# Estimating the Impact of Highways on Average Travel Velocities and Market Size

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**Abstract.** In this paper we examine the link between additions to highway infrastructure and development of a market area. We do so by first relating highway travel speeds to added highway-mileage and then relating travel speed to the size of the market area. This approach bypasses issues in the public finance literature that derive from estimates of highway infrastructure spending. Also, rather than examining the effects of improved transportation efficiency on enhancements of *productivity*, this research examines their effect on enhancements in *demand* for local production. Our thought, which is borne out in the literature, is that industry-level productivity in a metropolitan area may be improved only marginally by lower delivered prices of inputs due to very localized improvements in the freight transportation system. On the other hand, the market for locally produced goods and services will expand somewhat uniformly across industries due to generally improved traffic movements in a metropolitan area. By applying this approach to data from the Texas Transportation Institute, we find a significant but small positive effect of highways and arterials (as opposed to other roadways) on changes in metropolitan urbanized area and metropolitan population change. This suggests that demand for local production may well be enhanced by expansions of highway and principal arterials infrastructure.

**Introduction**

Since the late 1980s, much research time and money has been spent examining the relationship between public infrastructure and productivity in the United States. To date, the evidence is mixed on whether public infrastructure induces economic progress. In those studies that find a relationship, the magnitude of the influence has become a subject of some controversy. This is true at all levels of geography. Interestingly, even the data and methods applied to this line of research have become somewhat controversial. The one clear finding has been that enhanced infrastructure spending affects the transportation service sector most heavily.

While this line of literature continues to be of interest to academics and government agencies, transportation firms have wondered what it was all about. It is clear to them that if existent any productivity enhancements from highway improvements outside of those to the transportation service sector must surely be small. They understand that manufacturing firms, in particular, tend to allocate only small portions of their budgets to transportation services. Hence, even if the efficiencies captured by transportation firms are large from their perspective, manufacturers perceive them as minute when transportation firms transmit efficiency gains to their customers.

Moreover, the whole concept of using highway spending to determine productivity enhancements in their industry seems odd to transportation firms. Highways built in environmentally sensitive land, through rough terrain, or in urbanized areas costs more and may provide few benefits to freight carriers. Of course, public finance economists will counter that at least such estimates *should* be reasonable surrogates of what ought to be applied. Of course, this statement assumes that estimates of highway infrastructure capital stocks are viable, which they may not be below the state level in the U.S.

It turns out that most transportation firms do not immediately transmit their efficiency gains to their customers. (They may in the long run, however.) This is because many sign long-term contracts with their major customers. They are more apt to apply it to upgrading their reliability rating, fleet, return to stockholders, or revenue base. The last of these implies that transportation service firms may well enhance the size of their market areas.

We begin this paper begins with a brief review of the public finance literature. This is juxtaposed with a review of literature with the trucking industry's perspective. We follow this with a discussion of our basic approach and the data we use. (That later are from the 2002 Urban Mobility Study of the Texas Transportation Institute.) In our analysis, we first link changes in the physical stock of highways to changes in average highway speeds in the market areas. Changes in speed measures the direct service that new highways deliver to businesses and households, an issue not treated by previous studies. We next empirically link changes in both physical highway stocks and highway speed to the growth of market areas. We conclude the paper with a summary of our findings.

## Literature Review

### *Economic impacts of public infrastructure*

*The early years and national findings.* As Boarnet (1995) notes, street and highway capital is a major components of early work investigating the impact of infrastructure on economic growth. In particular, Aschauer (1989), Garcia-Mila & McGuire (1992), and Holtz-Eakin (1994) hypothesize that if any public capital is useful to private-sector production, highway infrastructure should be a prime suspect.

Eberts (1986) modified a metropolitan-level production function that included public capital stock as an input. In so doing, he developed the first estimates of metropolitan public capital stocks. His work found a small and significant contribution of public capital stock to manufacturing output in a sample of 38 metropolitan areas.

Aschauer (1989) and Munnell (1990a) used time-series data to model production functions. They found that public capital had statistically significant positive effects upon productivity. But, using a first-differences regression, Tatom (1991) did not.

