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The effect of government highway spending on road users' congestion costs

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Abstract

Policymakers attempt to reduce the growth of congestion by spending billions of dollars annually on our road system. We evaluate this policy by estimating the determinants of congestion costs for motorists, trucking operations, and shipping firms. We find that, on average, one dollar of highway spending in a given year reduces the congestion costs to road users only eleven cents in that year. We also find that even if the allocation of spending were optimized to minimize congestion costs that it still is not a cost-effective way to reduce congestion. We conclude the evidence strengthens the case for road pricing.

Keywords: Highway expenditures; Induced demand; Delays to freight

1. Introduction

As congestion on the nation's road system worsens, social costs are mounting. Road users' journeys to perform household tasks, to commute to work, or to deliver freight take longer every year. The facts—and so far the costs—are inescapable. Based on a sample of 75 major urbanized areas in the United States, the Texas Transportation Institute estimated that traffic congestion caused roughly 700 million person hours of delay per year in the early 1980s, more than 2 billion

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hours of delay in 1990, and nearly 3.5 billion hours of delay by 2000.[1] The costs of congestion—opportunity costs to motorists, reduced productivity of for-hire and private trucking operations, and higher inventory costs for shippers—are approaching $50 billion a year. And growth in the nation's population and income ensures that these costs will continue to rise.

Economists' proposed solution to the problem—charging road users efficient congestion tolls—has been analyzed exhaustively. Both its economic effects and political obstacles to its implementation have been well documented (e.g., Small, Winston, and Evans [1], Mohring [2], and Santos [3]). But the efficacy of government policy to address the problem—spending billions of dollars annually on our system of roads and freeways—has received little quantitative analysis. The lack of attention is particularly surprising because the issue bears directly on debates that recur every six years when Congress drafts a transportation bill to help state and local governments pay for highways and mass transit.

In practice, the states are responsible for highway spending using proceeds from the federal gasoline tax that primarily constitutes the Federal Highway Trust Fund, as well as a portion of their general revenues and revenues from their respective gasoline taxes. States are allocated money from the trust fund through a complex process that is based to a certain extent on formulas that place the greatest weight on the size of a state's road system—as opposed to a measure of congestion in the state (US Federal Highway Administration [4]). Under this system, some states receive more money from the trust fund than they put in and others receive less. States tend to allocate funds for freeways, arterials, and collectors within their borders based on the road mileage of these functional classifications. Between 1998 to 2003 highway spending from all sources of government amounted to more than $100 billion per year.

Each state has considerable flexibility in how to spend its highway funds. By expanding road capacity or repairing roads in well-traveled areas, roughly three quarters of total highway expenditures, classified as capital outlays or maintenance constitute the primary tool that policymakers can use to reduce the costs of congestion to motorists, trucking operations, and firms that ship freight by truck (US Federal Highway Administration [5]).[2] Such spending can also spur residential and commercial growth and increase the throughput of vehicle traffic without reducing congestion. The roughly one-quarter of highway spending that is not used for capital and maintenance is classified under administration, highway patrol and safety, and debt retirement. We do not include this spending in our analysis.

Given that a major goal of the federal transportation legislation that funds a large part of highway expenditures is to reduce travel delays, this paper assesses the efficacy of highway spending on road users' congestion costs. We estimate econometric models of the determinants of congestion costs to motorists, trucking operations, and firms and find that, on average, one dollar of highway spending in a given year reduces the congestion costs to road users only eleven cents in that year. We also find that if highway spending explicitly attempted to reduce congestion by targeting expenditures to those states whose urbanized areas experience the greatest travel delays and to those stretches of road where spending is most effective at reducing congestion, that annual congestion costs would fall as much as 40 percent. But even so, the congestion cost savings from one dollar of highway spending in a given year would amount to

[1] These figures are reported at http://mobility.tamu.edu. The growth in delay is accounted for by cities that experienced little congestion in the early 1980s but now experience measurable congestion and by cities that have become even more congested during the past twenty years.

[2] Policymakers may also try to reduce congestion by instituting ramp metering and encouraging employers to create flex-time arrangements and facilitate carpooling.

a modest twenty-five cents in that year, indicating that such spending, even if allocated more efficiently, is simply not a cost-effective way to reduce congestion. We conclude that the evidence strengthens the economic case for congestion pricing of roadways and provides some insight into policymakers' preference for public spending over road pricing to mitigate congestion costs.

2. An empirical model of motorists' congestion costs

Because congestion imposes different costs on motorists, trucking operations, and firms that receive freight shipped by truck, we conduct separate analyses of the effect of government highway spending on these distinct road users. Motorists are primarily affected by congestion when traveling within a city (or urbanized area) on major thoroughfares during peak travel periods, usually to get to and from work. In the transportation literature, highway travel delay in a cross section of cities would typically be specified as a function of the (average) peak-period volume–capacity ratios for the thoroughfares that comprise a city's road system, the attributes of a city, and road users' characteristics.[3]

We extend this formulation by accounting for the effect of state highway expenditures, classified by the American Association of State Highway and Transportation Officials as capital outlays, which are used for road resurfacing, rehabilitation, and new construction, and maintenance, which includes patching and crack sealing to keep the highway surface, shoulders, and roadsides in usable condition. Both types of spending improve the quality of existing roads thereby benefiting users by enabling them to travel at higher average speeds. In addition, capital expenditures that add lanes to existing roads can raise average speeds, and expenditures that result in new roads can reduce users' trip distances and total travel time. We will disaggregate highway spending by road classification denoted by freeways, arterials (major surface roads excluding freeways), and collectors (secondary surface streets). These functional classes are further divided into urban and rural spending, where urban spending consists of spending within Census-defined urbanized areas. "Rural" road spending amounts to spending outside of these areas.

Improvements in travel conditions may be offset by induced demand; that is, expenditures that increase road quality and capacity and raise peak-period speeds will attract users from transit, alternate routes, off-peak travel times, and so on who tend to fill the available capacity during peak travel periods (Downs [6]). The effect of induced demand may cause certain categories of road spending to actually increase congestion costs. For example, spending on local roads that increases residential development may lead to more (peak-period) commuter traffic on both local roads and congested arterials and freeways. Hence, delays for the entire urban area would rise.

Given that we are primarily interested in investigating the effect of highway spending on congestion costs, we will not hold constant other variables, such as traffic volume and road capacity, that may be affected by highway spending. In empirical work, traffic volume (vehicle-miles traveled) and road capacity (system road miles) are specified interactively as the volume–capacity ratio. By allowing such variables to vary, we avoid possible bias to our estimates of

[3] We will often interchange the term city with urbanized area and metropolitan statistical area (MSA). Urbanized areas and MSAs are determined by US Census demographic criteria; nonetheless, they are typically associated with a distinct city. Data on congestion for motorists are available for urbanized areas and data on congestion for trucking operations and shipping firms are available for MSAs.

the effect of highway spending. For example, if road capacity were held constant we would not account for the improvements in road capacity that result from spending and would therefore underestimate its effect on congestion costs. Similarly, if traffic volume were held constant we would not account for the traffic that spending induces and would therefore overestimate its effect on congestion costs.

Highway spending that induces travelers to switch to peak-period road travel raises the utility of those travelers and by increasing vehicle throughput may reflect an additional goal of highway spending. But this social gain is (partially) offset by the induced travelers' contribution to congestion and conflicts with the objective of reducing congestion costs. Our analysis will not attempt to quantify the benefits from greater vehicle throughput, but it will assess the extent to which induced demand affects our estimate of the effects of spending on congestion costs.

The attributes of a city that may affect congestion include its population, weather, public transit system capacity, and geography (e.g., whether few roads traverse a body of water that surrounds part or the entire city). Users' characteristics that may affect congestion include the percentage of trucks in the traffic mix, employment levels, and occupational differences that may be reflected in the extent of off-peak travel.

