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Traffic Congestion's Economic Impacts: Evidence from US Metropolitan Regions

Matthias Sweet

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Abstract

Traffic congestion alleviation has long been a common core transport policy objective, but it remains unclear under which conditions this universal byproduct of urban life also impedes the economy. Using panel data for 88 US metropolitan statistical areas, this study estimates congestion's drag on employment growth (1993 to 2008) and productivity growth per worker (2001 to 2007). Using instrumental variables, results suggest that congestion slows job growth above thresholds of approximately 4.5 minutes of delay per one-way auto commute and 11,000 average daily traffic (ADT) per lane on average across the regional freeway network. While higher ADT per freeway lane appears to slow productivity growth, there is no evidence of congestion-induced travel delay impeding productivity growth. Results suggest that the strict policy focus on travel time savings may be misplaced and, instead, better outlooks for managing congestion's economic drag lie in prioritising the economically most important trips (perhaps through road pricing) or in providing alternative travel capacity to enable access despite congestion.

Keywords: agglomeration, congestion, economic growth, employment growth, productivity planning, regional planning, transport

1. Introduction

Planners and policy-makers use both congestion alleviation and mitigating congestion's economic drag as core justifications for publicly desired and politically favoured transport programmes. Yet while congestion and its potential costs serve as powerful discourses to frame transport policy debates, the precise relationship between road gridlock and economic outcomes is unclear. This research contributes empirically to this gap. Does congestion impede the prospects of a regional economy?

Matthias Sweet is at the McMaster Institute for Transportation and Logistics, McMaster University, 1280 Main St West, School of Geography and Earth Sciences/MITL General Science Bldg, Room 213, Hamilton, Ontario, L8S4K1, Canada. Email: sweet@mcmaster.ca.

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Economic and travel behaviour 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 economy. This study uses panel data models to estimate congestion's drag on economic growth in comparison with other explanations of economic outcomes.

Understanding the link between congestion and the economy is critical to improving the leveraging of transport and land use policy to support more fundamental social objectives. US federal legislation explicitly identifies congestion reduction and economic support as primary surface transport policy objectives. Yet research on the link between congestion and economic growth is conflicted. The largest urban economies are also among the most congested. Many suggest that traffic congestion reduces city competitiveness and that only peak-period pricing, a highly unpopular tool, can reduce congestion to increase economic function (Boarnet, 1997; Hymel, 2009; Winston and Langer, 2006). Others question the assumption that congestion is an indicator of unsuccessful places and poor social outcomes (Mondschein *et al.*, 2009; Taylor, 2002) or whether long-term congestion alleviation is feasible (Downs, 1992). Instead, the extent and conditions under which congestion impedes social outcomes remain unclear and effective politically acceptable solutions to this murky problem remain even more elusive.

2. Literature Review

There are many important causes of economic growth, of which this study focuses on traffic congestion's potential drag on regional employment growth and productivity growth per worker. Each of these two metrics of economic activity contributes to total productivity (the sum of employment and productivity per worker), thereby focusing on how congestion might influence regional economic growth by either impeding worker productivity or slowing the hiring of new workers. Existing literature on congestion's diseconomy focuses on different scales at which congestion can potentially slow economic growth (within or between regions). Road congestion is an external byproduct of other common causes of economic growth, including big-city agglomeration benefits, social preferences and affluence, urban spatial structure, and municipal governance and therefore separating 'good' from 'bad' congestion is challenging.

2.1 Congestion's Economic Impacts

Research on congestion's economic consequences explores differences in regional or firm productivity, city growth and relocation responses by individuals and firms. The relationship between metropolitan economic activity and traffic congestion is complex and unclear (Taylor, 2002). Large regional economies lead to more congestion, while congestion may impede economic activities by degrading mobility services. Travel is a direct economic input which also leads to the congestion externality. In econometrics, this issue is called endogeneity and captures the methodological challenges of separating the competing benefits of big-city access and dense travel patterns from the drag of big-city road gridlock which raises travel costs or increases unreliability. Congestion reduces national (Fernald, 1999) and regional (Boarnet, 1997; Hymel, 2009) economic competitiveness across regions, but firms and workers adapt within regions through location decisions and bearing commuting burdens (Cervero, 1996; Gordon *et al.*, 1989). Thus, while congestion can potentially lead to travel and economic inefficiencies, it is unclear under what circumstances urbanisation benefits and adaptations by individuals, firms or through policy can no longer outweigh congestion's potential drag (Sweet, 2011).

Intrametropolitan studies of traffic congestion's economic consequences suggest that it shapes regional geographies, but that it is unclear whether resident and firm adjustments can overcome the impact of congestion on urban function. According to the co-location hypothesis, congestion simply induces employer-employee suburban co-location (Crane and Chatman, 2003; Gordon *et al.*, 1989; Levinson and Kumar, 1994). In contrast, empirical research on job–housing imbalance (Cervero, 1996; Cervero and Wu, 1998; Schwanen *et al.*, 2004) suggests significant commuting burdens while theoretical urban economic models likewise imply congestion-induced urban economic inefficiencies (Arnott, 2007; Anas and Xu, 1999; Fujita and Thisse, 2002; Weisbrod, Vary, and Treyz, 2001), most notably by reducing agglomeration benefits (Graham, 2007). Moreover, research suggests industry-variant sensitivity to congestion's potential drag—most notably, service industries are least sensitive while manufacturing industries are most sensitive, indicating that industry mix is important.

Intermetropolitan area studies suggest that traffic congestion reduces regional competitiveness and redistributes economic activity by slowing growth in county gross output (Boarnet, 1997) or slowing metropolitan area employment growth (Hartgen and Fields, 2009; Hymel, 2009). Boarnet (1997) finds that congestion reduces productivity in California counties. Similarly, using panel data for major American metropolitan areas, Hymel (2009) finds that higher congestion leads to slower employment growth, but that its short-term job growth impacts are stronger than those over the longer term—implying regional adaptation. Thus, while intrametropolitan studies suggest that firms and residents adapt to congestion, intermetropolitan studies suggest that such adaptations may not overcome congestion's regionally scaled drag.