More recently, at the national level, using demand and production functions for 35 sectors, Nadiri and Mamuneas (1998) concluded that highway capital contributes significantly to economic growth and productivity. Their elasticity of output relative to highway capital was 0.08. This represents an intermediate level compared with previous studies. Moreover, they also found that enhancements of highway capital stocks reduces the use of employment and materials but is complemented by private capital investment.

Using a production function approach that included transportation services and congestion for 29 sectors, Fernald (1999) found that when road growth rises, productivity in vehicle-intensive industries tends to rise, but at expense of non-vehicle intensive industries. The results do not support the view that new roads offer a net positive return at the margin.

*State and metropolitan area studies.* Using panel data techniques, research on the public finance of state and metropolitan quickly followed this national work. Like Eberts's cross-section study, Munnell (1990b), Duffy-Deno and Eberts (1991), and Garcia-Mila and McGuire

(1992) found considerably smaller impacts at state level than in the national studies. A second generation of cross-state and metropolitan studies (Garcia-Mila, McGuire & Porter 1996; Evans & Karras 1994; Holtz-Eakin 1994; Holtz-Eakin & Schwartz 1995) that included state fixed effects went even further, concluding that the public capital is not at all significant.

Crihfield and Panggabean (1995) developed a model of metropolitan per capita income using their own set of capital stock estimates and found that public infrastructure has at most a modest effect on factor markets, and an even smaller impact on the growth in per capita income. These same authors (Crihfield and Panggabean 1996a, 1996b) also proposed a firm-based profit model and concluded that public capital plays a small, positive, and declining role in enhancing productivity of manufacturers at the metropolitan level.

But more recent subnational studies have shown that infrastructure in general has positive effects on economic growth. And since highways are a main component of all infrastructure it would seem that they should yield similar returns to growth. For example, using a marginal cost model with state manufacturing data from 1970 to 1987, Morrison and Schwartz (1996) suggest that public capital has a high rate of return. In this work, externalities play an important role. In addition, Dalenberg *et al.* (1998) conclude that infrastructure is a significant in determining state employment levels. Lynde and Richmond (1992), Morrison and Schwartz (1996), and Nadiri and Mamuneas (1994; 1998) support this and found labor and public capital to be substitutes. Interestingly, Duffy-Deno and Dalenberg (1993) found that municipal employment is affected positively by public capital stocks at metropolitan level but had no net effect on municipal wages.

Using an equilibrium model of public goods that integrates the workers' utility functions with the cost function of industries of 40 metropolitan areas, Rudd (2000) concludes that the elasticity of output with respect to public capital is about 0.08. For all infrastructure capital, the estimated elasticity is 0.12, while the elasticity for highway capital is equal to 0.12.

*Localization and spillover effects*. Despite these more recent findings, the idea that public infrastructure might not be productive at the state or metropolitan level is consistent with the perception that highway and road capital have very localized effects on productivity. That is, it may be productive at the county level or lower, at the expense of neighboring areas. Boarnet (1998, 1995) showed just such a redistributive growth effect in California counties: if highway spending increases in a county, then output increases. If highway spending grows in neighboring counties, then local output decreases. This notion is the spatial equivalent of Fernald's (1999) sector-based finding that when road growth rises, growth in productivity for vehicle-intensive industry tends to rise at expense of the productivity of non-vehicle intensive industries tends to fall. Thus, Boarnet (1997a, 1999) and Fernald (1999) concur that road pricing or user fees would be an efficient means of supporting highways spending. That is, this approach would assure that those who use highways directly pay to expand and maintain them.

*Estimating Capital Stock.* All of the research discussed above use some estimate of public capital stock to determine the link between infrastructure and the growth of the economy. Hence, a parallel discussion has developed about the quality of public capital stock estimates. Most studies estimate national and states aggregates of public capital. We review the literature estimating capital stocks below.