Based on the preceding considerations, a plausible model of motorists' annual congestion costs in a city can be given by:

$$\begin{aligned} \mathit{Costs} = \exp\Bigg(& \sum_i \sum_j \sum_k \beta_{ijk} \text{ State Highway Spending}_{ijk}/\text{City Population} \\ & + \beta_1 \text{Geography} + \beta_2 \text{Weather} + \beta_3 \text{Transit} + \beta_4 \text{Trucks} + \beta_5 \text{Employment} \\ & + \beta_6 \text{Off-peak travel} + \mu \Bigg), \end{aligned}$$

where i indicates location (urban/rural), j expenditure (maintenance/capital), k functional classification (freeway, arterial, collector), βs are estimable parameters, and μ is an error term. The semi-logarithmic functional form is often used in analyzing delay because marginal delay is an increasing function of travel-related activity and a decreasing function of capacity (or policies that improve capacity). A constant is not included because delay should be approximately zero when travel-related activity is zero.

We include disaggregate measures of each state's highway expenditures in the specification to identify the type(s) of spending (e.g., urban highway capital expenditures) that may have an effect on congestion costs while accounting for each state's total spending. By dividing the state spending variables by a city's population, our specification effectively weights spending in each city within a state that experiences significant congestion by its share of the state's population. This specification implies that the marginal effect of any type of spending on congestion costs is inversely related to a city's population, which is plausible. We explored alternative specifications such as dividing the spending variables by state population, city population squared, and the log of city population, but they produced worse statistical fits. We assume that the coefficients of the spending variables divided by city population are constant across the sample; but we tested this assumption by estimating alternative specifications that, for example, interacted the spending variables with dummy variables that classified city sizes by population thresholds, and failed to reject the null hypothesis.

2.1. Sample and measurement of motorists' congestion costs

Our empirical analysis is conducted for the period 1982–1996 on 74 of the largest US cities comprising 72 distinct urbanized areas.[4] (Currently, it is not possible to get a consistent set of delay data for all road users much beyond 1996.) The urbanized areas correspond to those included in the Texas Transportation Institute (TTI) data base on motorists' delay and account for much of the nation's congestion costs. Annual congestion costs for motorists are obtained for each city as the additional gasoline costs attributable to congestion plus the product of the annual hours of delay per vehicle and motorists' value of time.[5] In our base case, we assume the value of time to be one-half the average hourly wage in the city (Small [7]), but we explore how our main findings are affected by alternative assumptions.[6]

The additional fuel costs attributable to congestion and the delay to motorists and trucks are obtained from TTI. Because TTI's estimates of delays assume trucks comprise 5 percent of vehicle traffic, we multiply the delay and operating cost figures by 0.95 to focus on only motorists' congestion costs in this section. TTI estimates intracity delay using data from the US Department of Transportation on traffic volumes for different functional classifications in each city (e.g., interstates and major arterials in Los Angeles). Delay for each classification is calculated as the difference between free-flow speeds and travel speeds during congestion based on speed-flow curves developed from those in the *Highway Capacity Manual*. TTI verifies their estimates of delay and adjusts them to reflect each city's particular road conditions and characteristics by collecting observations in each city on actual free-flow and congested travel speeds. Thus, TTI's estimates of roadway delay are more accurate for our purposes than computing delay from standard speed-flow curves because they incorporate a city's roadway configurations, weather conditions, and driver behaviors that may affect delay. Note that free flow as opposed to optimal travel speed is the relevant benchmark for calculating delay because we are interested in the effect of spending on total congestion costs, not just the portion of congestion costs that would remain if the road authorities implemented efficient pricing.

The travel delays reported in the TTI data conform to notions about the severity of congestion over time and across urban areas. For the entire sample, average daily delay increased from 1.63 minutes/vehicle in 1982 to 6.04 minutes/vehicle in 1996. Motorists in Los Angeles experienced 9 minutes of daily delay in 1982 and nearly 26 minutes of delay in 1996, while those in Milwaukee experienced 1 minute of delay in 1982 and roughly 5 minutes of delay in 1996.

Using these data, the assumed value of time, and the change in vehicle operating costs, we find that congestion costs to the nation's motorists in the last year of our sample, 1996, amounted

[4] New York City and Newark, for example, are separate cities that form an urbanized area. In the few cases where one urbanized area spanned state lines and both states had a substantial amount of vehicle miles traveled, we divided the city's annual delay based on its state's share of vehicle miles traveled. Our sample excluded Anchorage, Honolulu, and Washington, DC, because we were unable to obtain a complete and accurate set of all the relevant explanatory variables for these cities.

[5] Congestion is also likely to increase vehicle wear and tear, but we are unable to obtain estimates of these costs. In any case, the increase in vehicle operating costs from congestion is primarily due to lower fuel economy from stop-and-go driving.

[6] Following TTI, we assume 1.25 people per vehicle. City wage data are from the Bureau of Economic Analysis. Although some peak-period road travelers may not be employed, it is reasonable to use the average wage because the TTI data focus on delay during peak periods when unemployed people are less likely to be traveling. Furthermore, motorists tend to have higher average incomes than people who use other modes to commute to work; thus, it is appropriate to induce some upward bias in the wage.

to roughly $27.5 billion (2000 dollars).[7] Our estimate is plausible, although it is considerably lower than those reported by TTI because they use a higher value of time for both motorists and truckers.

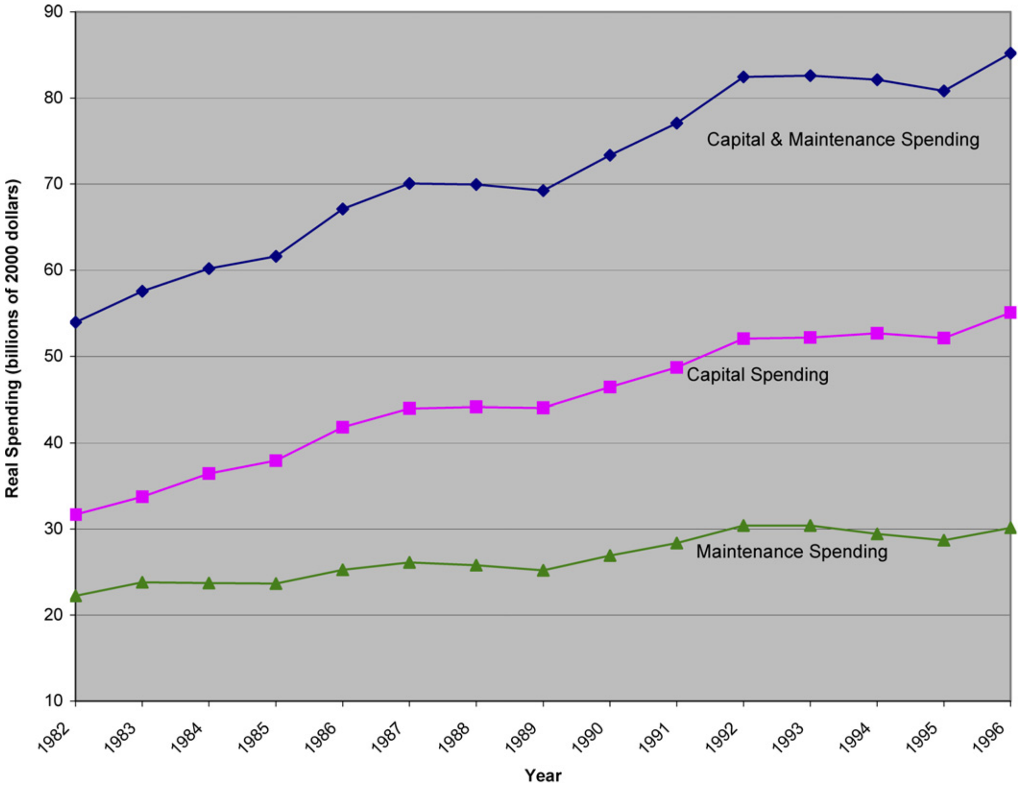
2.2. Measurement of highway spending and other explanatory variables

For each state in our sample, we obtained gross highway capital and maintenance spending by functional classification and location from annual volumes of the Department of Transportation's *Highway Statistics* and the 1997 US Federal Highway Administration's *Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance*. Note that state spending includes funds that are received from federal, state, and local sources. Federal funds are mainly used for capital outlays while their level is roughly equivalent to capital outlays funded by state and local governments. Capital outlays account for roughly two thirds of spending on road improvements, but only 20 percent is allocated for new roads and bridges (US Federal Highway Administration [5]). Indeed, since the early 1980s, highway spending has been primarily directed towards maintaining the highway capital stock rather than expanding it, as evidenced by the fact that highway mileage has grown only 2 percent during the period of our sample.