2.2 Explanations of Economic Activity

While past studies indicate that congestion is one contributing diseconomy, there are many other explanations of economic activity (Boarnet, 1997; Graham, 2007; Hymel, 2009). Findings on four types of explanations of economic activity are introduced: regional economic demand, urban spatial structure, transport infrastructure and municipal governance.

First, regional economic demand describes the quantity, diversity and type of firms and workers within a given metropolitan area. Agglomeration theory holds that economic mass of labour, capital or infrastructure inputs can generate knowledge-sharing, firm competition and returns to scale which can lead to economic premiums (Glaeser *et al.*, 1992; Henderson, 2003; Henderson *et al.*, 1995). Agglomeration benefits depend on easier access to economic inputs, but can be inhibited when transaction costs increase (for example, as a consequence of congestion). Qualitative characteristics of firms and residents likewise influence economic outcomes. Socioeconomic characteristics (including education, age, racial inequality/discrimination and crime) influence economic growth primarily by altering the marginal productivity of labour, the desirability and quality of life in a region and the wage rate (Murnane, 2009; Ribeiro *et al.*, 2010; Rose and Betts, 2004). Firm and industry type shapes economic growth because of different external conditions, structural competitiveness changes, and relative productivity differences. For example, industry specialisation can lead to growth through knowledge sharing and internalisation of dynamic externalities (Glaeser, Kallal, Scheinkman, and Shleifer, 1992), but diverse industry mixes can likewise contribute to growth through interindustry synergies.

Second, urban spatial structure influences the potential for agglomeration benefits, but can also shape traffic congestion. Urban spatial structure in large regions can foster agglomeration benefits and facilitate economic transactions (Anas and Rhee, 2007; Anas *et al.*, 1998; Fujita and Thisse, 2002; Safirova, 2002), while other spatial arrangements (most notably sprawl) can be economically inefficient (Fallah *et al.*, 2010; Knaap *et al.*, 2001). Others have found that polycentricity leads to agglomeration benefits at sub-regional scales (McMillen, 2001; McMillen and Smith, 2003).

Third, transport infrastructure is a direct input into the production process and indirectly enhances the productivity of other inputs, such as labour, by reducing general transaction costs (Apogee Research, Inc. and Greenhorne and O'Mara, 1998; Bell and McGuire, 1997). Yet while the link between transport infrastructure and economic growth has historically been strong, the link has weakened in developed economies with relatively ubiquitous road systems (Banister and Berechman, 2000; Boarnet and Chalermpong, 2001). Nevertheless, even recent studies suggest that transport investment can contribute to economic growth—albeit weakly and more localised (Jiwattanakulpaisarn *et al.*, 2012; Ribeiro *et al.*, 2010).

Finally, municipal governance is also a strong contributor to economic growth by enabling responsive municipal service provision. The availability of a competitive market in local municipalities can establish the potential for economically efficient matching of services to residents (Hamilton, 1975; Tiebout, 1956). In contrast, regional governance may reduce zoning-induced growth controls and thereby lead to higher economic growth rates (Orfield, 2008). Nevertheless, the efficacies of competing forces of regionalisation and localisation are likely to be different for different economic outcomes. While a competitive market in local municipalities might be best equipped to increase individual productivity by using voter incentives to focus on the needs of existing residents and businesses, regional governance might be best equipped to remove regulatory barriers to job growth by increasing development potential. Finally, efficient governance, often most critically influenced by the relative cost-effectiveness of public-sector labourers, contributes to both the outlook for regional job and productivity growth. Cost-effective governance transforms land values and services are direct productive inputs and indirectly enhance private-sector productivity (Inman, 1995).

3. Research Design

To estimate congestion's economic drag, its estimated effect is compared with competing explanations for regional economic growth. By controlling for industry share as an explanation of job and productivity growth, this highlights one important means by which congestion-adaptive and congestion-sensitive industries may self-select into regions to reduce congestion's drag. For example, while Boarnet (1997) and Graham (2007) have found evidence of congestion impeding productivity at, respectively, the US county level and at the firm level in Britain, it is unclear whether these impacts are redistributive within a metropolitan region (perhaps shifting regional economic geographies) or whether they are net losses which were not overcome through intraregional shifts in firms or inter-regional shifts in industry make-up.

In comparison, Hymel (2009) provides evidence that job growth may slow in response to congestion at the scale of the metropolitan region—implying that congestion's economic impact is not only redistributive.

3.1 Estimating Economic Growth

Using panel data, this study conducts an intermetropolitan study of 88 MSAs to estimate congestion's drag on regional employment and gross metropolitan productivity growth per worker (henceforth referred to simply as productivity growth). This research identifies the chief predictors of MSA employment growth using three- and five-year lag structures (data cover 1993 to 2008) and productivity growth using two- and three-year lag structures (data cover 2001 to 2007). Thus, in the case of employment growth models using panel data with three-year lags, predictors of growth are simultaneously estimated 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, $N = 88*5 = 440$).

This study uses employment and productivity data for 88 of the largest and most congested metropolitan areas in the US, representing those 90 included in the 2010 Urban Mobility Report but excluding two California regions (Indio-Cathedral City and Lancaster-Palmdale) based on other data gaps. Congestion's economic drag is estimated while controlling for the following competing explanations for economic activity: regional economic demand, urban spatial structure, transport infrastructure and municipal governance. Data sources include the Bureau of Economic Analysis, the US Census Bureau, the Texas Transportation Institute's Urban Mobility Report, the Federal Transit Administration's National Transit Database, the US Census of Municipalities, the US decennial census, the FBI crime statistics programme, and the Census Transportation Planning Package (see Table 1).

To measure the economy, this study focuses on growth in gross metropolitan productivity per worker and employment growth, for which data are available from the Bureau of Economic Analysis.

First, employment growth is defined as follows

$$y_{t,t-1} = \frac{y_t}{y_{t-1}} \qquad (1)$$

where, $y_{1m,t}$ represents MSA employment at time t; and y_{t-1} represents the MSA employment at time $t-1$, which is either three or five years before year t.

