The Fundamental Law of Road Congestion: Is it Truly Fundamental?

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Abstract

We investigate the universality of the Fundamental Law of Road Congestion through an in-depth examination of Duranton and Turner's findings from the *American Economic Review* October 2011 publication. We first reproduce their cross-sectional estimates of roadway elasticity of vehicle-kilometers traveled (VKT), then explore the fixed effects and time-series estimates of elasticity. In the remaining sections, we explore our hypothesis that the universality of the Fundamental Law of Road Congestion does not hold by examining individual MSA roadway elasticities and considering how population, geographic, and socioeconomic factors affect variation in the elasticity of demand. After careful consideration, our results suggest that we do not have enough evidence to conclude that the Fundamental Law of Road Congestion holds everywhere. While their data set is compelling, it is incomplete. We are hesitant to call the findings *fundamental* because of gaps in the analysis and large variations at the MSA-level. This study seeks to inform future transportation policymaking by scrutinizing the thoroughness of Duranton and Turner's claim that increases in road infrastructure lead to direct increases in kilometers traveled and providing further insight to the kinds of data needed.

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INTRODUCTION

Transportation policy has historically revolved around improving mobility by alleviating poor traffic conditions. This includes the construction of the Interstate Highway System in 1956 and overall increases in investment into public transit. However, previous studies provide evidence that additions of road lane kilometers along with increases in public transportation do not necessarily alleviate congestion. We believe it is important to understand the impact of these findings on both the nationwide and MSA-level because it has the potential to change current federal, state, and local approaches to transportation policy.

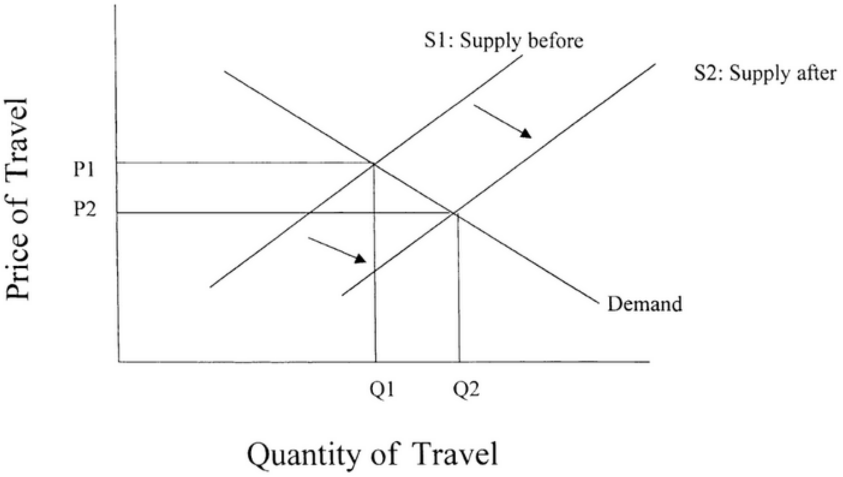
In the 2011 paper, *The Fundamental Law of Road Congestion: Evidence from Major U.S. Cities*, Duranton and Turner claim that increasing road lane kilometers will not be successful in relieving congestion. We investigate whether the Fundamental Law of Road Congestion originally cited by Duranton and Turner is truly fundamental. Their research is an extension of Down's *Law of Peak Traffic Hour Congestion* which states that additional lane kilometers on interstate highways lead to a proportional increase in traffic (Downs, 1962). While Duranton and Turner adjoin other road types to previous research, we pull apart their findings to determine how *fundamental* their "fundamental law of road congestion" is.