As shown in Fig. 1, total highway capital and maintenance spending in the United States has increased during the period of our sample with the aid of major federal legislation. Namely, the 1982 Surface Transportation Assistance Act instituted a 5 cents/gallon increase in the federal gasoline tax that enlarged the Highway Trust Fund, and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) increased support for highway demonstration projects and other road-related activities. Spending also increased because growth in automobile and truck travel during the period led to greater federal and state gasoline tax receipts. Figure 2 breaks down highway spending in our sample by road classification. Urban and rural arterials attract the most spending, rural freeways the least.

In our base case, we assume that the spending measures are exogenous because they are not systematically influenced by an urbanized area's congestion costs. As noted, spending is determined by formulas based to a significant extent on road mileage. However, we will test the assumption of exogeneity. Increases in spending that enhance road quality and expand capacity are likely to reduce a city's congestion costs, but this reduction will be offset by the extent of induced demand; thus, the effect of spending on congestion costs is not clear. The effect of spending could also be affected by the extent to which the state has invested in its highway capital stock. For example, capital spending may induce less demand and have a greater net effect on congestion costs in a state that has a well-developed road system. Thus, we explored interactions of the spending variables with a dummy variable indicating the per capita value of a state's highway capital stock in the year preceding spending compared with the per capita value

[7] Based on our sample, we estimate that annual congestion costs to motorists in 1996 were $24.5 billion (2000 dollars). Our sample accounted for 71.3 percent of national urban VMT. To convert our sample estimate to a national estimate, one might be temped to inflate the sample estimate by $1/0.713$ or 1.4. However, it is useful to test whether cities' congestion costs are proportional to their VMT. We found that the cities that accounted for 71.3 percent of the sample VMT accounted for 89 percent of the congestion costs in the sample, indicating that the largest cities account for a greater proportion of congestion costs. Thus, we would overestimate national congestion costs by inflating the sample estimate by 1.4. As a more defensible alternative, we obtain a national estimate of annual congestion costs by assuming the relationship between congestion costs and VMT in the sample is aligned with the relationship between congestion costs and VMT in the nation. Thus, we inflate the sample estimate by 1.12 ($1/0.89$).



Source: Highway Statistics, US Department of Transportation

Fig. 1. Real capital & maintenance spending on roads and highways in the continental United States, 1982–1996 (in 2000 dollars).

of other states' highway capital stock. Real state highway capital stock data come from Bell and McGuire [8].[8]

The political forces that surround highway spending suggest that its effect on congestion costs may be reduced for two reasons. First, political pressures may widen the gap in highly urbanized states between the money spent on a given city's roads and the city's level of congestion because several cities may "compete" for funds. Thus, based on data from the US Census, we explored whether any of the highway spending variables were affected if they were interacted with a dummy variable that indicated whether a state is highly urbanized.[9] Second, Altshuler and Luberoff [9] point out that states with members in Congress who occupy a position of party leadership in the House or Senate are likely to pursue funding for pet (pork barrel) projects that have little to do with reducing congestion. We control for this possibility by exploring whether

[8] The highway capital stock was estimated using the perpetual inventory method, in which the value of the capital stock in a given year is based on the current capital investment plus the sum of previous investments that have been adjusted for depreciation and discards. We used the FHWA composite price index to convert the states' highway capital stock to 2000 dollars.

[9] We assumed that a state was highly urbanized if 80 percent of its population lived in an urbanized area. Using alternative thresholds did not have a material effect on our findings.

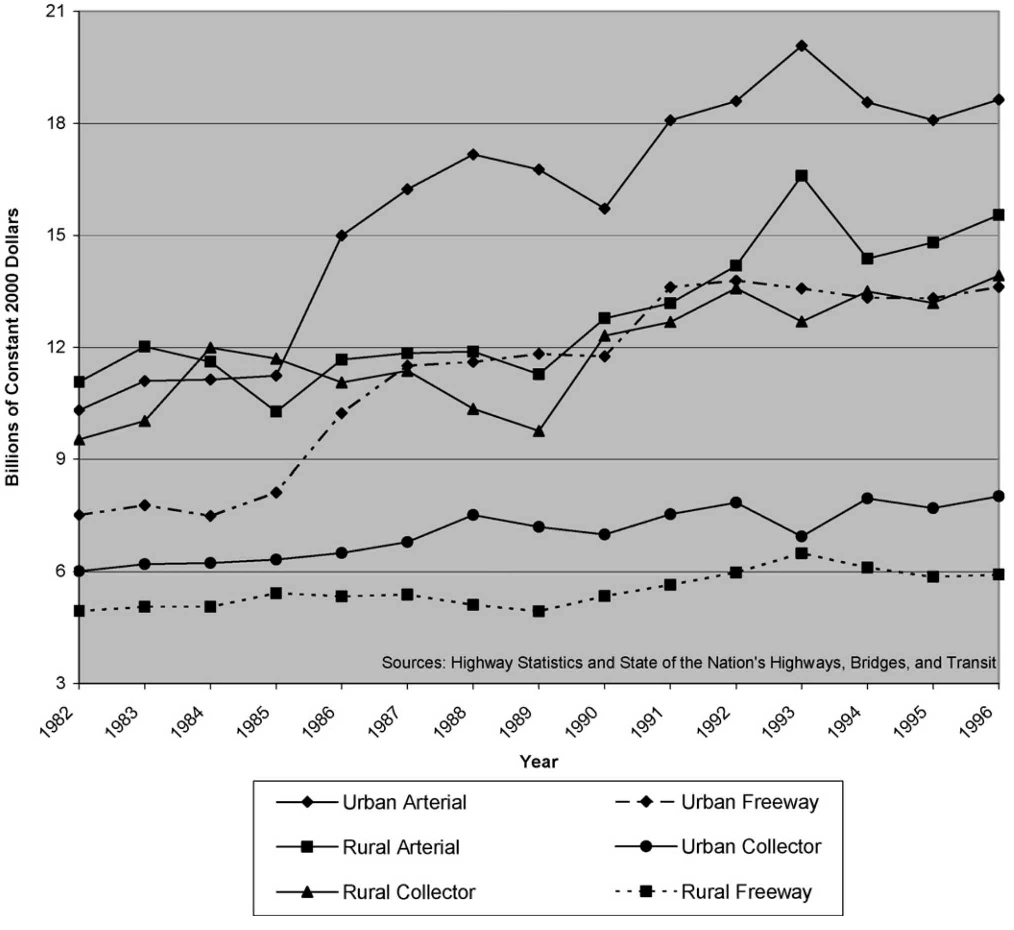


Fig. 2. Roadway spending in our sample by functional class, 1982–1996 (billions of constant 2000 dollars).

any of the spending variables were affected if they were interacted with a dummy variable that indicated whether at least one member of Congress from the state was in a position of national party leadership, defined in accordance with the *Congressional Directory*.[10]

Turning to the attributes of a city that may affect congestion, we included annual precipitation and the annual number of days with temperature over 90 degrees Fahrenheit to control for the effect of weather. Both variables were obtained from the National Oceanic and Atmospheric

[10] We also considered two other interactions that might capture factors that limit the effectiveness of highway spending. First, we interacted the highway spending variables with a dummy variable that indicated whether a city may be experiencing sprawl based on its population growth rate. However, this interaction was insignificant. Second, it could be argued that highway spending is less effective in highly unionized states that have high labor costs. However, federal highway wages are subject to the Davis Bacon regulations that require all highway workers to be paid the prevailing union wage rate. In addition, if state and local spending is supplemented by federal funds, which is likely for capital projects, then the regulations apply. Thus, variations in highway labor costs across cities are likely to be substantially reduced by Davis Bacon and have little effect on the relative effectiveness of highway spending. The cost of other inputs used to improve roads, such as asphalt, also does not exhibit much variation across cities.