Productivity growth per worker is defined as follows

$$z_{t,t-1} = \frac{z_t}{z_{t-1}} \qquad (2)$$

where, z_t represents the MSA's average productivity per worker at time t; and z_{t-1} represents the MSA's average productivity per worker at time $t-1$, which is two or three years before t.

Thus both equation (1) and equation (2) capture different forces which increase total productivity in a metropolitan area: either by hiring additional workers or increasing the productivity of existing workers. As would be expected based on economic theory, the two metrics are negatively correlated (-0.21 using two-year lags between 2001 and 2007), implying diminishing marginal returns from hiring new workers.

3.2 Modeling Framework

Both ordinary least squares (OLS) and generalised methods of moments (GMM)

Table 1. Model control variable descriptions

Variable			Source/description
Mean, Range, Standard deviation			
Regional economic demand			
Median MSA age			Estimated using decennial US census data
33.5	25.5–48.3	3.4	
Education (BAs per capita)			Estimated using decennial US census data
0.236	0.111–0.520	0.060	
Race (Blacks per capita)			Estimated using decennial US census data
0.117	0.001−0.434	0.092	
Crime rate per 100,000 residents			Crime is estimated using property crime rates per 100,000 city residents, available annually from the FBI Uniform Crime Reports
6815	2002–14,852	2089	
Industry specialisation (maximum)			Estimated using the maximum industry location quotient for any given industry in an MSA using data from the Bureau of Economic Analysis
1.43	1.02–2.38	0.25	
Transit services (per area)			Estimated annually using the number of public transit vehicle-seats per square kilometre of land area
37.62	0.00–945.08	91.24	
Road-stock (per area)			Estimated as the total number of arterial and freeway link-miles per square kilometre of land area
2.56	0.05−14.13	2.26	
Regional governance			Estimated using a Gini coefficient with data from the US Census of Governments and captures the level of regional concentration of residents in one or several regional municipalities; the range of values can be interpreted as fragmented (closer to 0) to regional (closer to 1) governance
0.793	0.423–1.000	0.123	
Residents per municipality			Estimated using data from the US Census of Governments
33,751	3531–871,766	91,572	

(continued)

Table 1. (Continued)

Variable			*Source/description*
Public sector unionisation rate 37.77	1.2–82	19.4	The public-sector unionisation rate (union members per 100 public-sector employees) is interpreted as an indicator of the relative cost-effectiveness of governance (Inman, 1995) and is from Hirsch and Macpherson (2010)
CBD job density 1080	48–5468	1058	Central density, capturing regional economic mass and agglomeration economies, is measured using the natural logged central business district (CBD) intercept estimate from a regression of employment density on distance from the CBD centre using a log-linear model
Job density grade/deconcentration −0.212	−0.697 to −0.047	0.107	Estimated using the slope estimate from a regression of TAZ job density on distance from the CBD centre using a log-linear model. Transformed by adding one and natural-logging Untransformed values are interpreted as a given percentage decrease in job density with each unit distance from the centre and indicate the relative central concentration, while transformed values are indicators of deconcentration
Area (square kilometres) 12,128	1553–70,603	11,745	Available MSA land area is measured using the US Census Bureau's 2008 boundaries
Job sub-centres 2.6	0–15	3.0	A count of employment sub-centres are measured using a methodology which identifies job clusters that are significantly denser (1.64 times the standard error higher) than monocentric expectations (centres are denser than expected according to the monocentric job density model at the $p = 0.10$ level). Criteria used by others (Giuliano and Small, 1991; Giuliano *et al.*, 2007), including absolute density thresholds, are tested, but all metrics are substantively similar
Job–housing balance 0.91	0.31–1.18	0.173	Job–housing balance is measured as the ratio of jobs to resident-workers within approximately 50 km of the CBD according to CTPP data for 1990
Interaction: CBD job density and job density gradient			Estimated CBD job density and estimated density gradient are interacted to account for sheer urban mass and the potential for urbanisation benefits
Weather (mean January temperature) (ln) 39.2	13.1–73.0	13.2	Estimated mean January temperature between 1971 and 2000 (natural-logged)

estimators are used to estimate predictors of economic growth, including traffic congestion, regional economic demand, transport infrastructure, municipal governance and urban spatial structure. Full model results are only displayed when using the GMM estimator to account for congestion's endogeneity in the economy.

Big metropolitan areas are inherently more congested and represent larger economies, so in GMM models, instrumental variables are used to cope with congestion's potential endogeneity in the economy. Endogeneity is clear when there is dual causation—for example, using a cross-sectional research design or when comparing changes in congestion with changes in economic activity. However, it is less clear with the panel data design used in this research, according to which the impact of initial congestion levels is estimated on subsequent economic growth. 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. Regardless of the temporally constrained causal loop, correlation between traffic congestion and the model error term—for example, equation (3) or (4)—would technically represent bias due to congestion's endogeneity. While the Hausman test suggests that this is only the case in the ADT models, as further discussed in the results, instrumental variables are preferred and employed to overcome the potential endogeneity issue in all subsequent models, similarly to Hymel (2009) and Boarnet (1997).

Predictors of employment growth are estimated as follows

$$y_{t,t-1} = \beta_0 + \mathrm{B}_1\mathrm{T}_{t-1} + \mathrm{B}_2\mathrm{A}_{t-1} + \mathrm{B}_3\mathrm{X}_{t-1} + \mathrm{B}_4\Phi_{t-1a} + \mathrm{B}_5\Gamma_{1990} + \beta_6\mathrm{H} + \mathrm{B}_7\vartheta_{t-1} + \varepsilon_{t,t-1} \quad (3)$$

where, $y_{t,t-1}$ indicates the MSA employment growth (equation (1)) between times $t-1$ and t according to a three- or five-year non-overlapping lag structure; $\beta_0$represents the intercept and in this case is transformed based on all fixed effect estimates and interpreted to represent the estimated job growth across all years for an MSA which is average in respect to all explanatory variables; T_{t-1} represents a series of fixed effects constructed using dummy variables for each year $(t-1)$ interacted with US census region (Midwest, Northeast, South and West) dummy variables; A_{t-1} indicates a vector of regional economic demand characteristics at time $t-1$; X_{t-1} indicates a vector of transportation infrastructure characteristics at time $t-1$; Φ_{t-1a} indicates a vector of municipal governance characteristics using data from the US Census of Governments immediately preceding year $t-1$; Γ_{1990} indicates a vector of spatial structure metrics in 1990; H controls for weather and indicates the average January temperature in a metropolitan area; ϑ_{t-1} indicates the congestion level in a metropolitan area at time $t-1$ plus a constant one in order to allow natural logging; B_1 through B_5 and B_7 indicate vectors of beta coefficients estimated for each vector of explanatory variables; β_6 represents the beta coefficients estimated for the weather control variable; $\varepsilon_{t,t-1}$ represents the error term, which is assumed to be independently and identically distributed across observations.