Munnell (1990b) constructed estimates of state and local government capital for each state using information from the Bureau of Census and the Bureau of Economic Analysis (BEA) to apportion national state-local capital stock to the states for the years 1969 to 1988. Criticizing Munnell's approach of producing biased estimates, Holtz-Eakin (1993) developed estimates for years 1960 to 1988. He estimated total public capital by state, and for specific public functions such as: all education; higher education; local schools; streets and highways; sewerage; and utilities. In practice the Holtz-Eakin's approach yields larger public sector capital stocks in higher-population states than does Munnell's.

Crihfield and Panggabean (1995) investigated whether the different measures of public capital yield very different model parameters, or different productivity measures for public capital, in particular. Apportioning the various state estimates of public infrastructure to metropolitan areas using population shares, they obtained few differences in the results.

Since the Crihfield and Panggabean study, Dalenberg and Partridge (1995) have estimated metropolitan area infrastructure capital stocks for the years 1966 to 1981 from *Government Finances* (U.S. Dept. of Commerce) using the perpetual inventory method. However, Fraumeni (1999) has argued that all previous studies have counted the highway capital stock on the basis of wealth capital stock, which is the capital stock evaluated at its market value. As a result, she estimated national productive capital stocks to capture the full impact of highway capital stocks. Productive capital stock is an estimate that has been adjusted for the effects of deterioration, e.g. efficiency decline and retirements using detailed information from the Federal Highway Administration.

Because of the data issues inherent with capital stocks (both private and public), we propose using a physical measure of highway capital stocks à la Canning (1999). The data set provided by the Urban Mobility Study of the Texas Transportation Institute (TTI) includes freeway lane miles, principal arterial lane miles, and roadway system centerline miles. The TTI bases its estimates on the Federal Highway Administration's Highway Performance Monitoring

System (HPMS) database with supporting information from states and local agencies. The TTI data cover 75 metropolitan areas from 1982 to 2000.

***Producers' responses to transit time savings***

In this section, we summarize the less formal literature that has attempted to answer the following to question. How does transit time savings induced by highway investments affect the logistics of firms that use their services?

*Reducing Logistics Costs*: *More Choices, Higher Profits, and Lower Prices*. Based on the literature available, investments in highway infrastructure that generate travel-time savings have a positive impact on the productivity of the trucking industry as well as the firms using their services. In general, this literature confirms Fernald's (1999) finding that the more intense the use of transportation services the more the industry stands to gain from time savings and reliable travel trends.

To most firms, the benefits of delivery-time savings transmit directly to a restructuring of their logistics network. The term 'logistics' pertains to the way companies organize the way they deliver the product to the market: this includes the actual transportation service, warehouses, inventory maintenance, customer service provision, and related information processing. Logistics costs are composed of transportation costs, costs of owning and operating warehouses, ordering costs and inventory carrying cost such as interest and insurance. Thus firms sometimes can use the savings to relocate warehouses or to shut down less-productive plants to achieve a net aggregate reduction in the costs of warehouses and inventory carrying that might compensate for a net increase in transportation costs.

According to Lakshmanan and Anderson (2002), "Firms in all industries have undergone a logistical revolution whereby inventories are thinner and production and transportation activities are more highly coordinated." As freight-intensive firms make such adaptations, they demand narrower delivery windows from the freight sector. "Just-in-Time" and "Quick-Response" delivery systems and technological changes, such as the use of intelligent transportation systems, have reduced the need for traditional stored inventory and in turn brought about cost savings. That is, more reliable travel trends translate to less need for "Just-in-Case" or "Buffer" inventories. The result has been a reduced cost of goods and services, which has facilitated both an increase in the producers' profit margins and lower product costs to consumers.

Another aspect of "Just in Time" delivery is that retail stores can stock a greater variety of products. The more space occupied by fast-moving items the less available is space for items with a lower turnover rate. More efficient transportation facilitates quicker replenishment of the fast moving items, which typically need more shelf space. Quicker replenishment, therefore can translate into the use of less shelf space for these fast-moving items. This enables the retailer to make larger displays of higher-profit items or of a wider array of products, the latter of which is often found to be a draw to customers.