Administration and should have a positive effect on congestion costs because they may impair pavement conditions and require drivers to reduce their speed or contribute to vehicle breakdowns that cause delays. We measured transit capacity with bus and heavy, light, and commuter rail directional route miles obtained from the *Section 15 Annual Report* (*National Transit Database*) of the Federal Transit Administration. We expect an increase in rail mileage to reduce congestion by attracting road users to rail. Similarly, an increase in bus mileage could reduce congestion by attracting motorists to bus, but it could also increase congestion because buses take up more road capacity per vehicle than cars and may disturb the traffic flow by stopping en route and accelerating slowly. Cities that provide exclusive bus lanes may improve bus service but also experience greater congestion because cars are prevented from using all of the available road capacity. Finally, we controlled for the salient features of a city's geography with a major interstate dummy, defined for cities with either a major north-south interstate (identified by a two-digit number ending in 5) or a major east-west interstate (identified by a two-digit number ending in 0). We expect this variable to have a positive sign because it captures the additional congestion caused by motorists who pass through the area. We also created a bottleneck dummy, defined for cities with few interstates or other roadways that traverse a major body of water (e.g., bay, river, or lake) that is located in a city. Bottleneck routes are prone to becoming congested because motorists often lack alternatives to such routes; thus, we expect this variable to have a positive sign.[11]

Two characteristics of road users that are likely to increase congestion costs in a city are the proportion of truck traffic and the level of employment. A greater share of trucks slows the traffic flow while higher employment leads to more commuters (i.e., traffic) on the road during peak periods. We obtained data on the percentage of VMT attributable to trucks from the Department of Transportation's Highway Performance Monitoring System and data on employment from the Bureau of Economic Analysis. Cities that have more road users, employed or otherwise, who travel during off-peak times will have lower congestion costs. We therefore included vehicle-miles-traveled off peak based on the TTI data. As discussed below, it is appropriate to include this variable because it is not related to highway spending.

3. Estimation results

Structural tests indicated that none of the estimated coefficients varied over time, and preliminary estimations revealed little empirical difference between specifying the spending variables as contemporaneous with congestion costs or with a lag; thus, we report results using current spending. However, we did find that it was appropriate to combine some of the spending variables, as their effects on congestion costs were not statistically different, and to allow others to have distinct effects. To enable us to compare and combine the estimation results for motorists and trucking operations and firms (presented later), we put all relevant variables in 2000 dollars using the consumer price index for urban consumers from the Bureau of Labor Statistics; for the highway spending variables, we used a construction cost index from the Federal Highway Administration.

[11] In addition to the variables discussed here, we also estimated specifications that included the number of days with freezing temperatures and, as an alternative way to account for the presence of a bottleneck, a dummy variable that indicated whether a city was adjacent to a body of water. However, these variables did not lead to improvements in the model.

Table 1
Coefficient estimates for motorists' congestion costs*
(Dependent variable: ln(Annual Congestion Costs in an Urbanized Area))

Explanatory variables (all variables in 2000 dollars, as appropriate)	Coefficient
Rural freeway spending divided by urbanized area residents	-9.61×10^{-4} (1.48×10^{-4})
Urban freeway spending divided by urbanized area residents	-1.08×10^{-4} (4.77×10^{-5})
Urban freeway capital spending divided by urbanized area residents interacted with a high capital stock dummy (1 if the state's capital stock divided by state residents is at or above the 80th percentile of the sample, 0 otherwise)	-4.48×10^{-4} (2.26×10^{-4})
Urban freeway capital spending divided by urbanized area residents interacted with above average capital stock dummy (1 if the state's capital stock divided by state residents is at or above the 60th percentile but below the 80th percentile of the sample, 0 otherwise)	6.66×10^{-4} (1.13×10^{-4})
Urban arterial spending divided by urbanized area residents	9.06×10^{-5} (4.84×10^{-5})
All other roadway spending divided by urbanized area residents (includes rural arterial, rural collector, and urban collector spending)	-4.65×10^{-5} (2.14×10^{-5})
Rail directional route mileage	-4.75×10^{-4} (2.65×10^{-4})
Bus directional route mileage (includes mixed right of way and combined right of way)	2.85×10^{-4} (9.38×10^{-5})
Exclusive right of way bus directional route mileage	0.0044 (0.0012)
Total annual precipitation (hundredths of inches)	4.41×10^{-4} (4.33×10^{-5})
Annual number of days with temperature over 90° F	0.0121 (0.0022)
Bottleneck dummy (1 if a major body of water in the urbanized area is crossed by two or fewer interstates and two or fewer other roadways, 0 otherwise)	0.4496 (0.1039)
Interstate dummy (1 if the urbanized area has a major interstate highway running through it, 0 otherwise)	0.7673 (0.1282)
Percentage of trucks in the traffic mix	0.4569 (0.0983)
Urbanized area employment	1.76×10^{-6} (2.67×10^{-7})
Urbanized area off-peak vehicle miles traveled	-3.80×10^{-5} (1.23×10^{-5})
Urbanized area volume–capacity ratio (daily vehicle miles traveled divided by system road miles)	–
State fixed effects included	*Yes*
R^2	0.86
Number of observations	1110

* White heteroskedasticity-consistent standard errors in parentheses.

Parameter estimates based on our semi-log specification of congestion costs are presented in Table 1. We include state fixed effects because, in general, they were statistically significant and had little effect on the spending coefficients. We also experimented with city fixed effects, but they tended to be statistically insignificant. Finally, we did not include year dummies or a time trend in the base model because they would tend to capture changes in VMT that would affect the spending coefficients. We did estimate a model that included the real price of gasoline to capture a broad exogenous influence on congestion costs that varied over time but was not affected by highway spending; however, it was statistically insignificant.

3.1. Highway spending

As noted, the a priori effect of spending on congestion costs is not clear because it produces conflicting outcomes: improvements in road quality and capacity that reduce delays, and additional traffic attracted to the improved (and possibly unimproved) roads that increase delays. We find that rural freeway and urban freeway spending (it was statistically justifiable to combine capital and maintenance expenditures) have statistically significant effects on a city's congestion costs and that the effect of the capital component of urban freeway spending varies in accordance with the value of a state's highway capital stock. The first two coefficients capture the base effect of urban and rural freeway spending and indicate that both types of spending reduce congestion costs in an urbanized area. Urban freeway spending has a smaller effect than rural freeway spending, most likely because it induces traffic while rural freeway spending diverts traffic from an urbanized area as it contributes to the growth of employment and housing in the exurbs.

The interaction terms between urban freeway capital spending and a state's capital stock indicate how the efficacy of spending is affected by the extent and quality of a state's road system. We find that an increase in urban freeway capital spending in states that have the highest per capita investments in their capital stock (e.g., Washington) reduce a city's congestion without inducing offsetting demand because such states have a highly developed road network that gives motorists sufficient alternative routings to reach their destinations.[12] In contrast, we find that an increase in urban freeway capital spending in states (e.g., Maryland) that have merely above average investments in their capital stock increase a city's congestion costs. In these states, the road network is sufficiently developed to serve a high volume of traffic. But when improvements to certain stretches of an urban freeway induce demand, the additional traffic may create congestion on other roads that may already be near congested conditions. Because these states have not invested in their road system to the highest extent, few alternative routings are likely to exist to diffuse the induced demand over an extensive road network. Thus, even if delays are reduced on part of an urban freeway that is improved, delays and congestion costs are likely to grow on unimproved roadways, resulting in a net increase in a city's congestion costs.