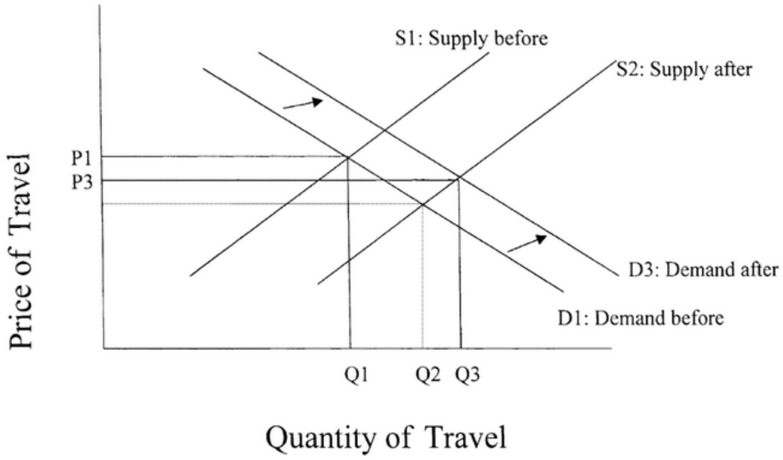
While previous research looks at demand elasticity from a broad scope to determine whether this law holds generally, we break down the data to discover whether this law holds in individual metropolitan statistical areas (MSAs) as well as considering how regional, geographical, and population factors affect variation in demand elasticity. Unfortunately, there are limitations to the Duranton and Turner research that carry over to our research. We only have data from three periods, 1983, 1993, and 2003. This narrows our findings to a 20-year period. Newer data may yield different results. It is also likely that there are other variables that we are unable to account for with our data set which could mean our results are not completely free of bias. Although we share these limitations with previous research, our closer look into individual MSAs along with how certain factors affect demand elasticity can be useful for future policy implementation in addition to these prior findings.

Our findings do not disprove the Fundamental Law of Road Congestion, but they do expose holes in Duranton and Turner's analysis, making us hesitant to consider it a truly fundamental law. We find large variation at the individual MSA level; however, a bivariate regression of the nationwide level suggests that roadway elasticities of VKT are between 1.1 and 1.3, which reflects values estimated in prior research. Our findings suggest that it may be more helpful to look at MSAs on an individualistic basis when performing research and developing future policy.

Literature Review

The effect of increased road capacity on road congestion is a heavily studied topic, especially due to its significance regarding the environment and current transportation policy. Various sources provide evidence in support of the Fundamental Law of Road Congestion. It is widely believed that increasing transportation capacity will only lead to increases in transportation as well. This is for many reasons, some of the most cited being changes in consumer behavior and population growth. It is a concept sometimes referred to as *induced travel*; the "price" of driving decreases for consumers as road capacity expands and time spent driving diminishes. As the "price" decreases, demand/quantity of driving increases as expected by the law of supply and demand (Handy, 2015; Noland and Lem, 2002). An example is the Katy Freeway in Houston, Texas. Immediately after the widening of the highway was completed, there was some congestion relief; however, soon after, the congestion became worse than before (Cortright, 2021; Goodin et al., 2013). The increase in supply eventually led to an increase in demand that exceeded expectations. The additional lanes did not have the intended effect of relieving congestion.





We see this pattern not only in the United States, but in other countries including the United Kingdom and Norway, both of which present similar findings. A 2019 Norwegian study found that either no congestion relief or merely short-term relief followed road expansions (Tennoy et al., 2019).

Most sources acknowledge that road congestion is a major factor in the negative effects on the environment caused by carbon emissions. However, they also state that their findings show that an increase in road capacity can actually have consequences and make road congestion worse. Duranton and Turner also state the need to manage carbon emissions as a reason why their investigation into the Fundamental Law of Road Congestion is relevant. A study estimated that, in 2012, an additional 43 million metric tons of carbon emissions were produced strictly due to the expanded road capacity (Handy, 2015). This research is pertinent to the ongoing fight against global warming. It is necessary to combine the information given by these sources in order to gauge how effective different forms of policy would be in reducing road congestion in order to improve the efficiency of transportation.

Data

The data used in this paper comes from Duranton and Turner's paper *The Fundamental Law of Road Congestion: Evidence from US Cities* (2011). Their study used the US HPMS "universe" and "sample" data for the years 1983, 1993, and 2003. Data was collected by the Federal Highway Administration within the US Department of Transportation (DOT). For each universe of the interstate highway system within state lines, states must report length, number of lanes, and the number of vehicles per lane per day passing any point annually. This is known as the average annual daily traffic (AADT). After that, Duranton and Turner used county identifiers to match segments of interstate highways to Metropolitan Statistical Areas (MSA). Once completed, they calculated the lane kilometers, vehicle kilometers traveled (VKT), and AADT per lane km for interstate highways within each MSA.

MSAs are defined as aggregations of counties. Our dataset uses the 1999 MSA definitions. To ensure that our definitions are constant over the three time periods (1983, 1993, 2003) in our dataset, changes in county boundaries were tracked back to 1920 and adjustments to the definitions were made if necessary.

