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Impacts of Highway Infrastructure Investment Under the American Recovery and Reinvestment Act

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This study evaluated the impact on highway demand of highway disbursements under the American Recovery and Reinvestment Act (ARRA). Vehicle miles traveled were used to estimate a highway demand equation employing a spatial Durbin model for the 48 contiguous U.S. states during 1994-2008. Estimates from the equation were used to test the hypothesis that highway disbursements caused different upward shifts in the highway demand curves of states. We estimated $8.2 billion in total net benefits for the 48 states as a result of the $27.2 billion in ARRA highway disbursements, yielding an average net benefit of $0.30 per dollar spent.

INTRODUCTION

After the United States entered an economic recesssion in December 2007, President Obama signed the American Recovery and Reinvestment Act (ARRA) into law in February 2009 (Romer 2009). The ARRA legislated $787 billion in spending by the federal government under three types of funding programs: $228 billion for tax benefits, $275 billion for contracts, grants and loans, and $224 billion for entitlement spending that included education, unemployment, compensation, food stamps, health care insurance, and other social programs.[1] Spending aimed to create employment oppportunities and save existing jobs (Recovery 2012). The stimulus package focused mainly on saving and creating jobs with ready-to-go (referred to as "shovel-ready") projects that could start straightaway (Berrens et al. 2002; Johnson 2009). Some of the most common shovel-ready projects funded under the ARRA were related to transportation (Rall 2009). Of the $48.1 billion in ARRA funds designated for transportation contracts, grants, and loans, $27.5 billion was allocated to highway infrastructure investment (Recovery 2012).

The ARRA highway disbursement was intended to satisfy increasing demand for highways, recondition aging infrastructure, improve road security and safety, and ease traffic congestion (U.S. Department of Transportation 2012). The highway investment component of the ARRA was particularly important as the U.S. transportation infrastructure has been in need of renovation for many years. Estimates suggest the U.S. economy lost $90 billion in 2010 due to poor transportation infrastructure (American Society of Civil Engineers 2011). The ARRA highway disbursement was expected to improve transportation infrastructure and, thus, mitigate some of the negative economic effects stemming from poor highway conditions.

The objective of this research is to explore the impacts of ARRA highway disbursements, focusing on the cost of the additional highway usage for each of the 48 contiguous states, and the benefits of increased highway usage in each state measured by changes in consumer welfare. The state-level cost-benefit analysis is based on the hypothesis that different levels of ARRA highway disbursements, *ceteris paribus*, shift the state-level demand curves for highway miles upward by different amounts. The hypothesis is premised on the notion that differences in ARRA highway disbursements are expected to improve the quality of state-level highway systems differently (e.g., time saved due to new and expanded facilities, reduced user costs, improved safety, greater passenger comfort, security, convenience and reliability, and/or less damage to goods and freighters).

The hypothesis was tested by estimating a highway demand equation using panel data at the state level for the 1995-2008 period. The price of highway usage was proxied by the sum of the average cost of gasoline ($/mile) and the opportunity cost of travel time ($/mile). Highway demand was represented by vehicle miles traveled (i.e., total number of miles traveled during a year by all vehicles within a state) (U.S. Environmental Protection Agency 2012). *Ex post* simulations of the highway demand equation with and without the ARRA highway disbursement using 2009 and 2010 data generated predicted changes in highway usage for each state. The simulated changes in highway usage were used to estimate changes in consumer welfare from upward shifts in the state-level demand curves, reflecting benefits from the improved quality and quantity of highway systems.

Determining the cost of ARRA highway disbursements requires estimates of both explicit cost (i.e., cost of ARRA highway disbursement) and implicit cost (i.e., cost of negative externalities including air pollution and traffic congestion). While the explicit cost is obtained directly from the government's official website, attaining the implicit cost involves multiple modeling efforts (e.g., contingent valuation of air pollution and estimation of total congestion cost including travel time delays, vehicle operating costs, and social costs of traffic congestion) that are beyond the scope of this research. Thus, the estimates of implicit costs of the additional highway usage due to ARRA higway disbursements were taken directly from previous research.

Our research contributes to the literature in the following way. To the best of our knowledge, our macro-scale cost-benefit analysis of the ARRA highway disbursement at the national and the state levels is the first attempt of its kind. While the literature has firmly established micro-level cost-benefit analysis of highway investment that typically evaluates user benefits and external costs for alternative transportation projects, there appears to be no previous attempt to assess the impact of macro-scale highway investment. For example, Cost-Benefit Analysis (COBA) (Department of Transport, UK 2012), the Micro-computer Benefit Cost Analysis Model (MicroBENCOST) (McFarland et al. 1993), and the Strategic Benefit Cost Analysis Model (StratBENCOST) (National Cooperative Highway Research Program 2004) evaluate the costs and benefits of specific highway improvement projects at the local level.

