of the slope estimate). With the monocentric job density model results, I use the estimates of employment density as a point of comparison to identify relativistic employment activity centers – in essence, those places where employment is significantly denser than one would expect.

First, I estimate a job density curve for each of the 85 MSAs in 1990 as follows:

Equation 16. Estimating a Job Density Curve

$$\ln \left(\frac{E_{mz}}{A_{mz}} \right) = B_{0m} + B_{1m} D_{mz}$$

⁷ For the purposes of modeling, the spatial structure in these three MSAs are imputed using random regression imputation, according to which spatial structure values are estimated using the other model variables and the predicted values for missing cases are each shifted using a random adjustment with the same variance as the corresponding spatial structure variable.

Where $\ln(E_{mz} / A_{mz})$ represents the natural-logged employment (E_{mz}) density per square mile (A_{mz}) for traffic analysis zone (TAZ) z in metropolitan area m ; B_{0m} is an intercept parameter to be estimated for each MSA; B_{1m} is a distinct slope parameter to be estimated separately for each MSA; and D_{mz} represents the distance between TAZ z in MSA m and the central business district (CBD) in MSA m . The intercept coefficient (B_{0m}) corresponds to the estimated job density at the CBD, while the job density gradient or slope estimate (B_{1m}) captures the degree of concentration around the center.

Identifying Employment Centers

I use two approaches to estimate the degree of polycentricity in metropolitan areas: models of employment clusters according to absolute thresholds, and models of employment clusters according to relative thresholds compared to monocentric expectations. To identify absolute activity centers, I modify the methodology applied by Casello and Smith (2006) and Giuliano and Small (1991). Employment data are available for 85 of the 88 metropolitan statistical areas through the 1990 Census Transportation Planning Package or the metropolitan area's local equivalent. Three metropolitan areas for which such data are not available are each in the Oregon State (Portland, Salem, and Eugene) and are unavailable due to regulations in accessing more locally-aggregated employment data. I will identify activity centers by two methods, one using absolute thresholds (Method 1) and one which focuses on employment clusters

which are significantly higher than one would expect according to the monocentric job density model.

Method 1 uses two thresholds to identify employment centers, one of which is based on employment density and the other of which is based on the absolute employment, as follows (Casello & Smith, 2006):

Equation 17. Employment Cluster Job Density Threshold

$$\frac{E_z}{A_z} \geq \varphi$$

and

Equation 18. Employment Cluster Total Jobs Threshold

$$\sum_z E_z \geq \xi$$

Where E_z represents employment within zone z ; A_z is the area of zone z ; and φ represents the employment density threshold; $\sum_z E_z$ is the sum of all employment for adjacent zone grouping z ; and ξ is a minimum total employment threshold. Based on existing research, see Casello and Smith (2006), Giuliano and Small (1991), or Giuliano et. al. (2007), thresholds of 10 jobs per acre and 10,000 total employees in a contiguous cluster are reasonable. In fact, Giuliano et. al. (2007) argue that the share of total regional employment in sub-centers does not markedly change even when testing for

sensitivity to different density and absolute employment thresholds. As a result, I apply the 10 employees per acre and 10,000 absolute employment thresholds to maintain as much comparability with previous research as possible.

Method 2 applies the same absolute employment threshold as above, according to which total contiguous employment must be greater than 10,000 employees ($\xi = 10,000$), but instead identifies clusters of employment as those with employment density significantly higher than what one would expect according to the monocentric job density model.

Upon estimating job density models in each of the 85 MSAs, I use results to identify relativistic employment activity centers. Using standard error estimates for each MSA's job density model, I focus on TAZs with significantly higher employment density at the $p=0.10$ -confidence level and at the $p=0.05$ -confidence level. Upon identifying significant positive residuals, I explore clusters of significant positive residuals, such that an employment cluster is composed of contiguous, significantly positive residuals (according to the given threshold), with a total of 10,000 employees or more. Thus, I define two categories of relativistic employment clusters: those according to the $p=0.10$ confidence level threshold, and those according to the $p=0.05$ confidence level threshold. Naturally, the lower p -value threshold generates more and larger employment clusters.