The sample data from the US HPMS data set reports the same information with additional details for segments of interstate highways within urbanized areas. By merging the sample and universe data sets, Duranton and Turner were able to distinguish between urban and nonurban interstates within MSAs. Furthermore, the sample data also reports information about other types of roads within urban areas. It is meant to represent all major roads in urbanized areas within the state. From there, they calculated road length, location, AADT, and share of truck traffic for all major roads in an urban area. It is important to note that while interstate highways constitute

Table 1: Summary Statistics for Our Main HPMS and Public Transportation Variables

Year	1983	1993	2003
Mean lane km (IH)	1,140	1,208	1,280
	1,650	1,729	1,858
Lane km (IH) Range	[8, 2611]	[45, 13628]	[10, 14582]
Mean AADT (IH)	4,832	7,174	9,361
	2,726	3,413	4,092
Mean AADT (MRU)	3,146	3646	3,934
	847	947	1,059
Mean lane km (MRU)	3,885	5,071	6,471
	7,926	9,119	12,426
Mean VKT share urbanized (IHU/IH)	0.38	0.44	0.48
Mean lane km share urbanized (IHU/IH)	0.29	0.36	0.4
Number MSAs	228	228	228
Mean MSA Population	753,726	834,290	950,054

one class, major roads as we refer to them constitute four classes from the US HPMS data set: collector, minor arterial, principal arterial, other highway.

We can take a look at Table 1 to see the MSA averages of AADT for the 228 MSAs analyzed with nonzero interstate mileage in 1983, 1993, and 2003. Most notable is the increase of annual average daily traffic (AADT) from 4,832 in 1983 to 9,361 in 2003. Therefore, over the 20-year study period, the average lane of interstate highway carries almost double the traffic as it did at the beginning of the study. Lane kilometers of interstate highways also increased by 6% each decade. Taken together, these two changes imply that interstate VKT in an average MSA more than doubled over the 20-year study period. Thus, studying the universality of the fundamental law of road congestion becomes very salient.

As for major roads presented in Table 1, they represent 3-5 times as many lane kilometers as interstate highways. However, they only represent twice the amount of VKT. The dramatic increase of urbanized area VKT and lane kilometers over the 20-year study period may also partly reflect the outwardly shifting borders of urbanized areas over time.

Table 2 depicts the estimates of the elasticity of MSA VKT to lane kilometers from univariate OLS regressions. Each panel represents a different kind of road. Panel A is interstate highways in MSAs. Panel B is interstate

Table 2 —VKT as a Function of Lane Kilometers, Univariate OLS by Decade

Year	1983	1993	2003
Panel A. Dep. var.: ln VKT for interstate highways, entire MSAs			
ln (IH lane km)	1.240***	1.258***	1.230***
	0.042	0.024	0.021
R^2	0.863	0.8718	0.8868
Panel B. Dep. var.: ln VKT			
ln (IHU lane km)	1.264***	1.232***	1.207***
	0.019	0.016	0.015
Panel C. Dep. var.: ln VKT for major roads, urbanized areas within MSAs			
ln (MRU lane km)	1.139***	1.104***	1.115***
	0.047	0.013	0.012
Panel D. Dep. var: ln VKT for interstate highways, outside urbanized areas within MSAs			
ln (IHNU lane km)	1.069***	1.035***	1.024***
	0.036	0.03	0.032

Notes: The same regressions for different types of roads are performed in all four panels.
All regressions include a constant. Robust standard errors in parentheses;
228 observations for each regression in panel A and 192 in panels B-D.
***Significant at the 1 percent level. **Significant at the 5 percent level. *Significant at the 10 percent level

highways in urbanized areas within MSAs. Panel C is major roads in urbanized areas within MSAs. Finally, Panel D is interstate highways outside urbanized areas within MSAs. For each decade, the elasticity of MSA interstate highway VKT with respect to lane kilometers is between 1.23 and 1.25.