As interyear variations and interregional variations are accounted for by including fixed effects for years and national US census regions, this study accounts for many unobserved explanations of economic activity.

Next, productivity growth in non-overlapping time periods is estimated as follows

$$z_{t,t-1} = \beta_0 + B_1 T_{t-1} + B_2 A_{t-1} + B_3 X_{t-1} + B_4 \Phi_{t-1a} + B_5 \Gamma_{1990} + \beta_6 H + B_7 \vartheta_{t-1} + \varepsilon_{t,t-1} \quad (4)$$

where, $z_{t,t-1}$ indicates the productivity growth (equation (2)) in a metropolitan area between times $t-1$ and t according to a two-year lag structure and all other variables are as described in equation (3).

Models retain the form of equation (3) and equation (4), but variations are tested. For example, this study includes quadratic effects for congestion and congestion-squared, as the strength of congestion's predicted diseconomy is expected to increase at higher congestion levels. Explanatory variables are mean centred in order to allow the intercepts to be interpreted with respect to a mean MSA if all variables are at their average values. Moreover, dependent and independent variables are transformed by taking the natural log, thereby allowing parameter estimates (except for quadratic specifications) to be interpreted as elasticities.

Traffic congestion is instrumented as follows

$$\vartheta_{t-1} = \beta_0 + B_1 T_{t-1} + B_2 A_{t-1} + B_3 X_{t-1} + B_4 \Phi_{t-1a} + B_5 \Gamma_{1990} + \beta_6 H + B_7 I \quad (5)$$

where, ϑ_{t-1} indicates the congestion in a metropolitan area at time $t-1$; $B_7 I$ indicates a vector of parameter estimates and instrumental variables which are selected for being orthogonal to economic growth but are predictors of congestion; all other variables are as described in equation (3).

Using GMM, predicted values of traffic congestion using equation (5) are substituted for ϑ_{t-1} in equations (3) and (4). Instruments are chosen based on their predictive relationship with traffic congestion and because they are not expected to directly cause changes in economic growth. Thus the instruments are designed to separate those elements of traffic congestion which are positively associated from those which are negatively associated with economic growth. Several instruments are loosely adopted from Hymel (2009), including a count of the number of federal representatives from a given MSA on the House Transportation and Infrastructure committee during the previous ten years, using data from Nelson (1993) and Nelson and Stewart III (2011). Two additional instruments are very similar to those employed by Hymel using a 1947 federal highway plan: a count of the number of interstate rays planned according to the US interstate plan (US Bureau of Public Roads, 1955) and the number of interstate rays planned according to the plan *Toll roads and free roads* (US Bureau of Public Roads, 1939). Two instruments are adopted from Boarnet (1997), including the interstate share of road stock and a count of vehicles per household (from the US Census Bureau decennial census), although these are subsequently dropped based on model diagnostics. In addition, a count of the number of beltways planned according to the US interstate plan (US Bureau of Public Roads, 1955) is employed as an instrument for congestion. Each of these instruments is sufficiently lagged to the study time frame to be reasonably exogenous to economic growth more than 35 years later.

Thus, if parameter estimates for congestion's predicted relationship with economic growth (B_6) using either GMM (with instrumental variables) or OLS indicate that higher levels of congestion are associated with slowing employment growth, this would provide evidence of traffic congestion as an economic drag. Moreover, if congestion's expected drag is stronger using GMM, this would be consistent with the notion that congestion is endogenous in economic growth—supporting the use of instrumental variables.

3.3 Data Sources for Controls

Metrics and data sources are described for each of the four primary categories of explanatory variables here and in Table 1. First, regional economic development ($A_{m,t-1a}$ in equation (3)) is measured using data available yearly and data available only through the decennial US census. Controls for metropolitan crime and industry specialisation are measured for each specific starting year within the panel dataset. However, age, education, and racial demographics are measured using decennial census data which corresponds to either 1990 (for initial year values before 2000) or 2000 (for all others). Industry share is measured using the share of total jobs made up by a particular industry at time $t-1$ according to data from the Bureau of Economic Analysis.

Second, transportation infrastructure ($X_{m,t-1}$ in equation (3)) is measured for both roadway infrastructure and transit services across all study years. Data on each transit service provider from the National Transit Database are manually identified according to the MSA boundary definitions. Both are expected to contribute positively to economic outcomes.

Third, municipal governance structures in metropolitan areas ($\Phi_{m,t-1a}$ in equation (3)) are estimated using data from the US Census of Governments and unionisation data provided by Hirsch and MacPherson (2010) using the Current Population Survey. U.S. Census of Governments data correspond to either 1992 or 1997, depending on whether the initial year is before or after 1997.

Finally, urban spatial structure metrics ($\Gamma_{m,1990}$ in equation (3)) are key indicators of urban form and of the potential for agglomeration benefits—either centrally, in urban deconcentration, through polycentric sub-centers, or through endowed land mass. Spatial structure is estimated for all panel data models using 1990 Census Transportation Planning Package (CTPP) data (see Table 1). Yet likewise, spatial structure metrics are also proxies for land and development capacity, thereby reflecting both the potential for agglomeration benefits and the limits on development potential.

Finally, weather (H_m in equation (3)) is controlled for using the historical mean January temperature from the US Census Bureau, 2002 Census of Governments. As fixed effects include US census regions (Midwest, Northeast, South and West), the effects of warmer winters are expected to strictly reflect the desirability of warm weather in attracting people and jobs (Glaeser, 2011).