*Reliability of delivery*. Transit time savings also translates directly into travel reliability. That is, if a firm is contracted to deliver a product from a plant to another location within fixed amount of time from order notification, then the possibility of a faster transit time should assure that a late delivery is less of a possibility. The more reliable or predictable is delivery, the more efficient is the flow and stocking of goods for the receiving firm. This, in turn, improves the overall logistics of the receiving firm (particularly their inventory carrying costs) and, hence, their productivity.

In NCHRP study, Hickling, Lewis, and Brod Inc (1993), tried among other things to find if there is a value placed on the predictability of travel times. They concentrated on the value of transit time during high congestion periods. They concluded "although the results of freight travel survey conducted for this research confirm the importance of transit time and freight cost in shipping decisions, the survey fails to measure a significant value for changes in transit-time predictability."

In many areas increasing congestion does pose a problem to the future reliability of service. The TTI's Travel Rate Congestion Index shows that highway congestion has worsened significantly from 1980 to 2000 for all 75 metropolitan areas it covers. This is despite that capital outlays on highways and highway mileage, itself, in these same areas have grown steadily since 1980 and even outpacing GDP growth.

While the upshot of this literature is that some efficiency benefits will be garnered by producers, retailers, and consumers alike, the magnitude of the benefits are not well enumerated. Brief interviews with a few New Jersey producers revealed that the transit savings would have to be substantial (on the order or 20 percent) before they would undertake significant restructuring of their logistical systems (warehouse or plant relocation). This is largely because logistics costs are but a small part of their overall product costs. Moreover, they noted that most of their freight movements are under long-term contracts with transportation service organizations. Thus, they would expect some stickiness in freight rates. Thus they *would* expect to seem rates to decline when their contracts are up for rebid, but only in real terms over the long term.

***Trucking industry responses to transit time savings***

As suggested in the last two sentences above, transit time savings enhances the competitive edge of trucking firms by reducing their costs, mostly through a reduced labor requirement effected by the use of a smaller fleet. In some cases, in addition to transit time savings, new roads can enable the use of heavier trucks, which exaggerates the transit time effect. Typically some of the resulting cost savings are passed along to customers, to give the trucking firm a pricing edge over its competition.

Alternative to or perhaps in concert with the pricing advantage, some trucking firms choose not reduce their labor force and instead opt to increase their market reach. To such firms, the time saved in transit translates to more highway miles per vehicle for the same amount of time. This can often lead to an increase in the size of market area they serve.

To date our interviews with trucking firms regarding their disposition of the transit-time savings have yielded mixed results, with different firms allocating the savings to the various options: improved returns to stockholders (profits), equipment investment, freight rate reductions, and market expansion. Most of these options (the first three) should yield productivity enhancements to the users of the goods and services being delivered. We would expect that such productivity should be measured reasonably well by the various studies measuring the effect of highway spending on the productivity of industries in a region. Of course, this literature remains somewhat contentious.

Only expansion of the market of trucking firms has no theoretical basis for enhancing other firms' productivities. To our knowledge, this line of inquiry has not been pursued for freight transportation providers. The theory behind such market expansion is predicated on von

Thűnen-like behavior. That is, it is a reduction of the freight rate enables the market expansion. It was with this in mind that we moved forward with our research.

**Data**

We use data for the years 1982 to 2000 from The Texas Transportation Institute's 2002 Urban Mobility Study. These data are based on the U.S. Federal Highway Administration's Highway Performance Monitoring System database with supporting information from various state and local agencies. The Texas Transportation Institute reviews and adjusts the data to make it comparable. The dataset contains the following variables for each year:

- Population
- Urban Area
- Freeway Lane Miles
- Principal Arterial Lane Miles
- Roadway System Centerline Miles[1]
- Peak Period Freeway Speed
- Congestion Index

Of these the only unclear variable is probably the Congestion Index. According to the TTI, this index shows the average amount of additional time required to make a trip due to congested conditions (recurring and incidental) on the freeways and principal arterials system. Hence, an index value of 1.25 would show that it takes an average of 25 percent more time to make a trip in the average peak than if the motorist could travel at free-flow speeds. Free-flow speeds baseline are 60 mph on freeways and 35 mph on major streets. Speeds less than that indicate delay.