Turning to the remaining spending coefficients, increases in urban arterial spending increase congestion costs. Similar to the preceding explanation, even if delays are reduced on an urban arterial that has been improved, induced demand may increase delays on unimproved freeways (and entrance and exit ramps) during peak periods. Given that most urban freeways operate under congested conditions during the peak—regardless of a state's investment in the highway capital stock—a city's overall congestion costs will increase.

Finally, spending on collectors and rural arterials reduces congestion costs, but not surprisingly the effect is much smaller than the effect of most freeway spending. The effect of spending on such roadways is, in general, likely to be confined to addressing their modest levels of congestion without inducing much demand that affects delays on unimproved arterials and freeways. It is notable that we were unable to obtain a significant effect of any of the spending variables

[12] For each year, we constructed dummy variables categorizing states within each decile of the sample based on the value of their per capita highway capital stock in the preceding year. We then interacted these dummies with state urban freeway capital spending per urbanized area resident to measure the relative effectiveness of this type of spending for different levels of highway capital investment. We obtained the best statistical fit indicating clear differences among states by characterizing states at or above the 80th percentile as states with high per capita capital stock and states at or above the 60th percentile but below the 80th percentile as states with above average per capita capital stock. We did not find any statistically significant effects for states whose capital stocks were in lower percentiles.

interacted with a state urbanization or party leadership dummy variable, suggesting that such political effects may be captured in a diffuse way by the disaggregate spending variables.[13]

We have argued that the highway spending variables should be treated as exogenous because they are not systematically influenced by an urbanized area's congestion costs. We tested this assumption with a Hausman specification test using rural freeway, urban freeway, urban arterial, urban freeway capital interacted with capital stock dummies, and other spending in all other states as instruments for these spending variables in a given state. We could not reject the exogeneity of all the highway spending variables at a high level of statistical significance (the Hausman test statistic is 3.06 while the chi-squared critical value at the 95 percent significance level is 12.59).

In sum, we find that most types of highway spending reduce congestion costs, but urban arterial spending and urban freeway capital spending in cities located in states with slightly above average per capita investment in their highway capital stock raise congestion costs. Using the coefficients, we estimate that one dollar of highway spending, accounting for all types of spending, in the last year of our sample, 1996, reduced motorists' congestion costs only 2.6 cents in that year (2000 dollars).[14] Note that this benefit is not an ongoing return, but only applies to the year in which spending occurred.[15] Although our estimate is roughly proportional to the value of time that is assumed, the estimate is sufficiently small that the overall finding that spending has a small effect on congestion costs is not affected by the assumed value. For example, if we assume that motorists' value time at 75 percent of the wage instead of 50 percent of the wage, congestion costs are reduced 3.8 cents per dollar of spending. If we assume that motorists value time at 25 percent of the wage, costs are reduced 1.3 cents per dollar of spending.[16]

Of course, highway spending serves other purposes such as beautification and improving safety, but a large fraction of available funds are channeled into activities that presumably attempt to reduce congestion (US Federal Highway Administration [5]). Thus, our estimate seriously questions the cost-effectiveness of current spending priorities if policymakers wish to achieve that goal.

[13] We found that the urbanization and party leadership dummies reduced the effect of spending on congestion costs when we just specified total state highway spending instead of its disaggregate components. We also explored whether the effect of any of the spending variables changed when a state had more than one city in our sample. We specified a dummy variable to identify urbanized areas from the same state, but this only affected the state fixed effects. We also interacted the dummy with the highway spending variables, but none of these interactions were significant.

[14] We obtained this figure by first using the estimated coefficients to predict congestion costs in our sample with and without 1996 highway expenditures by states. We inflated the difference by 1.12, as discussed in footnote 7, to obtain the effect of spending on congestion costs for the nation. We then divided this figure by 1996 total capital and maintenance spending, $85.2 billion (2000 dollars). If we constructed the inflator by assuming that our sample accounted for 71.3 percent of congestion costs (i.e., its share of VMT equaled its share of congestion costs), then the congestion cost savings from one dollar of spending would be 3.2 cents. Finally, the congestion cost savings per dollar of spending based on all years in the sample was 3.4 cents, indicating that spending has become somewhat less effective in reducing motorists' congestion costs.

[15] It could be argued that highway spending in 1996 would reduce congestion costs in future years by adding to the value of the capital stock. But such spending supplemented the value of each state's capital stock only six percent on average. In addition, any benefits from this modest improvement in the capital stock would be reduced significantly by depreciation in just a few years. Given that we found that spending reduced motorists' congestion costs only about three cents in the year that spending occurred and that additional cost savings in the future would be much smaller, our assessment of the efficacy of highway spending should not be affected by long-run considerations.

[16] It is possible that highway spending could affect the observed wage of drivers by changing their socioeconomic mix. However, such changes are likely to be small and within the range of our sensitivity analysis.

3.2. Other parameter estimates

Many urban planners have argued that bus and rail transit merit subsidies partly on the grounds that these modes help reduce congestion. We find that an increase in rail transit mileage reduces congestion costs, but bus service actually *increases* congestion costs to motorists, especially when it operates on exclusive bus lanes. Buses disrupt the traffic flow when they share road capacity and contribute to motorists' congestion by having exclusive use of available road capacity that would otherwise be available to all vehicles. Moreover, bus systems operate with very low load factors (roughly 15 percent over the course of the day, moderately higher during peak periods) and transport only a small share of urban travelers.

The remaining variables have their expected signs and are statistically significant. Annual precipitation, days with extremely high temperatures, routes with potential bottlenecks, a major interstate running through the city, a greater share of truck traffic, and higher levels of employment increase a city's congestion costs. Greater off-peak travel decreases these costs.[17] Although it may be argued that the share of truck traffic or the presence of bottleneck routes or a major interstate may be influenced by highway spending, we found that the effect of spending on congestion costs varied by no more than 6 percent when we included the city and user characteristics individually or collectively in the model.[18]

We have stressed the importance of allowing the volume–capacity ratio to vary because failure to do so in a model of congestion across cities may bias our estimates of the effect of spending on congestion costs.[19] However, we did explore the effects of induced demand by estimating a model that held the citywide volume–capacity ratio constant. In this specification, we specified total highway spending in a state, instead of disaggregate measures of highway spending, because we were not able to hold the volume–capacity ratios of specific road classifications constant.[20] Thus, the spending coefficient now captures the effect of spending on congestion costs when traffic volume is adjusted to keep the citywide volume–capacity ratio constant; but given that

[17] As noted, the reason for including the off-peak VMT variable is to capture demographic differences between cites such as the share of workers who do not commute during peak times. However, it is possible that this variable could capture motorists who shift from peak travel to off-peak travel because of high congestion costs. If this were the case, we would expect that the inclusion of off-peak VMT in the specification would increase the spending coefficients because people would be prevented from shifting to peak times (i.e., we would not be accounting for a specific source of induced demand). But we found that some of the spending coefficients decreased slightly when we included the off-peak VMT variable in the model.

[18] We also explored the effects of including other variables in the model, such as road quality, urban density, and a time trend, that may affect congestion costs but also may be affected by highway spending. We tried to measure road quality using the pavement serviceability index, but the definition of the index in *Highway Statistics* changed during our sample period. It is possible that congestion would be higher in cities with smaller land areas for a given population because of higher traffic densities. However, spending could expand commuter possibilities and extend urbanized area boundaries. We included the square miles for an urbanized area, assuming constant growth between decennial censuses, and found that it reduced the effect of some of the spending variables. It is also possible that congestion costs are affected by unobserved effects over time such as technical change in vehicle handling and breaking that enables vehicles to travel closer together at higher speeds. We therefore specified a time trend to capture this possibility, but it had a positive effect on congestion costs while reducing some of the highway spending coefficients. We suspect that the time trend was also capturing growth in VMT, some of which may be related to highway spending.

