The Impact of Congestion on Shippers' Inventory Costs

Final Report to Federal Highway Administration

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Introduction and Summary

Our previous report analyzed the extent that government spending on highways lowered firms' inventory and logistics costs. In that analysis, highway congestion was treated as a control variable. However, the impact of congestion on firms' inventories may be important in its own right. Unfortunately, popular and scholarly studies of the social costs of congestion have typically focused on motorists and failed to offer even a rough estimate of how firms' costs are increased by delays in the shipment of their goods.

Firms engaged in shipping goods (hereafter shippers) are exposed to congestion at the origin of their shipment (e.g., an MSA), the locales that the shipment passes through enroute to its destination, and at the destination (e.g., another MSA). In theory, congestion raises shippers' costs because it ties up their inventory in transit. Shippers will value the additional transit time in terms of an implicit discount rate that is aligned with the depreciation of their goods. For example, shippers of newspapers are likely to have a very high daily discount rate because the value of their commodity will depreciate substantially if its delivery is delayed by a day, while shippers of less perishable commodities will have lower discount rates. In addition, congestion forces a shipper to hold higher inventories, which increases inventory holding costs.

In this report, we present estimates of the costs of congestion to shippers using three different methodologies. The first is based on our previous econometric analysis of the impact of highway spending on shippers' inventory and logistics costs. We develop a more precise measure of congestion than in our earlier model and obtain an econometric estimate of congestion's impact on inventory and logistics costs. The second is based on data from the Texas Transportation Institute that estimates delays incurred in major urbanized areas. We combine these data with an independent estimate of shippers' value of transit delay to estimate the costs of congestion. The third estimate draws on the FHWA's Freight Analysis Framework, which routes intra and interstate shipments throughout the country and determines the total delay incurred between origin and destination MSA's. We combine these delay estimates with an independent estimate of shippers' value of transit delay to estimate the costs of congestion.

Our findings are very consistent across methodologies, when controlling for the different geographical sources of congestion. The econometric model controls for congestion at the state level and therefore does not capture the costs of congestion at the origin or out-of-state portion of interstate shipments. But it does capture the full costs of congestion for intrastate shipments. Using this approach, we find that the annual costs of congestion are as high as $4 billion. Our second method controls for congestion at the origin and destination of intra and interstate shipments, but does not capture the costs of congestion enroute. We find that the annual costs of congestion in this case approach $3 billion. Apparently, the costs of congestion enroute—even just for intrastate shipments—are sufficiently large to enable the first estimate to exceed the second. Our final method controls for all sources of congestion and, not surprisingly, yields a larger estimate of the annual costs of congestion—roughly $7 billion—than the preceding methods.

We conclude that the impact of congestion on shippers is an important component of the social costs of congestion and should be considered in policy discussions about how to improve the effectiveness of congestion management.

<u>Congestion Cost Estimates Based on an Econometric Model of Inventory Behavior</u>

Our previous report specified an econometric model where raw materials inventories were determined by inventory-theoretic variables, such as materials demand, the variability of demand, and the interest rate, and variables that affect the speed and reliability of highway transportation, such as government investment in highway infrastructure and congestion. Based on plant level data from the U.S. Census, estimation took place on the following equation:

$$\log(I) = \beta_1 * \log(\textit{annual demand}^{1/2}) + \beta_2 * \textit{Year} * \log(\textit{annual demand}^{1/2}) + \beta_3 * \textit{variability in demand} + \beta_4 * \textit{industry} + \beta_5 * \textit{location} + \beta_6 * \textit{year} + \beta_7 * \textit{interest rate} + \beta_8 * \textit{work} + \beta_9 * \textit{infra} + \beta_{10} * \textit{deregulation} + \beta_{11} * \textit{congestion}$$

where *I* denotes real raw materials inventories, *work* denotes work-in-progress inventories, *infra* denotes investment in highway infrastructure, and other variables are self-explanatory.

Measuring congestion. In the initial model, the congestion variable was defined as vehicle-miles-traveled in the state divided by total highway mileage. We improve upon this measure here by using data from the FHWA on peak-period traffic, which is when delays occur. Specifically, we measure congestion for different classifications of roads by a volume to service flow ratio defined as peak-period peak-direction traffic divided by capacity. The FHWA's volume-service flow categories range from roads with less than 21 percent of capacity filled during the peak period to greater than 95 percent filled during the peak. Road classifications include interstate highways, freeways, principal arterials, minor arterials, and collector roads. Thus, we were able to explore the effects on inventory costs of road mileage for a wide range of roads subject to different levels of congestion.