Appendix E. Instrumenting and Testing for Endogeneity

To assess whether congestion is endogenous to the economy using the chosen panel design, I use two-stage least squares (TSLS) regression and Hausman tests to investigate whether or not instrumentation is necessary to account for endogeneity bias. As large regional economies lead to congestion and congestion can potentially impede economic outcomes, instrumental variables can be used as an econometric technique to separate these independent effects within the dual feedback loop. Consistent with Hymel (2009), I begin by estimating congestion (\mathcal{G}_{mt}) using instrumental variables which correlate with congestion but are not themselves causes of change in economic activity (and are uncorrelated to ordinary least squares model error terms). First-stage models of congestion are used only for the purposes of instrumentation, but results are informative; therefore, I focus on the meaning of first-stage results in Appendix F, beginning on page 208. Then I use TSLS regression to insert predicted levels of congestion using the instruments in the models of economic growth. As identifying new potential instrumental variables is highly difficult and reduces to a conceptual argument about which variables predict congestion but do not cause changes in economic activity, I borrow instruments from Boarnet (1997) and Hymel (2009). I test various combinations of these instrumental variables, so the strength of the technique does not rest with any one instrumental variable. Thus, traffic congestion (\mathcal{G}_{mt}) in metropolitan area m at time t is

modeled as a linear function of several instrumental variables and their respective coefficients estimated using a first-stage regression:

Equation 19. Instrumenting MSA Traffic Congestion

$$\mathfrak{G}_{mt} = \beta_0 + B_1 T_t + B_2 A_{mt} + B_3 X_{mt} + B_4 \Phi_{m,ta} + B_5 \Gamma_{m,1990} + \beta_6 H_m + B_7 M_m + B_8 N_{mt} + \varepsilon_{mt}$$

\mathfrak{G}_{mt} indicates the congestion level in metropolitan area m at time t plus a constant one in order to allow natural logging.

β_0 represents the intercept, in this case interpreted as the mean congestion level in 1993 (the first value of t);

B_1 represents a vector of parameter estimates controlling for year fixed effects, for one of which T_t equals zero (the reference case and intercept);

T_t represents a series of dummy variables indicating the year t in the given lag structure. For example, if the initial year is 1993 and five year lags ($q=5$) are employed, t equals 1998 or 2003, while the initial value of t (1993) is omitted and the beta coefficient for 1993 is represented by the intercept.

M_m indicates a vector of instrumental variables corresponding to metropolitan area m , but which are not year-specific.

N_{mt} indicates a vector of instrumental variables corresponding to metropolitan area m , but which are specific to year t .

All other variables are described in Equation 3 (page 53), but are indexed according to year t instead of according to year $t-1$.

Time-invariant instruments (M_m in Equation 19) are defined as follows:

- The number of radial highways planned according to the 1955 federal Interstate Highway System plan;
- The number of downtown beltways planned according to the 1955 federal Interstate Highway System plan;
- The number radial highways planned according to Toll Roads and Free Roads (U.S. Bureau of Public Roads, 1939);

Time-variant instruments (N_m in Equation 19) are defined as follows:

- The sum of the number of years served on the U.S. House of Representatives Transportation and Infrastructure Committee over the previous ten years by a congress member whose jurisdiction intersects with a particular MSA (Hymel, 2009). This instrument accounts for the political influence over federal transportation expenditures and captures motivation for highly-congested MSAs to gain committee membership to potentially gain funds for transportation

investment and alleviation measures. Committee membership is identified using Nelson (1993) and Nelson and Stewart (2011) and manually compared to MSA boundary definitions.

- Vehicles per household represents the number of vehicles per household in an MSA and measures the potential for intense vehicle use and congestion, but is unexpected to be a direct cause of economic activity. I use U.S. Census Bureau data for either 1990 or 2000, depending on whether t is before or after 2000; and
- The proportion of roadway miles in an MSA which are highways or interstates indicates high-capacity networks which are often highly congested, but may reflect cross-through inter-city traffic which does not contribute to the local economy (Boarnet, 1997).

Next, if I define \hat{C}_m as the model estimated values of ϑ_m from Equation 19, I estimate changes in employment growth using TOLS regressions to instrument for congestion and account for its endogeneity, as follows:

Equation 20: Predictors of Employment Growth with Congestion Instrumentation

$$y_{1mt,t-1,q} = B_0 T_{t-1} + B_1 A_{m,t-1} + B_2 X_{m,t-1} + B_3 \Phi_{m,t-1a} + B_4 \Gamma_{m,1-9} + \beta_5 H_m + \beta_6 \hat{C}_{m,t-1} + \varepsilon_{mt,t-1}$$

$\hat{C}_{m,t-1}$ corresponds to the estimated congestion in MSA m at time $t-1$ using instrumental variables in Equation 19.

All other terms are already defined in Equation 3 (page 53).