**Specifying the Model**

No matter what data source is used, determine the change in the spatial or demand extent of a market area is difficult to ascertain. The TTI database provided two possibilities, urbanized area and population, so we opted to test them both. In addition, short of conducting a survey, average freight transit times were not available for the years of data available. We used TTI's peak period average freeway speed to proxy for this as well. This is proxy is satisfying in that our point is that time is money. And certainly velocity is essentially inversely related to transit time. That is, we would expect shorter transit times if average peak velocities increase.

We expected that increases in velocity cause the market area to expand (both population and urban area to increase). We add a time lag to velocity to help identify the direction of causality. We hypothesize that higher-density and more-congested areas will have relatively smaller increases in market area. We also hypothesize that increases in freeway and arterial mileages will enhance the market area since they form the backbone of freight routes. We had no rationale for an expected sign on other roads, however, since they primarily serve residential needs.

We opted to use a population-weighted panel-data random-effects FGLS regression model with a log-log functional form. Thus for a particular metropolitan area, the equations below resulted:

$$\Delta \mathbf{P} = \beta_0 + \beta_1 \mathbf{P}_{t-1} + \beta_2 \mathbf{V}_{t-5} + \beta_3 \mathbf{D} + \beta_4 \mathbf{M}^{\mathbf{F}}_{t-5} + \beta_{\backslash 5} \mathbf{M}^{\mathbf{A}}_{t-5} + \beta_6 \mathbf{M}^{\mathbf{R}}_{t-5} + \beta_7 \mathbf{C} + \varepsilon$$

$$\Delta \mathbf{A} = \beta_0 + \beta_1 \mathbf{A}_{t-1} + \beta_2 \mathbf{V}_{t-5} + \beta_3 \mathbf{D} + \beta_4 \mathbf{M}^{\mathbf{F}}_{\mathrm{t-5}} + \beta_{\backslash 5} \mathbf{M}^{\mathbf{A}}_{\mathrm{t-5}} + \beta_6 \mathbf{M}^{\mathbf{R}}_{\mathrm{t-5}} + \beta_7 \mathbf{C} + \varepsilon$$

$$\Delta \mathbf{V} = \beta_0 + \beta_1 \Delta \mathbf{V}_{t-1} + \beta_2 \Delta \mathbf{P} + \beta_3 \mathbf{D} + \beta_4 \mathbf{M}^{\mathbf{F}} + \beta_{\backslash 5} \mathbf{M}^{\mathbf{A}} + \beta_6 \mathbf{M}^{\mathbf{R}} + \beta_7 \mathbf{C} + \varepsilon$$

where

$\Delta \mathbf{V}$ = log of the change in Peak Freeway Velocity

$\Delta \mathbf{P}$ = log of the change in Population

$\Delta \mathbf{A}$ = log of the change in Urban Area

$\mathbf{D}$ = log of Density (Population /Urban Area)

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[1] We corrected roadway mileage for Fort Lauderdale in 1991 from 7,240 to 4,240 and for Miami in 1986 from 2,420 to 4,220.

$\Delta \mathbf{M^F}$ = log of the change in Freeway Lane Miles

$\Delta \mathbf{M^A}$ = log of the change in Principal Arterial Lane Miles

$\Delta \mathbf{M^R}$ = log of the change in Roadway Center-line Miles

**C** = log of the Congestion Index

Note that all variables are measured in natural logarithms. This permits interpretation of the regression coefficients as elasticities. Further note that we employ as an independent variable a one-year lag of the dependent variable. This basically supports the notion that a good predictor of change this year is the prior year's change.