3.4 Estimating and Interpreting Congestion

Traffic congestion (in equation (3)) is measured using congestion data for 88 of the urban areas from the Texas Transportation Institute's *2010 Urban Mobility Report* (Schrank *et al.*, 2010). Congestion is measured using both a metric of travel delay (travel delay models) and a metric of travel capacity (average daily traffic models). Congestion and roadway stock data are from the Texas Transportation Institute's urban mobility report for the urbanised area (UA) portion of MSAs—thereby omitting many rural portions of each MSA, but capturing urban congestion and the most important road stock for the purposes of congestion alleviation and economic support.

In the first case, congestion is measured using the average annual hours of delay per auto commuter (compared with free-flow speeds) in the urbanised area portion of a MSA (a constant +1 is added to each value to allow natural-log transformation). Delay ranges from one hour or less (Laredo, TX, Omaha, NE, and Bakersfield, CA) to 85 hours (approximately 10 minutes per one-way commute) in Washington, DC. In the second case, congestion is measured using the average daily traffic (ADT) per freeway lane across the entire network in the urbanised area portion of the MSA. If one were to assume that all freeway lanes have the same capacity, this metric would not only represent travel density, but would also approximate the variation in daily freeway volume-to-capacity ratios across the network. Values range from 5700 (Laredo, TX) to 23,700 (Los Angeles) ADT per freeway lane, with an average of approximately 13,200 across the 88 MSAs between 1993 and 2008. Additional metrics of congestion were considered, including the travel time index or the planning time index, but were not chosen because they did not fully capture congestion's effects beyond peak periods and therefore reflect less variation among regions.

The precise causal mechanisms through which congestion may impede regional employment growth or productivity growth per worker are beyond the scope of this study, but the most plausible mechanisms (discussed later) are likely to be different for the respective economic outcomes. For congestion to impede employment growth beyond the broader natural limits of land and development capacity, one would expect congestion to reduce the marginal productivity relative to the marginal cost of additional workers. Thus, congestion could slow job growth by increasing wages due to the need to compensate workers for inconvenient travel conditions, or by decreasing the productivity of workers—for example, by causing them stress or decreasing their capacity to access other economic inputs.

On the other hand, for congestion to impede growth in productivity per worker, one would expect this to be due primarily to a direct decrease in worker productivity through stress, lack of access to other economic inputs or higher travel costs (two of which have to do with the joint productivity of labour with other inputs). As a result, if congestion were to impede per worker productivity growth but not job growth, it appears reasonable to infer that wages are reduced at a similar rate as productivity is decreased in highly congested and less productive MSAs. Conversely, if congestion were to influence job growth but not productivity growth, this would suggest that wage compensation for inconvenient travel conditions may shift the balance of marginal worker productivity relative to wages and would be likely to be the principal mechanism for congestion's economic drag. Yet if congestion influences both job and productivity growth, the impact on worker productivity would be clear, but the role of wages would not be.

4. Results

Using the presented methodology, this study estimates congestion's drag on employment growth and productivity growth. While models using OLS are also estimated, full results using GMM with instrumental variables using panel data are preferred and only presented due to endogeneity issues, as previously discussed.

4.1 Employment Growth Model Results

First, equation (3) is estimated using a GMM estimator by applying three-year and five-year lag structures. An initial year of 1993 is employed 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. Two types of model are estimated for each of the lag structures: one which measures using the average annual hours of delay per auto commuter (henceforth called the travel delay model) and one which measures congestion using the average daily traffic per freeway lane (henceforth called the ADT model).

Goodness-of-fit tests suggest that the OLS models (not shown) have significant predictive power (adjusted R^2 values of 0.52 and 0.63) and Durbin–Watson tests of both the OLS and GMM models provide no evidence of serial autocorrelation. The J-statistic test, an omnibus test which explores the validity of the GMM model (for example, the overidentification restriction and the validity of instruments), suggests that the final displayed models are valid. J-statistic tests lead to the rejection of two instruments (the percent of road stock which are interstates and the auto ownership per household) and these are not included in the final models. While Hausman tests provide no technical evidence that congestion is endogenous to job growth in travel delay models, there is strong evidence of endogeneity in ADT models.

Based on the study data, growth rates vary significantly across MSAs and the highest growth rates occur in the early 1990s, including almost 8 per cent annual growth in Las Vegas, NV (omitted as an outlier). The most rapid job losses (almost 2 per cent 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. Industry share metrics and year and US census region (Midwest, Northeast, South and West) fixed effects are included in each of the panel models, but are not shown in the table. As all independent variables are mean-centred, the intercept has been transformed to represent the expected average three- or five-year job growth rates between 1993 and 2008 if all independent variables are at their mean. The three-year lag GMM models estimate on average 1.33 per cent annual growth (travel delay model) and 2.18 per cent annual growth (ADT model), while the five-year lag GMM models estimated on average 1.59 per cent annual growth (travel delay model) and 1.91 per cent annual growth (ADT Model). Differences in expected growth rates between the travel delay and ADT models are due to the difference in centring around average delay levels compared with the average ADT levels. Quadratic effects are included for some variables.

Each of the categories of explanations for economic activity appears to contribute to employment growth and signs are generally in the expected directions. Faster job growth is linked with less potential for racial tension and less crime (characteristics of Northeastern and Western US census regions), and fewer residents per municipality (a characteristic of the Midwestern region, perhaps allowing more efficient matching of residents with services). Unionisation rates are highly significant predictors of job growth and quadratic specifications suggest that higher unionisation levels are initially associated with slower job growth until approximately 35 per cent of public workers are union members, above which unionisation is associated with faster job growth. There is some evidence in ADT models that road stock is linked with job growth, but no evidence of a significant role for transit.