[19] Of course, congestion on particular thoroughfares in a given city is typically explained by the volume–capacity ratio.

[20] Accurate estimates of capacity—that is, *lane* miles for urban and rural roads by functional classification for the cities in our sample—were not available. Including citywide or functional class volume–capacity ratios in the model does not completely eliminate the effect of induced demand because delay could increase if drivers alter their route or time of day of travel.

capacity increased a small amount during the period covered by our sample, traffic volume will only change a small amount to keep the ratio constant.

The parameter estimates, available upon request, indicate as expected that the effect of highway spending on congestion costs increased when the volume–capacity ratio was held constant because improvements in road quality and capacity that reduced delays were not offset by induced demand. However, highway spending's ineffectiveness cannot be explained or justified by the additional traffic it induces because the effect of a dollar of spending on motorists' congestion costs only grew about a cent when the volume–capacity ratio was held constant.

4. Empirical models of congestion costs for trucking operations and firms

Congestion also reduces the efficiency of the surface freight sector of the US economy. Firms engaged in activities such as manufacturing, agriculture, and construction (hereafter firms) use for-hire trucking companies and provide their own trucking service to transport freight within and between cities. When traffic congestion increases the time that it takes truckers to deliver shipments, trucking operations incur the opportunity cost of the driver's time and higher vehicle operating costs. In addition, firms incur the costs associated with holding higher inventories to avoid shortages and stockouts that arise when demand for their products exists but none are in inventory. Of course, when congestion imposes costs on trucking companies, these costs are likely to be passed on to firms in higher rates given that trucking operations are highly competitive. However, we will estimate separate models for truckers and firms, rather than combining their congestion costs and estimating a single model, because highway spending may have different effects on these users' congestion costs.

4.1. Sample and measurement of truckers' congestion costs

Truckers are potentially exposed to congestion at the origins of the shipments, the locales that the shipments pass through en route to their destinations, and at the destinations. Congestion raises the cost of trucking operations because drivers are still "on the clock" and must be paid for the additional time spent on deliveries regardless of whether they are sitting in traffic or traveling to their destination at reduced speeds. In addition, trucks suffer losses in fuel efficiency and require greater maintenance when they are driven at reduced speeds or in stop-and-go driving conditions. The annual costs of congestion to truckers can be measured as the product of the hourly value of delay per vehicle, including labor and capital costs, and the annual vehicle hours of delay.

Our empirical analysis of the effect of government highway spending on truckers' congestion costs is based on shipping activity between and within 51 of the largest metropolitan statistical areas (MSAs) in the country during 1997 (intercity delay data were not available until that year). We used the 1997 US Census Commodity Flow Survey to determine the number of heavy vehicles transporting freight between and within the MSAs in our sample.[21] The vehicles account for 34.6 percent of the tons of freight shipped by truck in the United States. Note that 70 percent

[21] The Commodity Flow Survey reports tons of freight shipped between and within MSAs. To determine the number of heavy vehicles used to carry freight, we assumed each truck carries, on average, 12.5 tons or 25,000 pounds. This assumption is reasonable given that trucks that are fully loaded typically carry no more than 20 tons and that some trucks run empty or are partly loaded. Our findings did not change noticeably when we assumed that trucks' average loads were 15 tons or 10 tons.

of the tons of freight shipped by truck are transported less than 50 miles; we capture a share of those shipments that are made within the congested cities in our sample.

We used the TTI data to estimate the delay for shipments within an MSA. We obtained estimates of average delay between MSAs (i.e., the 51-by-51 off-diagonal origin destination pairs in our sample) from the Freight Analysis Framework (FAF) developed by the FHWA Office of Freight Management Operations. FAF routes intra- and interstate shipments throughout the country and determines the delay that trucks experience between MSA origins and destinations. Data on traffic volumes and road characteristics that might affect delay, such as shoulder width, inclines, and curves, are collected from state departments of transportation. Using the *Highway Capacity Manual*, delay is calculated as the difference between free-flow speeds, accounting for road characteristics, and estimates of travel speeds under congested conditions based on actual traffic volumes and speed-flow curves.[22] The estimates of delay are quite reasonable. For example, shipments between New York City and Los Angeles were delayed 3 hours by congestion, shipments between Los Angeles and San Francisco delayed 1.5 hours, and shipments between Kansas City, Kansas, and Kansas City, Missouri, delayed only 4 minutes.

The cost of congestion for each vehicle has three components: labor, fuel, and maintenance. Credible estimates of the cost of an hour of delay are roughly \$24 for average compensation, including wages and benefits, and \$2 for diesel fuel. We assumed \$4 for maintenance to bring the \$30 per hour total in line with the National Cooperative Highway Research Program's [10] estimates.[23] We also performed estimations using alternative values of the hourly cost of congestion. We estimated annual congestion costs incurred by trucks transporting freight from a given origin to a given destination. Summing over all origin–destination pairs, our estimate of congestion costs for the nation's trucking operations in 1997 is \$2.46 billion (2000 dollars), which is in proper proportion to motorists' congestion costs, as discussed below.[24]

4.2. Measurement of firms' congestion costs

Firms that receive freight shipped by trucks are also affected by congestion at the origins of the shipments, the locales that the shipments pass through en route to the firms' destinations, and at the destinations. Congestion raises firms' costs because it ties up their inventory in transit, thereby forcing firms to hold higher inventories to reduce the probability of a stockout caused by late deliveries. In addition, delays caused by congestion could depreciate the value of perishable shipments such as fresh fruit. The costs that firms attach to the additional time that shipments spend in transit are captured in an implicit discount rate which indicates the loss they incur, as a

[22] We are grateful to Bruce Lambert of the FHWA for his assistance in procuring delay data based on FAF.

[23] Driver wages of roughly \$18 per hour are reported in the Bureau of Transportation Statistics' 2000 *Motor Carrier Financial and Operating Information Report*. We inflate this figure 30 percent to account for fringe benefits. The additional diesel fuel costs are obtained by using TTI's assumptions that trucks travel at 60 miles per hour in free-flow conditions and 37.8 miles per hour in congestion and calculating fuel usage based on the Federal Highway Administration's *Highway Economic Review System* fuel economy equations. We use the US Census *Vehicle Inventory and Use Survey* to calculate a weighted average of additional fuel costs based on the distribution of truck sizes and trailer configurations in the country.

[24] Truckers' congestion costs in our sample are \$1.13 billion (2000 dollars). As noted, the sample accounts for 34.6 percent of tons of freight shipped by truck in the United States. The cities that compose 34.6 percent of the sample account for 46 percent of the truckers' congestion costs in the sample, indicating that the largest cities account for a greater proportion of congestion costs. Following the argument in footnote 7, we therefore multiplied the sample estimate by 2.17 $(1/0.46)$ to obtain a national estimate of the cost of congestion to truckers.

percentage of shipment value, for each day that their shipments are delayed. The annual costs of congestion to firms can be measured as the product of an implicit daily discount rate, the annual value of shipments, and the average delay in days that shipments incur because of congestion.

As in the case of truckers, our empirical analysis is based on shipping activity between and within 51 of the largest metropolitan statistical areas (MSAs) in the country during 1997. We used the 1997 US Census Commodity Flow Survey to obtain the value of commodities shipped by truck between and within the MSAs in our sample. The sample accounts for 33.8 percent of the national value of goods shipped by truck. Note that a significant fraction of the value of freight shipped by truck is not exposed to congestion because it is transported short distances or consists of basic manufacturing inputs such as basic metals and chemicals that are hauled between low-density areas. We used the TTI data to estimate the delay for shipments within an MSA and the Freight Analysis Framework to obtain estimates of average delay between MSAs. We classified commodities as either perishable (e.g., fresh produce), bulk (e.g., gravel), or other to quantify shippers' implicit discount rate. Based on estimates derived from Winston's [11] freight demand model, we assumed for our base case that firms' daily discount rate is 15 percent for perishable commodities, 5 percent for bulk commodities, and 10 percent for other commodities.