In Table 3, we incrementally consider more variables. In panel A of this table, the dependent variable is once more MSA interstate VKT. Columns 1 to 3 consider the 1983 cross-section. In the first column, we include our variable of interest, the log of lane kilometers of road, MSA population, and a constant. In the second we add nine census division dummy variables along with five measures of physical geography: elevation range within the MSA, the ruggedness of terrain in the MSA, two measures of climate, and a measure of how dispersed is development in the MSA. In column 3 we also add socioeconomic controls: share of population with at least some college education, log mean income, share of the poor, share of manufacturing employment, and an index of segregation. Also, we add decennial population variables from 1920 to 1980 to control for the long-run growth of MSAs.

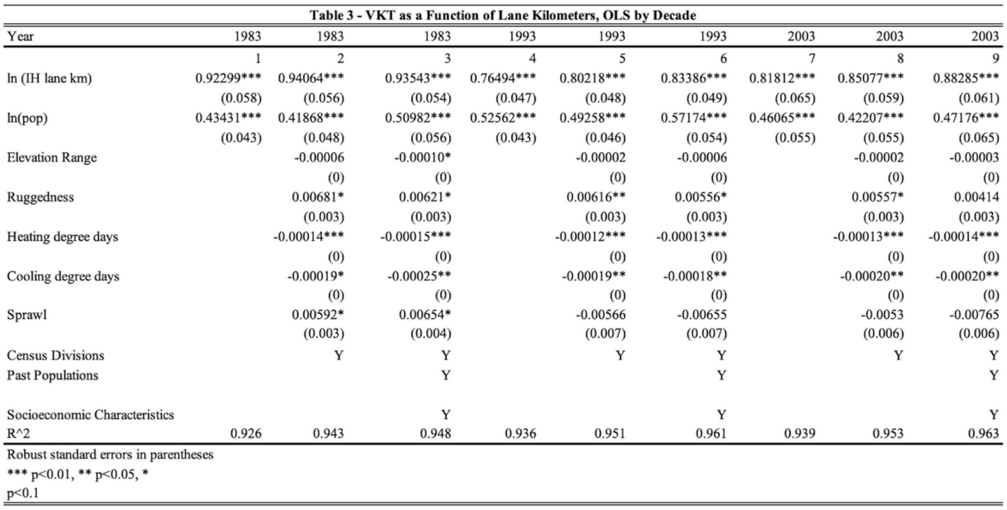


Table 3 - VKT as a Function of Lane Kilometers, OLS by Decade

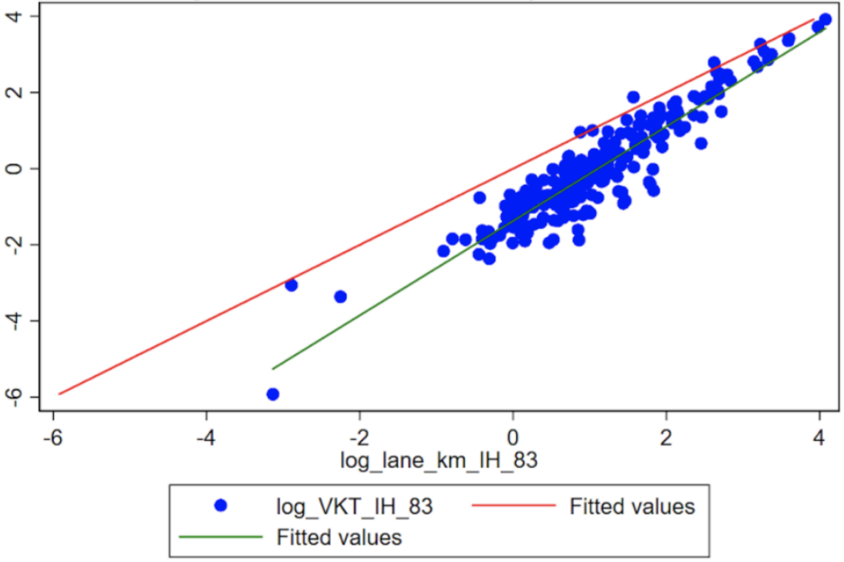
Year	1983	1983	1983	1993	1993	1993	2003	2003	2003
	1	2	3	4	5	6	7	8	9
ln (IH lane km)	0.92299***	0.94064***	0.93543***	0.76494***	0.80218***	0.83386***	0.81812***	0.85077***	0.88285***
	(0.058)	(0.056)	(0.054)	(0.047)	(0.048)	(0.049)	(0.065)	(0.059)	(0.061)
ln(pop)	0.43431***	0.41868***	0.50982***	0.52562***	0.49258***	0.57174***	0.46065***	0.42207***	0.47176***
	(0.043)	(0.048)	(0.056)	(0.043)	(0.046)	(0.054)	(0.055)	(0.055)	(0.065)
Elevation Range		-0.00006	-0.00010*		-0.00002	-0.00006		-0.00002	-0.00003
		(0)	(0)		(0)	(0)		(0)	(0)
Ruggedness		0.00681*	0.00621*		0.00616**	0.00556*		0.00557*	0.00414
		(0.003)	(0.003)		(0.003)	(0.003)		(0.003)	(0.003)
Heating degree days		-0.00014***	-0.00015***		-0.00012***	-0.00013***		-0.00013***	-0.00014***
		(0)	(0)		(0)	(0)		(0)	(0)
Cooling degree days		-0.00019*	-0.00025**		-0.00019**	-0.00018**		-0.00020**	-0.00020**
		(0)	(0)		(0)	(0)		(0)	(0)
Sprawl		0.00592*	0.00654*		-0.00566	-0.00655		-0.0053	-0.00765
		(0.003)	(0.004)		(0.007)	(0.007)		(0.006)	(0.006)
Census Divisions		Y	Y		Y	Y		Y	Y
Past Populations			Y			Y			Y
Socioeconomic Characteristics			Y			Y			Y
R^2	0.926	0.943	0.948	0.936	0.951	0.961	0.939	0.953	0.963