***The Reduced Form***

In addition to the above, we reduced the equations for population and area change by omitting velocity as an explicit variable. We adopt a random coefficient model with a log-linear functional form to their reduced forms shown below:

$$\Delta \mathbf{P} = \beta_0 + \beta_1 \mathbf{P}_{t\text{-}1} + \beta_3 \mathbf{D} + \beta_4 \mathbf{M^F}_{t\text{-}5} + \beta_{\backslash 5} \mathbf{M^A}_{t\text{-}5} + \beta_6 \mathbf{M^R}_{t\text{-}5} + \beta_7 \mathbf{C} + \varepsilon$$

$$\Delta \mathbf{A} = \beta_0 + \beta_1 \mathbf{A}_{t\text{-}1} + \beta_3 \mathbf{D} + \beta_4 \mathbf{M^F}_{\mathrm{t\text{-}5}} + \beta_{\backslash 5} \mathbf{M^A}_{\mathrm{t\text{-}5}} + \beta_6 \mathbf{M^R}_{\mathrm{t\text{-}5}} + \beta_7 \mathbf{C} + \varepsilon$$

Thus, velocity is designed to be an instrumental variable that it is contained implicitly in the reduced form of the population function. This same is true for the change in urban area formulation.

***Testing for Homoscedasticity***

A random effects model by design permits individual heteroskedasticity in overall disturbances (Maddala, 1993, p. 28). According to Greene (2000, p. 520), homoscedasticity may be tested through a Likelihood Ratio test between the estimation of both models with and without panel-level heteroskedasticity. This test is performed for the three extended models i.e., velocity, population, and urban area. The test statistic was computed as the absolute value of the double of difference of Log likelihood results. In all models, homoscedasticity was rejected. As a result we specified all of the estimates using panel-level heteroskedasticity. This conclusion is relevant because the estimates of the regression coefficients were somewhat larger different when homoscedasticity was assumed. It was also clear during the application of

FGLS that, within urban areas (panels), there was a one-year autoregressive lag—AR(1). This AR(1) process is specific to each panel.

**Discussion of the Results**

Table 1 shows that additional highway mileage enhances metropolitan highway speeds. If the magnitude of the regression coefficients can be to believed, a 100 lane-mile increase in freeways effects a 2.3 percent change in the average peak speed. Interestingly additions to principal arterial mileage have the opposite effect of almost equal magnitude. Additions of road system mileage have no significant effect on highway speed.

**Table 1: Determinants of Change in Metropolitan Average Peak Speed, 1982-2000**

| | Coefficient | Std. Error |
|---|---|---|
| $\mathbf{\Delta V_{t-1}}$ | -.03707 | .03255 |
| $\mathbf{\Delta P_{t-1}}$ | -.06667 | .01671 |
| **D** | -.00412 | .00107 |
| $\mathbf{M^F}$ | .02315 | .01080 |
| $\mathbf{M^A}$ | -.02020 | .00845 |
| $\mathbf{M^R}$ | .00377 | .01367 |
| $\mathbf{\Delta M^F}$ | -.01227 | .00772 |
| $\mathbf{\Delta M^A}$ | .00917 | .00682 |
| $\mathbf{\Delta M^R}$ | .00956 | .00864 |
| **C** | -.02459 | .00468 |
| Constant | .00132 | .00079 |

# of groups= 75, # of time periods=17.

Wald chi2(10) = 108.9. Log likelihood = 4,261

This set of findings suggests that additions to freeway mileage improve freight transit times. Moreover, they imply that of the types of possible spending on street and highways only that on freeways should enhance productivity. They also show that additions to arterial mileage are counterproductive. It is not clear why this is so. Its lack of correlation with density and peak congestion, which were also negative as hypothesized, would suggest that it is not congestion related, however.

**Table 2: Determinants of Change in Metropolitan Population, 1982-2000**

| | Standard Model | | Reduced-form Model | |
|---|---|---|---|---|
| | Coefficient | Std. Error | Coefficient | Std. Error |
| $\Delta P_{t-1}$ | .47585 | .03320 | -- | -- |
| $\Delta P_{t-2}$ | -.15401 | .02638 | -- | -- |
| $\Delta V_{t-1}$ | -.05217 | .02043 | -- | -- |
| $\Delta V_{t-2}$ | .00508 | .01345 | -- | -- |
| **D** | -.00121 | .00119 | -.00207 | .00180 |
| $M^F_{t-5}$ | .00947 | 00304 | .01676 | .00404 |
| $M^A_{t-5}$ | .00921 | .00230 | .01512 | .00322 |
| $M^R_{t-5}$ | .00500 | .00428 | .01018 | .00502 |
| **C** | -.00423 | .00321 | -.00366 | .00456 |
| Constant | .00646 | .00095 | .01341 | .00128 |
| # of groups | 75 | | 75 | |
| # of periods | 13 | | 13 | |
| Wald Chi2 | 357.7 | | 56.4 | |
| Log likelihood | 3,320 | | 3,314 | |