Next, I estimate predictors of productivity growth using TSLS, as follows:

Equation 21: Predictors of Productivity Growth with Congestion Instrumentation

$$y_{2mt,t-1,q} = \beta_0 T_{t-1} + \beta_1 A_{m,t-1} + \beta_2 X_{m,t-1} + \beta_3 \Phi_{m,t-1a} + \beta_4 \Gamma_{m,1-9} + \beta_5 H_m + \beta_6 \hat{C}_{m,t-1} + \varepsilon_{mt,t-1}$$

All other terms are already defined in Equation 4 (page 56), Equation 20 (page 69) or in the key to model variables in Appendix A (page 189).

In each of these TSLS regression models, independent and dependent variables are natural log transformed, allowing estimated parameters to be interpreted as elasticities; and finally all independent variables are mean-centered. Quadratic effects are inserted as necessary based on theory and model fit. I expect the estimated influences of job-housing balance and unionization on economic outcomes to be non-linear based on theory. For example, public sector unions protect workers, but if unionization levels are too high and public sector unions are too powerful, this may drive up public sector wages and reduce the value of public services relative to service costs – thereby reducing the economic competitiveness of a region. Likewise, I expect job-housing balance to have non-linear effects on economic outcomes because spatial specialization by employment or workers is an expected outcome of bid-rent theory; but if the job-worker balance is significantly misaligned, a region may experience economic inefficiencies.

To perform the Hausman test indicating whether instrumentation may be necessary, I first estimate predictors of congestion using the explanatory variables and instruments with Equation 19 and then I insert error terms from Equation 20 and Equation 21 into the second-stage regression as a modification to Equation 20 and Equation 21. Thus, if the parameter estimate on the error terms in the first-stage model is significantly different from zero in the second stage, this suggests that the OLS estimates are biased and inconsistent (Baltagi, 2011).

Hausman tests are completed using various combinations of the instrumental variables with each of the panel datasets (Equation 20 and Equation 21). To statistically test for valid instruments, I test for statistically significant correlations between each instrument and the error terms for the OLS regression (Equation 3 on page 53 or Equation 4 on page 56). Only in the case of downtown beltways planned in 1955 is the instrument deemed invalid for the panel data, so this instrument is omitted in subsequent TSLS analyses and endogeneity tests. As this is the most important instrument in illustrative first-stage regressions (see Table 12 on page 212), this may indicate weak instruments.

Nevertheless, using different combinations of instrumental variables, I fail to reject the null hypothesis in each case at the .30-level or better, concluding that OLS error terms are unbiased and consistent. Thus, I prefer OLS model estimates over TSLS model estimates with instrumental variables both on technical and on conceptual grounds.

Appendix F. First-Stage Regressions: Predictors of Cross-Sectional Congestion

In the two-stage least squares (TSLS) regressions, which I ultimately reject on both conceptual grounds and on the basis of Hausman tests, I conduct first-stage regressions in which I instrument for traffic congestion to account for its endogeneity in the economy. The first stage regression includes pooled data for each time period (for example, 1993, 1998, and 2003, in the case of five-year lags), resulting in pooled regressions for which congestion is estimated for multiple years in each metropolitan area simultaneously. But while pooled regressions violate assumptions of independence between observations, they increase the number of observations, leaving all parameter estimates statistically significant and making it more challenging to identify the relatively more important predictors. Thus, un-pooled cross-sectional estimates of traffic congestion for each individual year (measured as hours of travel delay per auto commuter per year) give a better sense of the most important predictors of traffic congestion.

Although these first-stage models of cross-sectional congestion are only estimated in order to address potential endogeneity biases, results are informative in and of themselves. The primary predictors appear to be an MSA's education level, the proportion of blacks, the urban spatial structure, and one of the instruments: the number of downtown beltways planned according to the 1955 U.S. highway plan (see Table 12, page 212). Congestion appears to be highly elastic with respect to education (parameter estimates indicate unit elasticity or higher), while higher proportions of blacks are also

associated with higher rates of congestion. Spatial structure metrics are very important: more dense CBDs are linked with higher congestion and more compact cities (steeper job density gradients) are linked with less congestion. Meanwhile, planning of intra-urban beltways appears to be a strong and statistically significant long-run predictor of lower congestion levels (elasticities between -0.189 and -0.442).