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, *
p<0.1

Because past populations and socioeconomic variables are likely to correlate with unobserved attributes of MSAs that determine the demand for driving, regressions including these variables are useful robustness checks. Columns 4 to 6 replicate these regressions for 1993, while columns 7-9 are for 2003 (Duranton Turner, 2011).

As a preliminary measure, we created a scatter plot to see how the demand elasticities for lane kilometers compared to the predictions forecasted by the Fundamental Law of Road Congestion, where the demand elasticity for lane kilometers would be unit elastic. Figure 1 shows the relationship between ln(VKT) and ln(lane kilometers) mapped on top of the Y=X line which represents unit elasticity. The slope of the line of best fit for the demand elasticities is approximately 1.2, which fits well with our simple estimates in Table 2. While there are a few outliers to the left of the graph, the majority of the data points are centered around the fitted line. So far this fits the argument laid out in Duranton and Turner's 2011 article. Later, we will conduct a hypothesis test to determine if individual elasticities are significantly different from 1.

Figure 1: Demand Elasticity Per MSA



Methodology

To test the fundamental law of road congestion, we defined a fixed effects model. The fixed effects approach allowed us to effectively control for all time-invariant factors by giving our regression model MSA-specific intercepts, since time-invariant variables only affect the expected outcome via differing intercepts across people. We included a set of MSA fixed effects by considering the following regression model:

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 X_{it} MSA_i + MSA_i + \varepsilon_{it} \tag{1}$$

where Y_{it} is the log of vehicle kilometers traveled and X_{it} is the log of road lane kilometers. The variable MSA_i refers to our MSA fixed effects, and $X_{it}MSA_i$ represents an interaction between the log of road lane kilometers and specific MSAs.

After we ran our model, we were interested in observing the estimated coefficients of the interaction between the log road lane kilometers and specific MSAs. We recalled that a log-log transformation caused the interpretation of our estimated to reflect percent changes, $\frac{\%log(VKT)}{\%log(roadlanes)}$. In other words, a