Travel delay models of job growth suggest that MSAs with denser CBDs or with flatter job-density gradients (less concentration) grow faster, but that these effects are constrained by the significant joint negative effect of dense CBDs and flat density gradients (the significant and negative interaction term). In contrast, ADT models suggest that these effects are statistically insignificant. According to both travel delay and ADT models, MSAs with larger land area are expected to grow faster, but parameter estimates suggest a very small magnitude (indistinguishable from zero when rounded to three significant digits). In addition, consistently with others (Glaeser and Kahn, 2003), results indicate that the warmer temperatures appear to be highly important in attracting workers. Fixed effects for each year and US census region are included, so the attraction of warm winters appears to be independent from other regional effects.

When initially inserting only congestion without its squared effect (not shown here) results suggest that congestion is simply associated with faster job growth (a positive and significant parameter estimate). The preferred quadratic specification (shown in Table 2) provides significant evidence that congestion's effects are non-linear and include thresholds beyond which higher congestion levels are associated with slower economic growth. The effects of congestion and congestion squared are also significant in the five-year lag ADT Models, but the congestion-squared parameter is only weakly significant ($p = 0.10$ level) in the five-year lag travel delay model. This result differs from Hymel (2009), in which the author found a constant elasticity estimate for congestion's drag on job growth.

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). This study estimates the thresholds at which one would expect higher congestion to be associated with slower employment growth rate (the congestion diseconomy threshold) to respectively be approximately 37 or 35 hours of delay per auto commuter annually using either the three- or five-year lag travel delay models. According to the ADT models, one would expect congestion to function as a drag above thresholds of approximately 11,300 or 11,400 ADT per freeway lane (respectively using three- or five-year lags). To illustrate, with all else being equal, according to the three-year lag travel delay model, one would expect an annual MSA job growth rate of 1.46 per cent with 30 annual hours of travel delay per auto commuter, but 0.58 per cent annually for an MSA with 85 annual hours of delay (the maximum observed value between 1993 and 2008). Of the 88 study MSAs, most have historically exceeded the estimated congestion diseconomy thresholds at least once: 36 MSAs have met or exceeded the 35-hour travel delay threshold (approximately 4.5 minutes of delay per one-way commute); 31 MSAs have met or exceeded the 37-hour travel delay threshold; 75 have exceeded the 11,300 ADT threshold; and 74 have exceeded the 11,400 ADT threshold.

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 is perhaps best interpreted as representing the inefficiency of alleviating congestion on uncongested roadways (Boarnet, 1997). Hence, the thresholds appear to signify those congestion levels above which either workers are relatively less productive (the topic of the next section) or because workers are compensated for exposure to inconvenient commutes at a faster rate than their productivity premiums. Nevertheless, these congestion diseconomy threshold estimates should not be viewed as unbending, as threshold estimates are likely to vary by MSA and represent order-of magnitudes and not absolute limits.

In Figure 1, expected employment growth rates are displayed using estimates from both the travel delay models and ADT models estimated using instrumental variables (Table 2) and using OLS (not shown in results table). All explanatory variables are held constant at their means, thereby

Table 2. Job growth results with GMM using instrumental variables (equation (3))

Dependent variable = job growth rate (ln) (equation (1))	*Initial year = 1993*			
	Three-year lags		*Five-year lags*	
	Travel delay model	*ADT model*	*Travel delay model*	*ADT model*
Variable				
Average growth for 3|5-yr periods across all study years	0.039***	0.065***	0.079***	0.095***
Congestion (travel delay | ADT)	0.215***	2.806*	0.230**	1.685**
Congestion squared	−0.030**	−0.579*	−0.032*	−0.346**
Regional economic demand				
Median MSA age	−0.025	0.030	−0.019	0.014
Education (BS per capita)	−0.010	0.025	−0.011	0.023
Race (Blacks per capita)	−0.015***	−0.022***	−0.020***	−0.020***
Crime rate per 100,000 residents	−0.011*	−0.033*	−0.016*	−0.025**
Industry specialisation (maximum)	−0.027*	0.004	−0.019	0.014
Transportation infrastructure				
Road-stock (per area)	0.000	0.035**	0.001	0.027**
Transit services (per area)	−0.001	−0.011	0.005	−0.004
Municipal governance				
Regional governance	0.004	−0.058	0.010	−0.011
Residents per municipality	−0.006	−0.009	−0.007	−0.008
Public sector unionisation rate	−0.347***	−0.420*	−0.356**	−0.255**
Public sector union rate squared	0.049***	0.061*	0.049**	0.035*
Urban spatial structure				
CBD job density	0.106**	−0.024	0.117*	−0.001
Job density grade/deconcentration	1.111***	−0.240	1.255*	0.004
Interaction: CBD job density and job density gradient (ln)	−0.131***	0.035	−0.153*	−0.007
Area (square miles)	0.000*	0.000***	0.000**	0.000***
Job sub-centres (p90 method)	0.008	0.026*	0.009	0.018**

(continued)

Table 2. (Continued)

Dependent variable = job growth rate (ln) (equation (1))	*Initial year = 1993*			
	Three-year lags		*Five-year lags*	
	Travel delay model	*ADT model*	*Travel delay model*	*ADT model*
Job–housing balance (within 30 mls.)	0.016	0.024	0.009	−0.004
Weather (mean January temperature) (ln)	0.033***	0.054**	0.049**	0.057**
J test statistic	2.25	0.10	2.61	2.62
J test stat. p-value (H_{null} = valid model)	0.324	0.747	0.271	0.270
Observations (*N*)	432	432	261	261

Notes: * 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 and US census region fixed effects and industry shares are included but not shown. All continuous variables are natural logged with the exception of the Job density grade/deconcentration metric and all other parameter estimates represent elasticities (with the exception of quadratic specifications). Explanatory variables are mean-centred and the intercept is converted to represent the three- or five-year growth rate for an MSA which is average in all explanatory variables (through mean centring) across all study years for all US census regions.