We estimated annual congestion costs for firms at each given destination that received freight from each given origin. Summing over all origin-destination pairs, our estimate of the congestion costs for the nation's firms in 1997 is \$7.58 billion (2000 dollars).[25] Thus, adding this figure to the \$2.46 billion in congestion costs incurred by truckers yields roughly \$10 billion in congestion costs for the surface freight sector. Although truck traffic represents roughly 5 percent of all vehicle miles, our estimate indicates that the freight sector experiences a much higher share, 27 percent (\$10 billion/\$37.5 billion), of annual congestion costs. This should be expected because truckers travel through multiple urbanized areas to deliver shipments whereas motorists typically travel between their residence and workplace in a given city. In addition, the hourly cost of delay for truck transportation is typically much higher than the hourly cost of delay to auto travelers. For example, based on our assumptions, the average value of an hour of delay for a passenger vehicle is \$9.71, while the average value of an hour of delay for a truck, accounting for truckers' costs (\$30/hour) and firms' costs (\$33.69 per hour, as implied by the inventory costs of congestion), is \$63.69.

4.3. Specifications

Similar to our model for motorists, we specify the congestion costs of trucking operations that transport freight to a given MSA and of firms in a given MSA that receive freight to be a semi-logarithmic function of highway spending variables, city attributes, and road user characteristics (allowing variables that may be affected by highway spending to vary). Initial estimations indicated that of the different types of highway spending, only urban freeway and arterial spending had a statistically significant effect on truckers' and shippers' congestion costs. This is not too surprising because truckers' journeys may take them through several congested regions, which may diffuse any effect of rural road spending. In addition, trucks tend to travel on urban collec-

[25] Firms' congestion costs in our sample are \$2.98 billion (2000 dollars). The sample accounts for 33.8 percent of the value of goods shipped by truck. The cities that make up 33.8 percent of the sample account for 39.3 percent of the congestion costs in the sample, indicating that the largest cities account for a greater proportion of congestion costs. Thus, to obtain a national estimate of the cost of congestion to firms, we multiplied the estimate derived from the sample by 2.54 (1/0.393).

tors only for relatively short distances at the beginning and end of a haul; thus, we did not include other types of road spending in the model.

Given that truckers' and firms' congestion costs reflect delay that is in-state and possibly out-of-state, we explored ways to expand the geographic scope of some of the explanatory variables. Shirley and Winston [12] report the value of the highway capital stock varies markedly by the nine Census geographic divisions. We therefore interacted highway spending with a dummy variable for each Census division to explore how the effect of spending on truckers' and shippers' congestion costs varies with a division's investment in its capital stock. We also included as a separate variable highway spending in all other states (out-of-state spending) where freight may be shipped to a given MSA. However, we did not find that out-of-state spending had a statistically significant effect on congestion costs, presumably because one state's spending tends to have a diffuse influence on the delay experienced by trucking operations in another state. We control for intermodal competition from water carriers that may reduce intercity freight traffic by including a dummy variable that indicates whether the MSA has direct access to ocean shipping.[26] And we account for congestion caused by trucks in the traffic mix and urbanization by measuring these variables at the state level.[27] Other influences on truckers' and firms' congestion costs that are important only in urbanized areas, such as bus route mileage, are measured at the MSA level.

5. Estimation results

As shown in Table 2, spending on urban freeways and arterials (it was statistically justifiable to combine both types of spending) reduces congestion costs for trucking operations and firms and the effect is statistically significant. We could not reject the hypothesis that this spending is exogenous and obtained the best statistical fits by dividing it by MSA residents. We also find that total highway spending is more effective in reducing congestion costs in the New England and Pacific Census divisions than in other divisions. This finding suggests there are increasing marginal returns to truckers and firms from road spending in broad geographical regions that have a low value of highway capital stock per capita.[28]

Based on the coefficients for each model, we estimate that one dollar of state highway spending, accounting for all types of spending, in 1997 reduced truckers' congestion costs 5.1 cents (2000 dollars) and reduced firms' congestion costs 3.3 cents (2000 dollars) in that year.[29] Given that truck journeys are potentially subject to delays in multiple MSAs and that congestion is

[26] Rail and inland water carriers also provide intermodal competition for intercity trucking operations, but it was difficult to construct measures that indicated the degree to which MSAs were or were not served by these alternative modes.

[27] Data for the number of truck registrations at the state level are from the 1997 US Census Truck Inventory and Use Survey. It is unlikely that this variable is influenced by highway spending (or congestion costs) because trucks are typically registered in states where motor carriers base their operations, which is influenced by tax rates and network considerations.

[28] This interpretation should be qualified because the dummies could also capture other divisional differences such as topography that may influence the effectiveness of spending.

[29] We obtained these figures by using the coefficients to predict congestion costs for truckers and firms in our sample with and without 1997 highway spending and inflating these values by the appropriate inflators given in footnotes 24 and 25. We then divided the congestion cost savings by 1997 total capital and maintenance spending. Our findings were not particularly sensitive to the assumptions that we made to construct congestion costs. For example, if we doubled (halved) the assumed discount rates for firms, then their average cost savings per dollar of highway spending were 8.0 cents (1.4 cents). If we increased or decreased the assumed \$30 hourly cost of congestion for trucks by \$5, then the congestion cost savings per dollar of highway spending changed by less than one cent.

Table 2
Coefficient estimates for freight sector congestion costs*
(Dependent variable: ln(Congestion Costs in an MSA))

Explanatory variables (all variables in 2000 dollars, as appropriate)	Trucking operations	Firms
Urban freeway and arterial spending divided by metropolitan statistical area residents	−0.7018 (0.1950)	−0.3512 (0.1156)
State highway spending divided by metropolitan statistical area residents interacted with a regional dummy (1 if the city is in the New England Census Division, 0 otherwise)	−2.3966 (0.4138)	−0.9103 (0.4235)
State highway spending divided by metropolitan statistical area residents interacted with a regional dummy (1 if the city is in the Pacific Census Division, 0 otherwise)	−0.3650 (0.1389)	−0.1656 (0.0670)
Rail directional route mileage	-7.34×10^{-4} (5.11×10^{-4})	-6.97×10^{-4} (3.30×10^{-4})
Exclusive right of way bus directional route mileage	0.0048 (0.0025)	0.0055 (0.0015)
Total precipitation (hundredths of inches)	3.13×10^{-4} (5.11×10^{-5})	1.16×10^{-4} (3.35×10^{-5})
Registered trucks in the state (thousands)	0.0042 (0.0013)	0.0029 (7.55×10^{-4})
Metropolitan statistical area employment	6.23×10^{-7} (8.92×10^{-8})	2.00×10^{-7} (6.54×10^{-8})
Percent of state population in urban areas	0.1039 (0.0045)	0.0333 (0.0030)
R^2	0.67	0.84
Observations	51	51

* White heteroskedasticity-consistent standard errors in parentheses.

much more costly on an hourly basis for truckers and firms than for motorists, it is understandable that the average effect of one dollar of spending on the freight sector's congestion costs, 8.4 cents, exceeds its average effect on motorists' congestion costs, 2.6 cents. A further consideration, which we discuss in more detail below, is that the relative impact of spending on motorists and the freight sector is strongly affected by how expenditures are allocated among locations and functional classes. In any case, the combined eleven cents reduction in road users' congestion costs in the year in which a dollar of spending occurs is quite small.[30]

In contrast to the parameter estimates for motorists, we did not find that variables that may affect the spending coefficients if they were included in the model (e.g., the volume–capacity ratio), had a statistically significant effect on truckers' and firms' congestion costs, possibly because many vehicles travel through (or around) many MSAs, some of which may be out of state.[31] We also did not find that some variables that had a statistically significant effect on motorists' congestion costs, namely the interstate and bottleneck dummies, extremely high temperatures, and off-peak travel, had a statistically significant effect on truckers' and firms' congestion costs.