Given the detail of these data, we could potentially include in the model many combinations of road classification (e.g., urban interstate) and volume-service flow category (e.g., miles congested between 31 to 40 percent). However, examination of the data showed that many of the combinations were highly correlated. For example, states with many miles of interstate highway congested at the 95 percent level also had many miles of highway congested at the 70 percent level, and so forth. Thus, we distilled the many possible combinations into an essential few.

Specifications and Findings. In our first specification, we include roads with the highest level of congestion: urban interstates and freeways with congestion greater than 95 percent, and rural interstates and principal arterials (rural areas do not have freeways by definition) with congestion greater than 95 percent. We estimated the same specification of raw materials inventories given above and substituted the new congestion variables for the previous measure. Table 1 presents the parameter estimates for our previous model and the parameter estimates for the new congestion variables.[1]

We found that urban freeway mileage was statistically insignificant and therefore dropped it from the model, which leaves three congestion variables. As shown in the second column of the table, these variables have a positive statistically significant effect on materials inventories, with the rural congestion variables having a slightly higher marginal impact than the urban congestion variable. Generally, highway speeds are slowed when the level of congestion reaches approximately 70 percent of capacity; thus, we use this threshold as an alternative measure of congestion for urban interstate mileage. As shown in the third column of the table, this variable also has a positive and statistically significant effect on raw materials inventories.

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[1] The estimated coefficients for the non-congestion variables in the regression were not perceptibly changed when we replaced the old congestion variable with the new congestion variables; thus, we focus on the parameter estimates for the congestion variables and refrain from repeating the parameter estimates for the other variables.

We use our new specifications of congestion to simulate the impact of congestion on shippers' logistics costs. That is, we simulate the effect on inventories in the sample from reducing congestion below a specified level. For example, we assume that no urban and rural roads in the country experience congestion greater than 95 percent. We then inflate our sample estimate of the impact of this change on inventory costs to obtain a national estimate of the change in logistics costs. Table 2 summarizes the procedure to inflate our sample estimates (used in our previous report) and the numerical findings. The first specification yields \$3.2 billion in annual logistics cost savings to shippers from reducing the worst congestion in the country—alternatively, this can be interpreted as saying that the logistics costs associated with this level of congestion amount to \$3.2 billion. The second specification indicates that the annual cost to shippers from congestion, using the traditional 70 percent threshold to signify reductions in free flow speeds, is \$3.9 billion.

As noted, these estimates understate the full cost of congestion to shippers because we do not account for congestion levels on urban and rural roads that are not in the state where a plant is located. Given that interstate shipments represent a sizable share of the freight market, this underestimate could be significant. Nonetheless, \$4 billion is a sizable cost that should at least arouse interest in how congestion impacts shippers.

Congestion Cost Estimates Based on Delay Data and an Implicit Discount Rate

An alternative approach to measuring the costs of congestion to shippers is to directly calculate this cost as $C=dVT$, where d is the shipper's implicit daily discount rate that indicates how much that a firm perceives that the value of its shipment declines per day, V is the total value of the shipment, and T is the number of days (or fraction of a day) that the shipment is delayed by congestion. The implicit discount rate varies by commodity type. Consistent with estimates derived from Winston's (1981) disaggregate freight demand model, we assume for our base case that the daily discount rate is 0.15 for perishable commodities like fresh produce, 0.05 for bulk commodities like gravel, and 0.10 for other commodities.[2] To test for the sensitivity of our congestion cost estimates to alternative discount rate assumptions, one can simply vary *d* in our linear congestion cost equation (e.g., discount rates that are 10 percent lower than those in our base case will reduce *C* ten percent).

Data on the value of shipments within and between origin and destination pairs (defined at the MSA level) comes from the 1997 Commodity Flow Survey (CFS) conducted by the U.S. Census. We use state-level breakdowns of shipments by mode to only include those goods shipped by truck. Our sample consisted of 51 of the largest metropolitan areas in the country and accounts for 33.8 percent of the national value of goods shipped by truck.[3] Travel delay data for 1997 were obtained from the Texas Transportation Institute (TTI) and included estimated daily delay per motor vehicle for major metropolitan areas. Estimates of delay were obtained using a combination of observed traffic flows and modeling techniques from the U.S. Department of Transportation's *Highway Capacity Manual*.[4]

Our assumptions of shippers' discount rates combined with the CFS and TTI data yielded a $1.03 billion cost to shippers in our sample from congestion during 1997. Inflating this figure

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[2] Clifford Winston, "A Disaggregate Model of the Demand for Intercity Freight Transportation," *Econometrica*, July 1981, pp. 981-1006.