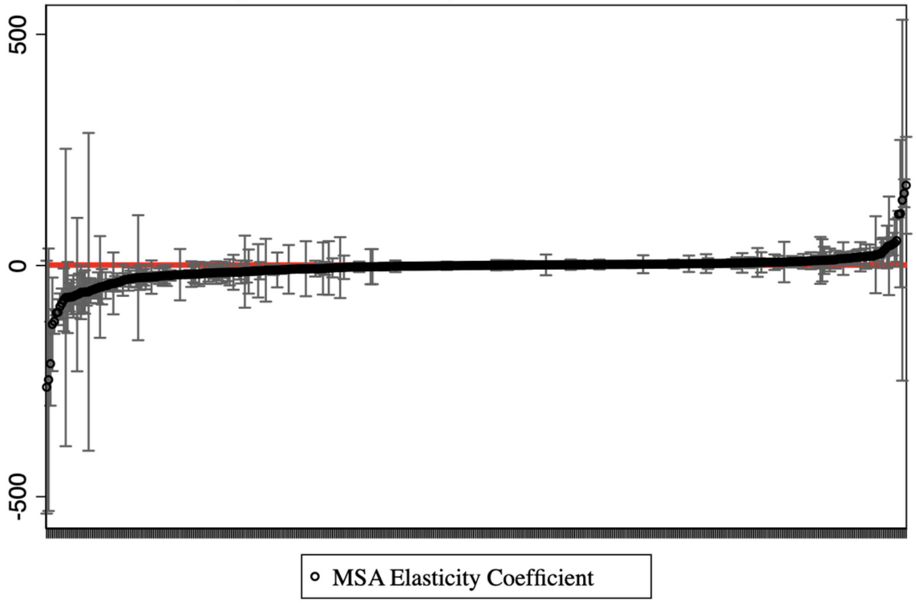


Figure 2: Elasticity Coefficient Per MSA

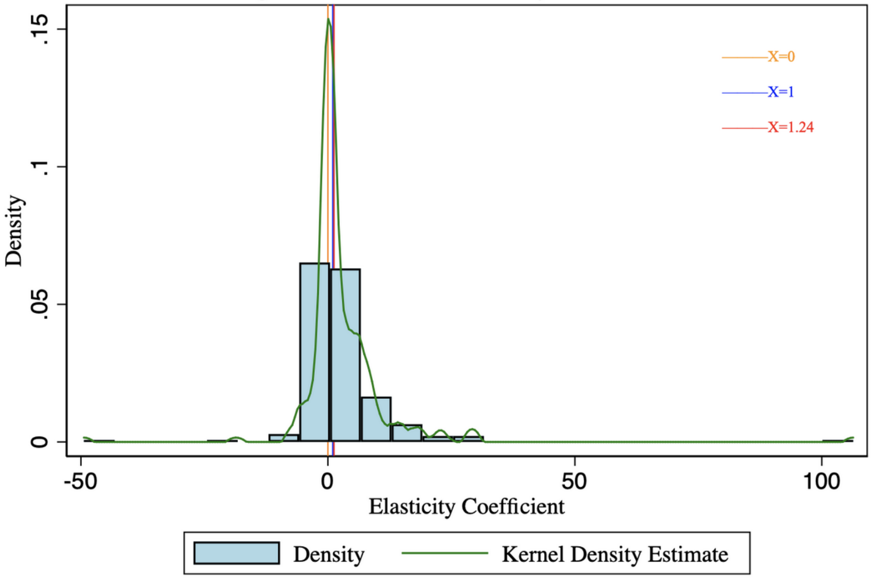
1% increase in road lanes caused a $\hat{\beta}\%$ increase in vehicle kilometers traveled. The log-log transformation could also be interpreted as an "elasticity". Hence, the coefficient of each road lane and MSA interaction was interpreted as an MSA-specific roadway elasticity of VKT. Assuming the Fundamental Law of Road Congestion, we expected the demand elasticity for each MSA to be close to 1.

Results

Figure 2 presents the estimated elasticity coefficient for each MSA with its corresponding confidence interval. A red line was drawn at $Y = 1$ to represent the expected elasticity coefficient under the fundamental law of road congestion. The values were sorted for readability. We expected that, should the law hold, the coefficient at $Y = 1$ should lie within each MSA's confidence interval.

The results of our regression analysis showed significant variation across MSAs. We noticed that the elasticity coefficients range from -25.8 to 49.1. We conducted a two-tailed hypothesis test at a significance level of $\alpha = 5\%$,

Figure 3: MSA Elasticity Coefficient



for each MSA included in the regression where:

$$H_0 : \hat{\beta}_2 = 1$$
$$H_A : \hat{\beta}_2 \neq 1$$

We found that 112 out of the 227 estimated MSA coefficients were statistically significant. This was unsurprising considering the wide confidence intervals visualized in the plot. In particular, we noticed that the confidence intervals for elasticity coefficients further from 1 seemed to be larger than the elasticity coefficients centered around the red line. This led us to use an inverse-variance weighting method to observe our results in proportion to its precision so that more precise estimates were weighted greater than less precise estimates. We used these measurements to create a density plot showing a kernel density estimation. Earlier, when we regressed $ln(VKT)$ on ln(lane road km) without the fixed effects in Table 2, we saw that the elasticity of interstate highway VKT with respect to lane kilometers was roughly 1.24. Thus, we included a line at $X = 1.24$ to show where we expected the greatest density of the elasticity parameter to be.