It is notable that the best evidence of inter-city highways' influences on congestion indicates that inter-city rays planned in 1955 appear to be associated with higher long-run levels of congestion (elasticities between 0.058 and 0.214), while inter-city rays planned in 1939 appear to be associated with lower rates of long-run congestion (elasticities between -0.025 and -0.090). Some of the rays overlap between the 1939 and 1955 plans, but while the 1939 plan focused on more limited freeway building to nationally-important metropolitan areas, the 1955 plan added significant highway alignments to accommodate the politics of federal surface transportation policy legislation (Gifford, 1984). Although these parameter estimates are not significant for many of the years, and therefore this point should not be overstated, the technically-motivated 1939 national highway plan and politically-motivated 1955 national interstate plan appear to have had different impacts on long-run congestion. This supports other research finding that political involvement in transportation finance (and thereby transportation planning) results in "worse" outcomes (Taylor, 2000) – in this case, lower congestion alleviation potential.

Many of the potential instruments are not statistically significant for many of the demonstrated years (see Table 12), but the parameter estimates are stable with one exception: the proportion of total road stock made up by highways. Deeply-lagged plans for inter-city rays in 1955, for inter-city rays in 1939, and for intra-city beltways in 1955, and political influence over transportation expenditure process are all stable predictors of congestion and the parameter estimate for intra-city beltways is always highly significant. The lack of significance among many of the instruments may indicate weak instruments. However, the presence or absence of weak instruments depends not only on the technical analyses (one significant instrument is technically sufficient (Baltagi, 2011)), but also on the argument about how these instruments can shape congestion, are not correlated to error terms, and are not – in and of themselves – explanations of economic activity. Boarnet (1997) and Hymel (2009) argue that these instruments are reasonable, as each does not directly lead to economic outcomes. Higher household vehicle ownership, a higher proportion of interstate highways representing total road stock, higher political influence over federal transportation expenditures, or deeply-lagged plans for inter-city and intra-city highways and beltways are not direct inputs into the economy.

Of the other explanatory variables, only four are consistently statistically significant predictors of congestion across all years (see Table 12). Models imply that the dominant predictors of congestion are the demographic characteristics of MSA residents (education levels and race) and urban mass (CBD density and a flat job-density gradients), consistent

with the view of some urban economists and planners (Downs, 1992; Sorensen, et al., 2008; Stopher, 2004; Taylor, 2002). In fact, results suggest that traditional road and transit capacity building are unlikely to meaningfully change congestion, consistent with the findings of many (Duranton & Turner, 2011; Winston & Langer, 2006). These results and those of others indicate that many chosen congestion alleviation measures are unlikely to meaningfully alleviate regional congestion, particularly over the long term. Thus, shifting from a discourse on congestion alleviation to one of managing congestion using an accessibility planning paradigm becomes paramount to advance the welfare of metropolitan residents.

Table 12. Predicting Cross-Sectional Congestion Illustrative First-Stage Models (Equation 19)

Dependent Variable: Annual Hours of Travel Delay per Auto Commuter (ln)					
	Year 1993	Year 1996	Year 1999	Year 2002	Year 2005
Variable	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept	3.192 ***	3.318 ***	3.370 ***	3.314 ***	3.391 ***
Interstate share of Roads	0.063	0.043	0.141 **	-0.029	-0.030
Vehicles Per Household	0.666	0.875	0.645	0.817	0.511
House Committee Members	0.086	0.073	0.079 *	0.096 **	0.070
Interstate Rays in 1955 Plan	0.058	0.108	0.127	0.160	0.214 *
Interstate Beltways in 1955 Plan	-0.442 **	-0.300 *	-0.356 **	-0.231	-0.189
Interstate Rays in 1939 Plan	-0.090	-0.071	-0.074	-0.044	-0.025
Median MSA Age	0.497	0.645	0.496	0.607	-0.077
Education (BS Per Capita)	1.074 ***	0.982 ***	1.028 ***	1.065 ***	1.111 ***
Race (Blacks Per Capita.)	0.164 ***	0.141 ***	0.127 ***	0.133 **	0.128 **
Road-Stock (Per Area)	0.114	0.217	0.148	0.035	0.218
Transit Stock (Per Area)	2.818	3.122	1.038	-2.133	-1.561
Crime Rate Per 100,000 Residents	-0.198	-0.096	-0.221	-0.028	-0.254
Regional Governance	0.234	0.065	0.190	0.019	0.015
Municipalities Per Capita	-0.016	-0.011	-0.065	0.100	0.091
Public Sector Unionization Rate	0.059	-0.062	-0.129	-0.081	0.026
CBD Job Density	0.265 ***	0.232 ***	0.246 ***	0.176 ***	0.141 **
Job Density Grade/Concentration	-2.162 ***	-1.781 **	-2.451 ***	-1.862 ***	-1.796 *
Area (square miles)	0.076	0.037	-0.014	0.031	0.065
Job Subcenters (p95 method)	0.040	0.037	0.009	0.008	0.022
Job-Housing balance (w/in 30 mls.)	-0.066	0.187	0.236	0.796	0.620
Job-Housing Balance Squared	1.322	1.361	1.410	2.376 *	1.850
Weather (mean January Temp.)	0.296	0.295	0.190	0.166	0.368 **
Adjusted R-Squared	0.580	0.575	0.639	0.606	0.640
Observations (N)	88	88	88	88	88