[30] Shirley and Winston [12] found that the rate of return from highway investments during the 1990s was only about 1 percent. Their estimate was based on firms' logistics cost savings and did not include congestion cost savings. According to the findings here, congestion cost savings would not add much to the rate of return.

[31] We measured the volume–capacity ratio at the MSA and state level. We were not able to construct a measure of it that accounted for out-of-state traffic.

However, several other influences do parallel and a few extend our qualitative findings for motorists. Bus transit system mileage, precipitation, registered trucks, and higher levels of employment and urbanization increase truckers' and firms' congestion costs, while rail transit capacity decreases these costs. Intermodal competition from water-based competitors had a statistically insignificant effect. As we found previously, including these variables in the model had little effect on the spending coefficients.

6. Efficient allocation of highway funds among and within states

Congestion costs vary significantly among and within states, but the allocation of highway funds is not based on these variations. It is therefore likely that highway spending would be more effective in reducing road users' congestion costs if expenditures were explicitly targeted to the areas in the country with the greatest congestion. We estimated how much the cost-effectiveness of highway spending would improve if funds were allocated to states' urban or rural locations, and functional classifications within a state to minimize total highway costs, *TC*, composed of road users' congestion costs and state highway expenditures, subject to the current level of highway spending. Formally, the problem can be expressed as:

$$\min_{s_i} TC = \sum_i C_m(s_i) + C_t(s_i) + C_f(s_i) + s_i \quad \text{s.t.} \quad \sum_i s_i = S,$$

where s_i is highway spending by state i with distinct expenditure, urban or rural location, and functional classification components, C_m, C_t, and C_f are motorists', truckers', and firms' congestion cost functions as respectively given in Tables 1 and 2, columns 1 and 2, and S is the current level of highway spending in the nation (all appropriate variables are in 2000 dollars).

We first found that congestion costs would be reduced \$6.46 billion, or some 20 percent of the annual congestion costs incurred by road users, if state highway expenditures were allocated among states to minimize total highway costs.[32] When spending is optimized across states and within states, cost savings nearly double to \$12.2 billion, or almost 40 percent of the annual congestion costs incurred by road users. Spending on rural freeways in the most congested states, such as California, Florida, and Washington, would sharply increase while most other roadway spending would be reduced. Highway spending thus appears to be most effective at reducing congestion costs when it is able to divert road users from congested urban areas. Such a strategy may also contribute to sprawl, but it is nonetheless more effective at reducing congestion than expenditures on urban roads that may be extremely expensive and induce offsetting demand.

Optimal spending would curtail spending throughout the country—which benefited truckers relative to motorists because truck journeys often encounter congestion in multiple small and large urbanized areas en route—in favor of greater expenditures near highly congested cities in a few states, which benefits motorists relative to truckers because of their large share of traffic during peak-periods. Hence, under optimal spending motorists' congestion costs would decrease \$14.21 billion, while truckers' and firms' congestion costs would increase \$0.77 billion and \$1.24 billion respectively.

Accordingly, the effect of a dollar of highway spending in reducing motorists' congestion costs would increase from 2.6 to 19.3 cents, while its effect on truckers' and firms' congestion costs would decrease from 8.4 to 6 cents. Thus, the combined savings in annual congestion costs

[32] We determined the cost savings in the sample from minimizing total highway costs and used the inflators for motorists, truckers, and firms to obtain national cost savings.

from a dollar of spending would increase from 11 to 25.3 cents. This represents a clear improvement for road users overall and partly illustrates why current policy is inefficient. Nonetheless, even with a more efficient allocation of funds among and within states, highway spending is still not a cost-effective way to reduce congestion. In fact, we have overestimated the gain because some states would actually be given less money than they raised from their gasoline tax and general revenue. Incorporating a minimum spending constraint to prevent this possibility from occurring would reduce the estimated savings.

7. Discussion and policy implications

We have estimated that one dollar of government spending on highways in a given year reduces road users' congestion costs eleven cents that same year. Given that motorists, trucking operations, and firms incur \$37.5 billion in annual congestion costs, states would have to spend nearly \$350 billion annually to eliminate these costs.[33] Nor is reallocating funds among and within states to minimize congestion costs a realistic option. To be sure, highway spending serves functions other than reducing congestion, but it is clearly an inefficient way to address the problems caused by congestion. Such spending also does not appear to substantially increase throughput, which would benefit certain travelers.

Why is government spending so ineffective at reducing congestion costs? Shirley and Winston [12] argue that highway spending is compromised by inefficiencies related to pork barrel politics, by slow and inappropriate responses to demographic changes, by excessive maintenance expenditures caused by poor road design, and by inflated labor costs attributable to the Davis Bacon Act. Roth [13] points out that no explicit mechanism now links state highway expenditures with congestion in specific localities.

But the most fundamental obstacle to effective highway spending is that the US intracity road system is largely complete and the nation's urbanized areas have little available land to expand their infrastructure. As noted, cities that are experiencing sprawl can improve their road system, but these infrastructure investments yield a modest reduction in current congestion costs. In most congested cities, it is extremely difficult or prohibitively expensive to widen major freeways and arterials to reduce congestion or for such construction to keep up with traffic growth. Notwithstanding the nation's \$15 billion investment to improve Boston's traffic flow, it is highly doubtful that another US city will have the opportunity to replicate that experience or that projects on such a scale come close to being cost effective. And highway spending to rehabilitate lanes and occasionally widen an arterial can, at best, have a small effect on delays in most US cities. Instead of being used as the primary combatant against congestion, road spending could potentially play an effective supplemental role if it were based on careful cost-benefit considerations.

The implication of this conclusion is that the nation must change its approach to reducing congestion costs. Economists have argued that road pricing should be the primary approach, especially because it is effective during the very rush hours that would otherwise require the most expensive capacity expansions. Moreover, unlike spending, road pricing produces benefits without using public financial resources. The only government spending required is the modest sums to set up the initial tolling mechanism. If road pricing were tied to modest reductions in highway spending, then states could improve their budgets (or use these funds for more socially desirable purposes) without fear that these spending cuts would significantly increase congestion.

[33] This figure clearly overstates the annual amount of highway spending that would be required to eliminate congestion costs because such huge additions to the capital stock would undoubtedly reduce congestion costs greatly in future years.

Notwithstanding its contribution to efficiency, congestion pricing is criticized—and dismissed as politically infeasible—because it would primarily benefit high-income motorists who value the time savings. However, Small, Winston, and Yan [14] show that road prices can be adjusted to account for motorists' different preferences and substantially reduce distributional concerns while producing efficiency gains. In contrast, current highway spending is financed primarily by the gasoline tax, which is generally considered to be regressive (Chernick and Reschovsky [15]). We are not aware of estimates of how road pricing would affect the freight sector, but given their high value of time, truckers and shippers are likely to find that efficient congestion tolls are cost effective. Moreover, they would likely pass on some of the cost savings to consumers.

In the final analysis, policymakers' lack of interest in congestion tolls may have less to do with pricing's distributional effects than with the distributional effects of highway spending. Highway spending supports projects so politically popular with federal, state, and local policymakers and constituents that Senator Rick Santorum recently warned lawmakers "not to get between a congressman and asphalt, because you will always get run over."[34] Instituting congestion pricing for road users would not only be a far more effective solution to clogged roads than current state highway spending but would also justify a reduction in public expenditures. Road pricing's fatal flaw may be that it threatens one of the most visible ways that elected officials reward their supporters.

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