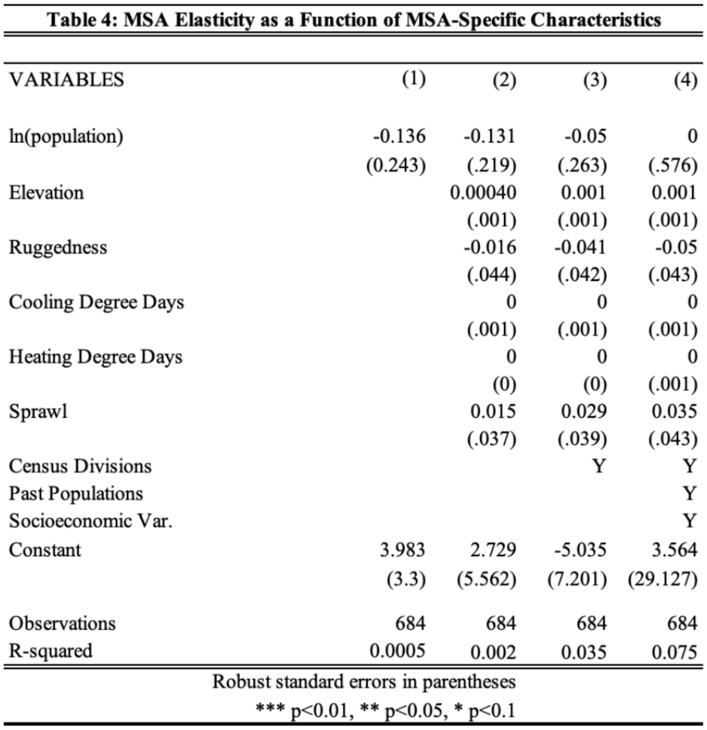


Table 4: MSA Elasticity as a Function of MSA-Specific Characteristics

VARIABLES	(1)	(2)	(3)	(4)
ln(population)	-0.136	-0.131	-0.05	0
	(0.243)	(.219)	(.263)	(.576)
Elevation		0.00040	0.001	0.001
		(.001)	(.001)	(.001)
Ruggedness		-0.016	-0.041	-0.05
		(.044)	(.042)	(.043)
Cooling Degree Days		0	0	0
		(.001)	(.001)	(.001)
Heating Degree Days		0	0	0
		(0)	(0)	(.001)
Sprawl		0.015	0.029	0.035
		(.037)	(.039)	(.043)
Census Divisions			Y	Y
Past Populations				Y
Socioeconomic Var.				Y
Constant	3.983	2.729	-5.035	3.564
	(3.3)	(5.562)	(7.201)	(29.127)
Observations	684	684	684	684
R-squared	0.0005	0.002	0.035	0.075

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

In Figure 3, we plotted a kernel density estimation (KDE) of the MSA elasticity coefficients with an inverse variance transformation, $\frac{1}{se(\hat{\beta}_2)^2}\hat{\beta}_2$. We also constructed a histogram in order to compare KDE to another density function estimator. We included three reference lines at $X = 0$, $X = 1$, and $X = 1.24$. The line at $X = 1$ was included to show the expectation of 2 according to the fundamental law of road congestion, the line at $X = 1.24$ was included to show the expectation of 2 according to the regression of $ln(VKT)$ on ln(lane road km), and the line at $X = 0$ was included to better indicate where the mode lies. The figure suggests that the distribution of the MSA elasticity coefficients tightly fits a distribution centered around 0.

Our kernel density plot provided strong evidence that MSA elasticities do tend toward values close to 1. However, we still wondered what could explain the outlier MSAs in our fixed effects estimation. For the law of road congestion to be truly fundamental, it should hold for all cities.

In Table 4, we regressed our elasticity coefficients on MSA-specific characteristics such as population, geography, and socioeconomic factors. Our estimates suggested that there is not a linear relationship between the MSA elasticities and the explanatory variables in Duranton and Turner's dataset. If given more time, we would have explored other nonlinear transformations. However, the statistically insignificant coefficients and very poor fit implied that the chosen variables were not enough to fit the model. Thus, we concluded that we do not have enough evidence to prove or disprove whether a systematic "law" induced the elasticity to 1, or if there were some omitted variables which explained the outlier elasticities.