* Statistical significance at the $p=0.10$ level.

** Statistical significance at the $p=0.05$ level.

*** Statistical significance at the $p=0.01$ level.

Year fixed effects are included but not shown.

All continuous variables are natural logged and parameter estimates represent elasticities.

Explanatory variables are mean-centered.

Appendix G. Predictors of Congestion Growth

Following I estimate policies which can potentially alleviate regional congestion by slowing congestion growth. This analysis provides guidance on how specific policies may contribute to congestion resilience (the topic of Chapter 6) by slowing congestion growth (the focus of this analysis). Congestion growth is the denominator in the metric of congestion resilience (economic growth per unit of congestion growth), thus the following models of congestion growth are simply to facilitate the interpretation of congestion resilience models (Table 6 on page 110 and Table 7 on page 119), as follows:

Equation 22. Predictors of Congestion Growth (average annual delay per auto commuter)

$$\mathfrak{G}_{mt,t-1,q} = \beta_0 + B_1 T_{t-1} + B_2 A_{m,t-1} + B_3 X_{m,t-1} + B_4 \Phi_{m,t-1a} + B_5 \Gamma_{m,1-9} + \beta_6 H_m + \varepsilon_{mt,t-1}$$

Where $\mathfrak{G}_{mt,t-1,q}$ represents the congestion growth rate (+1) between time $t-1$ and t using q -year lags (see Equation 7, page 70)

All other variables are described previously in Equation 3 (page 53) and Equation 10 (page 73) or in the key to model variables in Appendix A (page 189).

As shown in Table 13, very few explanatory variables are significant in either of the models, suggesting that congestion growth is largely a function of general economic trends. Among those variables which are significant in either of the lagged models, median age is significantly associated with slower congestion growth in the five-year lag models. But contrary to expectations and previous literature which frames congestion as

a problem of insufficient transport infrastructure, evidence does not suggest that congestion grows slower in response to either road or transit infrastructure and services. In fact, these results suggest that differences in congestion growth rates are predominately a function of the population at large, consistent with the findings of others (Downs, 1992; Sorensen, et al., 2008; Stopher, 2004; Taylor, 2002) that frame congestion's causes in a broader social context.

Table 13. Predictors of Congestion Growth (Equation 22)

Dependent Variable: Congestion Growth (see Equation 7) Initial Year = 1993		
	3-Year Lags	5-Year Lags
Variable	Estimate	Estimate
Intercept	0.147 ***	0.212 ***
Median MSA Age	-0.147 *	-0.118
Education (BS Per Capita)	-0.035	-0.055
Race (Blacks Per Capita.)	-0.002	-0.012
Road-Stock (Per Area)	0.008	-0.004
Transit Stock (Per Area)	-0.006	0.009
Crime Rate Per 100,000 Residents	-0.027	-0.039
Regional Governance	0.026	0.052
Municipalities Per Capita	-0.016	-0.022
Public Sector Unionization Rate	-0.018	-0.028
Public Sector Union Rate Squared	-0.014	0.031
Industry Specialization (Maximum)	0.003	-0.050
CBD Job Density	-0.006	-0.010
Job Density Grade/Concentration	-0.165	-0.195
Area (square miles)	0.003	0.002
Job Subcenters (p95 method)	0.006	0.007
Job-Housing balance (w/in 30 mls.)	0.021	0.065
Job-Housing Balance Squared	-0.115	-0.112
Weather (mean January Temp.)	0.022	0.034
Adjusted R-Squared	0.394	0.455
Observations (N)	434	251

* Statistical significance at the $p=0.10$ level.

** Statistical significance at the $p=0.05$ level.

*** Statistical significance at the $p=0.01$ level.

*Year fixed effects are included but not shown.
All continuous variables are natural logged and
parameter estimates represent elasticities.
Explanatory variables are mean-centered.*

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