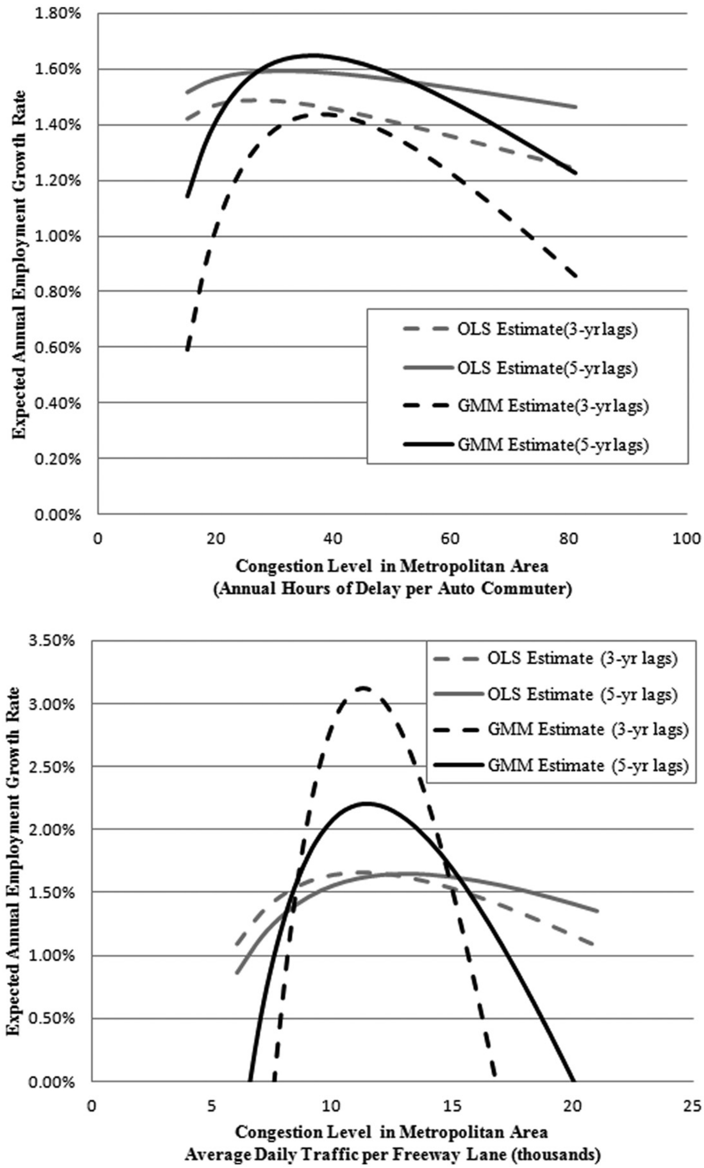

Figure 1. *Above*: congestion level in metropolitan area (annual hours of delay per auto commuter). *Below*: Congestion level in metropolitan area average daily traffic per freeway lane (thousands).

focusing on expected changes in annual employment growth rates with respect to different levels of congestion. Model results using instrumental variables (noted in black) suggest that traffic congestion's drag is significantly stronger than that expected using OLS (in grey)—consistent with expectations that congestion should be instrumented due to endogeneity. Congestion diseconomy thresholds are similar across models, but the estimated magnitude of congestion's drag is significantly different.

Results suggest that—at least for a hypothetical 'average' metropolitan area (see Table 1) without other competitive disadvantages, as assumed in Figure 1—the observed range of travel delay levels is not sufficiently high to expect no regional job growth. Yet even without other competitive disadvantages, observed ADT per freeway lane across the regional network would be sufficiently high to expect no job growth. When extrapolating the trend in Figure 1 using the GMM models, one might expect job growth in this hypothetical 'average' city to cease at approximately 126 annual hours of commuter delay (15 minutes per one-way commute) using three-year lags or 180 annual hours (22 minutes per one-way commute) using five-year lags. In contrast, one might expect no growth at approximately 16,800 ADT per lane across the freeway network using three-year lags or 20,000 ADT using five-year lags. No MSA has approached these travel delay levels, but these ADT levels are within the range of observed values: 21 MSAs have exceeded 16,800 ADT per freeway lane and six MSAs have exceeded 20,000 ADT per lane on average across the freeway network (Chicago, Los Angeles, Phoenix, Riverside, San Diego and San Francisco). However, among high-congestion MSAs, only Detroit has sustained job losses during any period between 1993 and 2008, indicating that high-congestion MSAs retain other advantages, that are not 'average' in all other respects (as in Figure 1) and that economies do not stagnate as a consequence of traffic. Detroit's shrinking economy is related to deindustrialisation and a failing auto industry (Pedroni, 2011; Ryan and Campo, 2012), while other highly congested MSAs continue to grow despite gridlock.

4.2 Productivity Growth Model Results

Next, this study explores whether congestion also hinders the 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. However, 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.

Equation (4) is estimated using both OLS and GMM estimators to explore predictors of productivity growth using two-year and three-year lags. Results were estimated using the GMM instrument for traffic congestion and are shown in Table 3. Goodness-of-fit tests for OLS models (not shown) suggest that the explanatory power of the productivity growth models (R^2 values between 0.362 and 0.419). J-statistic tests of GMM models suggest that they are acceptable, while Durbin–Watson tests provide no evidence of serial autocorrelation. Year controls, year-specific industry mix and US census region fixed effects are included but not shown in Table 3. All variables are mean-centred and intercepts have been converted to represent the average two- or three-year growth rates across all study years for an MSA that is mean with respect to all explanatory variables.

Congestion is only introduced linearly, although quadratic specifications are tested but rejected due to inferior model fit (Table 3). While the quadratic specification generated a better fit in job growth models, evidence for congestion's drag on productivity growth suggests a linear relationship only in the ADT models and a statistically insignificant relationship in the travel delay models. This result differs from Boarnet (1997), in which the author found a non-linear relationship according to which higher congestion levels are associated with stronger drags on county productivity growth.