**Table 3: Determinants of Change in Metropolitan Land Area, 1982-2000**

| | Standard Model | | Reduced-form Model | |
|---|---|---|---|---|
| | Coefficient | Std. Error | Coefficient | Std. Error |
| **$\Delta P_{t-1}$** | .48365 | .03227 | -- | -- |
| **$\Delta P_{t-2}$** | -.13511 | .02990 | -- | -- |
| **$\Delta V_{t-1}$** | -.04281 | .02413 | -- | -- |
| **$\Delta V_{t-2}$** | .03230 | .01631 | -- | -- |
| **D** | .00340 | .00135 | .00296 | .00204 |
| **$M^F_{t-5}$** | .01762 | .00382 | .02709 | .00477 |
| **$M^A_{t-5}$** | .00697 | . 00269 | .01100 | .00376 |
| **$M^R_{t-5}$** | -.00517 | .00452 | -.00269 | .00612 |
| **C** | -.02080 | .00393 | -.02669 | .00551 |
| Constant | | | .01365 | .00147 |
| # of groups | 75 | | 75 | |
| # of periods | 13 | | 13 | |
| Wald Chi2 | 458.2 | | 84.0 | |
| Log likelihood | 3,049 | | 3044.7 | |

**Conclusion**

We find a significant but small positive spillover of highways and arterials (as opposed to other roadways) on changes in metropolitan urbanized area and metropolitan population change. Other roadways appear to have a positive and significant spillover only on metropolitan population change. This suggests that demand for local production is enhanced by expansions of highway and principal arterials infrastructure. Other roadways seem to enhance the number of consumers but not the market area boundaries, then enhance the metropolitan urban density.

We find a significant but small positive effect of highways and other roadways (as opposed to arterials) on changes on highway travel speeds. If highway and other roadways mileage increases then velocity increases, so travel time and travel reliability do. Thus, companies may implement quick response distribution and logistics investment (trucks, warehouses, inventories) optimization strategies. Improvements on travel reliability may incentive the use larger and articulated trucks.

However if principal arterial mileage increases then highway velocity decreases. In fact, additions of principal arterials results a significant and small negative effect on highway travel speeds. This evidence suggests an intuitive observation that more drivers decide to occupy highways when there are more access (mileage) to arterials, obtaining worst congestion levels.

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**Appendix 1**

**Appendix 2**

**DATA CONVERTED IN THIS RESEARCH**

All data are converted in natural logarithms.

lndensity = ln(population/urban area)

d1_<variable name>

It means the first difference of <variable name>

- d1_ln_pop
- d1_ln_area
- d1_ln_speed (peak period freeway speed)
- d1_ln_fwy_miles
- d1_ln_arterial_miles
- d1_ln_roadway_miles

d2_<variable name>

It means the first difference of the difference of <variable name>

- d2_ln_fwy_miles
- d2_ln_arterial_miles
- d2_ln_roadway_miles

d_lag1_<variable name>

It means the first difference of the lag of <variable name>

- d_lag1_pop
- d_lag1_area
- d_lag1_speed

d_lag2_<variable name>

It means the difference of the difference of the lag of <variable name>

- d_lag2_pop
- d_lag2_area
- d_lag2_speed

<variable name>_1

It means the lag of <variable name>

- ln_tti_1

s*n*_<variable name>_1

It means the lag-*n* difference of the first lag of <variable name>

- s5_ln_freeway_miles_1
- s5_ln_arterial_miles_1
- s5_ln_roadway_miles_1

## Appendix 3

**Comparison between panel-level homoskedastic model and panel-level heteroskedastic**