[3] Other metropolitan areas were not included because commodity flow data or travel delay data (see below) were not available for them.

[4] A complete description of the TTI delay data is contained in http: //mobility.tamu.edu/ums/.

to account for shippers throughout the country yields a \$2.46 billion annual cost of congestion.[5] As expected, this estimate is lower than the proceeding one because it only accounts for congestion incurred by truck shipments at their origin and their destination but not enroute to their destination.

Congestion Cost Estimates Based on FHWA's Freight Analysis Framework

The preceding estimates suggest that the cost of congestion to shippers is at least \$3 billion to \$4 billion per year. This range understates the true cost of congestion because it does not account for all sources of delay. We tried to remedy this problem by using two data sources for delay. We used the TTI data to estimate delay for shipments within a given MSA and used the Freight Analysis Framework (FAF) developed by the FHWA Office of Freight Management Operations to estimate delay for shipments between MSAs. The FAF system routes intra and interstate shipments throughout the country and determines the delay incurred between MSAs using modeling techniques in the Department of Transportation's *Highway Capacity Manual*.

We recalculated our formula for congestion costs, $C=dVT$, using the same assumptions as before to determine d, using the CFS data to calculate V, and, where appropriate, using the TTI or FAF delay estimates to determine T. We found that the cost to shippers in our sample from congestion in 1997 was \$2.77 billion. Inflating this figure to include shippers throughout the

[5] 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 42 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, we multiplied the estimate derived from the sample by 2.38 (1/.42). If we assumed that our sample accounted for 33.8 percent of congestion costs (i.e., its share of the value of truck shipments equaled its share of congestion costs), then the national cost of congestion to shippers would be \$3.06 billion.

country yields an annual cost of congestion of $7.04 billion.[6] As expected, this estimate is higher than the previous estimates because it includes all sources of delay for intra and interstate shipments.

A Proposal for Further Research

We have found that by accounting for all sources of delay that a shipment incurs from its origin to its destination that highway congestion imposes substantial annual costs on shippers throughout the United States. Our best estimate of this cost is some $7 billion. Estimates by the Texas Transportation Institute suggest that the annual cost of congestion to motorists amounts to more than $50 billion, but they are based on a high value of travel time. If we assume that travel time equals half the wage, a plausible estimate given the existing empirical literature, then the cost of congestion to motorists amounts to roughly $25 billion. Thus, the total annual cost of congestion to shippers and motorists exceeds $30 billion, with the cost to shippers accounting for nearly 25 percent of this cost. Although truck traffic represents roughly 5 percent of all vehicle traffic, shippers' share of the total cost of congestion is considerably greater than 5 percent because freight shipments are exposed to more sources of delay than most auto traffic and because the cost of delay for some shipments may be extremely high.

In sum, our estimates indicate that it is important to include the cost of congestion to shippers in any discussion of congestion policy—preferably the impact of congestion policy on

[6] As before, the sample accounted for 33.8 percent of the value of goods shipped by truck. The cities that make up 33.8 percent of the sample, however, now account for 39.3 percent of the congestion costs in the sample. (Recall that we are now including congestion incurred enroute.) Thus, to inflate the congestion cost estimate derived in the sample to obtain a national estimate, we multiplied it by 2.54 (1/.393). If we assumed that our sample accounted for 33.8 percent of the congestion costs (i.e., its share of the value of truck shipments equaled its share of congestion costs), then the national cost of congestion to shippers would be $8.2 billion.

shippers and motorists should be jointly analyzed. We propose to carry out such a study by assessing the impact of recent highway spending on shippers' and motorists' congestion costs. Government's primary response to growing levels of congestion has been to increase spending on roads. It is thus vital to know how effective this strategy has been in curbing congestion costs and what alternatives are available for improving the efficacy of spending to reduce congestion.