While productivity growth appears to be unaffected by congestion's influence

Table 3. Productivity growth results with GMM using instrumental variables (equation (4))

Dependent variable = per worker productivity growth rate (ln) (equation (2))	*Initial year = 2001*			
	Two-year lags		*Three-year lags*	
	Travel delay model	*ADT model*	*Travel delay model*	*ADT model*
Variable				
Average growth for 2|3-yr periods across all study years	0.039***	0.065***	0.079***	0.095***
Congestion (travel delay | ADT)	0.008	−0.066**	0.015	−0.067*
Regional economic demand				
Median MSA age	−0.029	−0.061**	−0.042	−0.076*
Education (BS per capita)	0.000	0.012	−0.011	0.008
Race (Blacks per capita)	0.003	0.004*	0.005	0.006
Crime rate per 100,000 residents	−0.013**	−0.012**	−0.017*	−0.014
Industry specialisation (maximum)	0.001	−0.003	−0.010	−0.011
Transportation infrastructure				
Road-stock (per area)	−0.009	0.005	−0.012	0.001
Transit services (per area)	−0.002	0.000	−0.005	−0.001
Municipal governance				
Regional governance	0.001	−0.010	0.009	−0.007
Residents per municipality	0.001	0.001	0.003	0.003
Public sector unionisation rate	0.022	0.034	−0.035	−0.016
Public sector union rate squared	−0.003	−0.004	0.007	0.004
Urban spatial structure				
CBD job density	0.040*	0.054**	0.060*	0.071**
Job density grade/deconcentration	0.445*	0.643***	0.694*	0.873**
Interaction: CBD job density and job density gradient (ln)	−0.043*	−0.060**	−0.064	−0.078**

(continued)

Table 3. (Continued)

Dependent variable = per worker productivity growth rate (ln) (equation (2))	*Initial year = 2001*			
	Two-year lags		*Three-year lags*	
	Travel delay model	*ADT model*	*Travel delay model*	*ADT model*
Area (square miles)	0.000**	0.000	0.000**	0.000
Job sub-centres (p90 method)	0.006*	0.005	0.009	0.007
Job–housing balance (within 30 mls.)	0.008	0.004	0.020	0.013
Weather (mean January temperature) (ln)	0.005	0.016	0.007	0.017
J test statistic	8.007	2.128	6.975	3.124
J test stat. p-value (H_{null} = valid model)	0.156	0.831	0.223	0.681
Observations (*N*)	264	264	176	176

Notes: * 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 and US census region fixed effects and industry shares are included but not shown. All continuous variables are natural logged with the exception of the job density grade/deconcentration metric and all other parameter estimates represent elasticities (with the exception of quadratic specifications). Explanatory variables are mean-centred and the intercept is converted to represent the two- or three-year growth rate for an MSA which is average in all explanatory variables (through mean centring) across all study years for all US census regions.

through commuting delay, congestion appears to impede productivity growth by restraining travel capacity. Parameter estimates imply annualised elasticities of −0.033 using two-year lags and −0.022 using three-year lags. As a result, one would expect a 5 per cent increase in ADT per freeway lane across the MSA road network to reduce the predicted annual productivity growth rate per worker by 0.16 per cent (two-year lags) or 0.11 per cent (three-year lags). Instrumental variable estimates provide evidence for stronger economic drags than those using OLS (which are statistically insignificant): annualised elasticities of −0.0004 (two-year lags) or −0.0002 (three-year lags).

Regional economic demand and urban spatial structure, and not transport infrastructure or municipal governance, are the strongest predictors of productivity growth per worker. Results suggest that MSAs with dense CBDs and with flat job density gradients (deconcentration) are associated with faster productivity growth, but that—similarly to the models of job growth—these effects are constrained by the slowing productivity growth predicted by joint dense CBDs and flat density gradients. More simply, spatial agglomeration benefits appear to be realised through a dense urban core and through region-wide density (a flatter job–density gradient), characteristics most frequently seen in the Northeast US census region, but that there are diminishing and eventually negative productivity growth returns to these two potential sources of agglomeration benefits (central density or region-wide density). Among metrics of regional economic demand, crime is consistently important in each of the four models, implying annual elasticities of between −0.004 and −0.006, while age (negatively) and race (positively) are also strong predictors of productivity growth.

5. Conclusion

Expensive transport programmes are often justified on the basis of congestion alleviation to prevent regional economic stagnation (Hartgen and Fields, 2009). This study explores the effects of congestion on economic growth and evidence using instrumental variables suggests that congestion's drag is most strongly a function of restrained travel capacity (higher ADT per freeway lane) and only more modestly a function of congestion-induced delay. Results indicate that higher congestion through restraining capacity for additional travel (ADT models) appears to be associated with decreasing regional employment growth rates (not just a diminishing rate of increase) and that higher levels of congestion appear to be associated with slower productivity growth per worker (annualised elasticities ranging from −0.022 and −0.033). In contrast, higher levels of congestion-induced commuting delay (travel delay models) appear to be associated with decreasing job growth rates, but there is no evidence of a drag on regional productivity growth per worker. Thus, while congestion may degrade mobility services and induce delay and longer travel times, the highest economic costs of congestion appear to be associated with high ADT per freeway lane by spreading road use across the entire day (perhaps indicating travel at less desirable and less beneficial time periods). These results suggest that, alone, congestion alleviation policies which improve peak-period commuting services (such as road pricing) are unlikely to moderate congestion's drag in isolation and, moreover, the focus of congestion alleviation programmes on travel time savings may be misplaced.

Results suggest that the threshold at which higher levels of congestion are associated with slower employment growth—referred to as the congestion diseconomy threshold—appears to be approximately 35 to 37 hours of delay per auto commuter per year (respectively using five- and three-year lags) in the travel delay models. In the ADT models, results imply thresholds of 11,300 and 11,400 ADT per freeway lane across the regional network (respectively using three- and five-year lags). These thresholds are not unmoving and represent orders of magnitude which are likely to vary over time, across regions and in accordance with other competitive advantages, most notably efficient governance, less potential for racial tension and low crime (strong predictors of job growth), and central and regional agglomeration economies and low crime (strong predictors of productivity growth). For example, insofar that congestion's drag is a consequence of higher wage rates due to compensation for inconvenient commutes (leading to slowing job growth), MSAs with many other types of amenities would be likely to be less sensitive to congestion's drag because access to these amenities would drive the wage rate down relative to worker productivity. Conversely, insofar that congestion's drag is due to impeded access via the saturated road network, urban congestion's drag may be reduced if the economically most important trips can be prioritised (perhaps through peak-period pricing) or if additional travel modes are available to enable access despite road gridlock.

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