By estimating state-level highway demand curves for use in evaluating nationwide investment, such as the ARRA highway disbursement, we quantify the benefits of increased highway usage at both the national and the state levels. Using our benefit estimates and the explicit and implicit costs of the ARRA highway disbursement, we estimate the impacts of the ARRA highway disbursement on the aggregate 48 contiguous states and on each state individually. This analysis is meaningful in that the results offer, big picture as well as local impacts of nationwide investment in transportation systems.

EMPIRICAL MODEL

Highway Demand Equation

Based on relationships found in the previous literature (Noland 2001; Choo et al. 2004; Small and Van Dender 2005; Washington State Department of Transprotation 2010), highway demand q (measured by vehicle miles traveled) is specified as a function of the price of highway usage p (proxied by the sum of the average cost of gasoline per mile and the cost of travel time per mile), highway disbursements d, and other exogenous factors g, including the number of licensed drivers to represent the population of highway consumers, per capita income to reflect other socio-economic characteristics, and total highway miles within a state:

$$(1) \quad q = f(p, d, g)$$

Assuming constant elasticity of demand, we linearize the demand equation by taking natural logarithms of the continuous variables and denote them by capital letters:

$$(2)\quad Q_{i,t} = \alpha + \gamma D_{i,t-1} + \mathbf{X}_{i,t}\boldsymbol{\beta} + \mu_i + \lambda_t + \varepsilon_{i,t}\,,$$

where i and t represent the state and year; $\mathbf{X}_{i,t}$ is a 1 × 4 row vector of explanatory variables, including P and G; α and γ are scalar parameters; **β** a 4 × 1 parameter vector; and ε is an error term. Highway disbursements (D) are lagged one year (t-1) because the largest portion of disbursements was for maintanance and capital outlays—land acquistion, design, construction, reconstruction, resurfacing, rehabilitation, installation of guard rails, and fencing—and most of those activities would likely cause some delay in facilitating highway usage. The terms μ and λ, respectively, denote unobserved state-specific and time-specific effects.[2]

The equation (2) intrinsically involves a spatial network system because the highway vehicle miles of states located near one another may have unobserved characteristics that are correlated across states. These unobserved characteristics represent the spatial autocorrelation of the highway demand as an unobserved spatial process. For example, there may be spatial spillover impacts on vehicle miles traveled in states neighboring the states where the funds were disbursed. We take account of the spatial spillover impacts by framing the highway deamand equation in a spatial regression model that accounts for such spatial dependence (LeSage and Pace 2009; Parent and LeSage 2010). Inclusion of the spatially lagged depdendent variable assumes that highway demand in one location is codetermined by demand for highways in neighboring regions.

Following a routine suggested by Elhorst (2010), we tested the non-spatial highway demand equation against the corresponding spatial model. We specified the highway demand equation as a spatial Durbin model for panel data (SDMP) that include both spatial lag, error, and cross-regressive structures (Anselin 1988; LeSage and Pace 2009):

$$(3)\quad Q_{i,t} = \rho\sum_{j=1}^{N} w_{ij}Q_{j,t} + \alpha + \gamma D_{i,t-1} + \psi\sum_{j=1}^{N} w_{ij}D_{j,t-1} + \mathbf{X}_{i,t}\boldsymbol{\beta} + \sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\boldsymbol{\Phi} + \mu_i + \lambda_t + \varepsilon_{i,t}$$

where subscripts *i* and *j* represent the *i*th and *j*th states, w_{ij} is element (*i*, *j*) of the *N* × *N* spatial weight matrix W whose diagonal elements are zero $\sum_{j=1}^{N} w_{ij}Q_{j,t}$, is annual vehicle miles traveled within the neighbors defined by the spatial weight matrix *W*, *ρ* is a parameter of spatially lagged annual vehicle miles, ψ is a parameter of spatially lagged highway disbursement, and **Φ** is a 4 × 1 parameter vector of spatially lagged independent variables. We estimated the highway demand equation with a fixed effect model allowing for arbitrary correlation between the 48 contiguous U.S. states' heterogeneity and other explanatory variables. The lag AR term ρ explains this dependence. If the covariates are measured with error, and those measurement errors are correlated across spatial units, then inclusion of the error correlation term is warranted. If level effects of neighboring covariates determine highway expenditures, then the cross-regressive terms are important. These hypotheses can be tested to determine if the SDM, or some nested version of the SDM model, is suitable.