We propose to carry out the analysis by estimating econometric models of the costs of delay incurred by motorists and shippers at the MSA level as a function of government spending on roads and variables that control for the characteristics of the city, such as weather conditions and road structure, that may influence congestion. We will be careful to allow variables that may be influenced by highway spending, such as road quality and traffic levels, to vary. We will then use the models to calculate the impact of spending on congestion costs for shippers and motorists and explore alternative ways to reallocate spending to reduce congestion more efficiently. The results from this study should give policymakers a reasonable sense of the efficacy of using public funds to try to combat the costs of congestion and enable them to identify alternative ways to use these funds more efficiently.

Table 1. Inventory Model Parameter Estimates*
(Dependent Variable: Natural Log of Raw Materials Inventories)

Variable (in 1987 dollars as appropriate)	**Previous Model Coefficient****	**New Model 1**	**New Model 2**
State Highway Capital Stock	-8.93E-08 (1.35E-08)	---	---
State Highway Capital Stock interacted with dummy for the 1980s (1 if year is 1980-1989, 0 otherwise)	3.80E-08 (1.41E-08)	---	---
State Highway Capital Stock interacted with dummy for the 1990s (1 if year is 1990-1996, 0 otherwise)	7.34E-08 (1.39E-08)	---	---
National Highway Capital Stock	-5.54E-08 (1.29E-08)	---	---
National Highway Capital Stock interacted with dummy for the 1980s (1 if year is 1980-1989, 0 otherwise)	3.81E-08 (1.25E-08)	---	---
National Highway Capital Stock interacted with dummy for the 1990s (1 if year is 1990-1996, 0 otherwise)	5.27E-08 (1.28E-08)	---	---
Natural Log of Square Root of Materials Demand	1.7103 (0.0033)	---	---
Variability of Materials Demand (Variance of Demand/Mean Demand)	0.0373 (0.0121)	---	---
Work-in progress Inventory Ratio	0.1424 (0.0051)	---	---
Prime Interest Rate	-2.7945 (0.2459)	---	---
Deregulation Dummy (1 for 1980-1996, 0 otherwise)	-23.349 (8.1330)	---	---
Deregulation Dummy (1 for 1990-1996, 0 otherwise)	-10.265 (3.1846)	---	---
Year Trend	0.0174 (0.0011)	---	---
State-Level Congestion (VMT/Miles of Road)	0.1086 (0.0167)	---	---
State Urban Area Interstate Mileage Greater Than 95% Peak Congestion	---	0.00009 (0.00003)	---
State Rural Area Interstate Mileage Greater Than 95% Peak Congestion	---	0.00013 (0.00005)	---
State Rural Area Principal Arterial Mileage Greater Than 95% Peak Congestion	---	0.00014 (0.00006)	---
State Urban Area Interstate Mileage Greater than 70% Peak Congestion	---	---	0.00012 (0.00002)
R^2	0.69		
Number of Observations	941,844	941,844	941,844

*State dummies, year dummies, industry fixed effects, and materials demand year interaction parameter coefficients are not shown.
**Huber-White robust standard errors in parentheses.

Table 2: National Logistics Cost Savings from Reducing Congestion

	Traffic Congestion Specification 1
Reduced Materials Inventory Holdings per unit (thousands)	$1,201,300
Inventory Cost Percentage	x 0.25
Reduced Materials Inventory Costs per unit (thousands)	$300,325
Scaling Factor for Materials Inventory Not in Sample	x 1.48
Marginal Materials Inventory Cost Savings per unit (thousands)	$445,038
Scaling for Retail and Wholesale Inventories	x 2.58
Marginal Materials, Retail, & Wholesale Inventories Cost Savings per unit (thousands)	$1,148,485
Units	x 1×10^{-6}
National Annual Inventory Cost Savings (billions)	$1.148
Scaling Factor for Transport Cost Savings	x 2.76
National Annual Logistics Savings (billions)	$3.173

	Traffic Congestion Specification 2
Reduced Materials Inventory Holdings per unit (thousands)	$1,458,962
Inventory Cost Percentage	x 0.25
Reduced Materials Inventory Costs per unit (thousands)	$364,741
Scaling Factor for Materials Inventory Not in Sample	X 1.48
Marginal Materials Inventory Cost Savings per unit (thousands)	$540,492
Scaling for Retail and Wholesale Inventories	x 2.58
Marginal Materials, Retail, & Wholesale Inventories Cost Savings per unit (thousands)	$1,394,819
Units	x 1×10^{-6}
National Annual Inventory Cost Savings (billions)	$1.395
Scaling Factor for Transport Cost Savings	x 2.76
National Annual Logistics Savings (billions)	$3.853