Limitations and Future Work

By utilizing only the Duranton and Turner (2011) dataset, we were limited by our ability to study other relevant variables such as average income per MSA, urban/rural segmentation, and infrastructure development. Additionally, while the dataset contained a public transit variable, it only measured public transportation as the daily average peak service of large buses. Other forms of transit such as railroads and subways were not accounted for in the estimations.

In their paper, Duranton and Turner emphasized that previous studies only focused on MSA-specific or state-specific data. They saw this as a detriment because state-by-state case studies do not provide enough information to inform nationwide transportation policymaking. However, we found that the broadness of the Duranton and Turner approach was limited in its ability to produce accurate estimations as well. Because they focused on nationwide data, the selected variables were too general and unable to accurately explain the differences between MSA-specific elasticities. For instance, by missing variables such as the number of businesses on the side of MSA roadways, it is possible that we omitted the effects of positive externalities from congestion which could explain high roadway elasticities of MSA VKT to lane kilometers. Conversely, the lack of variables which measure factors such as the walk/bike-friendliness of individual MSAs meant we could not determine if the convenience of non-motorized transportation contributed to smaller increases in roadway elasticities. Hence, we believe this dataset suffers from omitted variable bias.

Furthermore, selecting from just three time periods (1983, 1993, and 2003) did not capture enough time-variant information about individual MSAs. By running a fixed effects model on 275 MSAs, we experienced a high loss in degrees of freedom which gave us less power to reject false null hypotheses and find significant results. In future studies, we recommend first studying MSAs at the individual-level to discover salient variables before scaling upward and gathering more years of data.

Conclusion

This paper contests the universality of the Fundamental Law of Road Congestion proposed by Duranton and Turner. By examining the impact of lanes of roads on the vehicle miles traveled for individual Metropolitan Statistical Areas (MSAs), we show that their dataset is not robust enough to prove that demand elasticity is 1 across all MSAs in the United States. Our results do not refute Duranton and Turner's claim that the fundamental law exists, but uncover gaps in their data and analysis. We find that the explanatory variables included in the dataset, such as various geography, population, and socioeconomic characteristics, do not help predict the differences in elasticities across MSAs. We expect that obtaining data from other time periods could improve the model fit and strengthen Duranton and Turner's Fundamental Law of Road Congestion declaration. However, to truly minimize the bias in the elasticity measurements, we believe it is necessary to observe MSAs on a case-by-case basis.

References

[1] Cortright, J. (2021). *The Fundamental, Global Law of Road Congestion*. City Observatory. `https://cityobservatory.org/the-fundamental-global-law-of-road-congestion/`.

[2] Downs, A. (1962). *The Law of Peak-Hour Expressway Congestion*. Traffic Quarterly, 16(3). `https://trid.trb.org/view/694596`.

[3] Duranton, G., Turner, M. A. (2011). *The Fundamental Law of Road Congestion: Evidence from US Cities*. The American Economic Review, 101(6), 2616–2652. `http://www.jstor.org/stable/23045653`.

[4] Goodin, G., Benz, R., Burris, M., Brewer, M., Wood, N., Geiselbrecht, T. (2013). *Katy Freeway: An Evaluation of a Second-Generation Managed Lanes Project*. Texas A&M Transportation Institute. `https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6688-1.pdf`.

[5] Handy, S. (2015). *Increasing Highway Capacity Unlikely to Relieve Traffic Congestion*. National Center for Sustainable Transportation. `https://escholarship.org/uc/item/58x8436d`.

[6] Noland, R., Lem, L. (2002). *A review of the evidence for induced travel and changes in transportation and environmental policy in the US and the UK*. Transportation Research Part D, 7(1), 1-26. `https://doi.org/10.1016/S1361-9209(01)00009-8`.

[7] Tennøy, A., Tønnesen, A., Gundersen, F. (2019). *Effects of urban road capacity - Experiences from two Norwegian cases*. Transportation Research Part D: Transport and Environment, 69, 90-106. `https://doi.org/10.1016/j.trd.2019.01.024`.