Estimation Procedure

Based on the specification results and the panel data model discussed above, the highway demand equation was estimated by maximum likelihood.[3] In the spatial regression model, interpretation of the estimates, i.e., β and Φ, is not straightforward because spatial spillover effects play signficant roles in determining the marginal effects of the variables (LeSage and Pace 2009). Applying the approach by LeSage and Pace (2009), the total marginal effect of a change in an explanatory variable in state *i* on vehicle miles traveled in the 48 U.S. states was decomposed into the effect on vehicle miles traveled in state *i* as a direct marginal effect (hereafter referred to as direct effect) and the effect on vehicle miles traveled outside state *i* as an indirect marginal effect (hereafter, referred to as indirect effect).[4] The direct effect refers to the combination of (1) the effect of an explanatory variable for the *i*th state on vehicle miles traveled in the *i*th state and (2) the effect passing through neighboring regions that exert a feedback influence on vehicle miles traveled of the *i*th state (referred to as "feedback effect"). The indirect effect refers to the sum of the effects of an explanatory variable for the *i*th state on vehicle miles traveled in the other states ($-i$). The total effect is the sum of the direct and indirect effects, which denote the effect of a one-unit change in an explanatory variable on the aggregate vehicle miles traveled in all 48 states.

Cost-benefit Analysis With and Without ARRA Highway Disbursement

Using the parameter estimates from Equation (3), the highway demand curves for vehicle miles traveled in state i 1) in the absence of ARRA highway disbursements to any of the 48 states (Q_i^{wo}), 2) with the ARRA dibursement to state i only (Q_i^{own}), and 3) with the ARRA distbursements to each of the 48 states (Q_i^{all}) are:

$$\text{(4-1)}\quad Q_i^{wo} = \left[(I-\hat{\rho}W)^{-1}\boldsymbol{i}_i\right]'(\hat{\alpha}\boldsymbol{i}_N + \hat{\gamma}D^{wo} + \hat{\chi}WD^{wo} + \mathbf{X}\hat{\boldsymbol{\beta}} + W\mathbf{X}\hat{\boldsymbol{\Phi}} + \hat{\mu}),$$

$$\text{(4-2)}\quad Q_i^{own} = \left[(I-\hat{\rho}W)^{-1}\boldsymbol{i}_i\right]'(\hat{\alpha}\boldsymbol{i}_N + \hat{\gamma}D^{own,i} + \hat{\chi}WD^{own,i} + \mathbf{X}\hat{\boldsymbol{\beta}} + W\mathbf{X}\hat{\boldsymbol{\Phi}} + \hat{\mu}),$$

$$\text{(4-3)}\quad Q_i^{all} = \left[(I-\hat{\rho}W)^{-1}\boldsymbol{i}_i\right]'(\hat{\alpha}\boldsymbol{i}_N + \hat{\gamma}D^{all} + \hat{\chi}WD^{all} + \mathbf{X}\hat{\boldsymbol{\beta}} + W\mathbf{X}\hat{\boldsymbol{\Phi}} + \hat{\mu}),$$

where *wo* denotes without ARRA disbursements to any state, *own* represents the case where only state i receives its ARRA disbursement with all other states not being funded, *all* represents the case where all 48 states receive their ARRA disbursements, i indexes states, D is highway disbursements in 2009, **X** is a matrix of explanatory variables (i.e., the price of highway usage, per capita income, length of highway, and number of licensed drivers) in 2010, and $\boldsymbol{i}_i$ is an N by 1 unit vector with the i^{th} element being 1 and the other elements being 0. Note that we obtain 48 different predicted values for equation (4-2) since $D^{own,i}$ varies by $i = 1,\ldots,48$. Equation (4-2) is constructed to see what would have been the effect of ARRA disbursement in a state if only that state had been funded with ARRA disbursement. While comparing the predicted values from equations (4-3) and (4-1) shows the total effect of ARRA disbursements on highway demand, comparing those from equations (4-3) and (4-2) shows the portion of the total effect resulting from spillovers. Intuitively, the difference between the predicted values from (4-3) and (4-2) is the effect of other states' ARRA disbursements on state i's demand for highway use.

Once predicted vehicle miles traveled are obtained, we draw three different constant-elasticity demand curves for each state. The inverse demand curves for each of the 48 states are $p_i = k_i^{wo}q_i^{\eta_i}$, $p_i = k_i^{own}q_i^{\eta_i}$ and $p_i = k_i^{all}q_i^{\eta_i}$, where k_i^{wo}, k_i^{own}, and k_i^{all} denote all factors including ARRA disbursements that shift the demand curves of state i (referred to as "demand curve shifter"), and $\eta_i^{wo}, \eta_i^{own}$ and η_i^{all} are price flexibilities (inverse price elasticities).

An important question deals with which value is an appropriate estimate for the price elasticity. As pointed out in the section Estimation Procedure, the parameter estimate for the price elasticity β_p is not the marginal effect because it does not reflect spatial iterations. The total effect includes the indirect effect, which by definition represents changes in demand caused by price changes in neighboring states. Because highway use in neighboring states is either a substitute or complement to one's own state highway use, a price change in neighboring states shifts the one's own state demand curve rather than changing its price elasticity of demand.

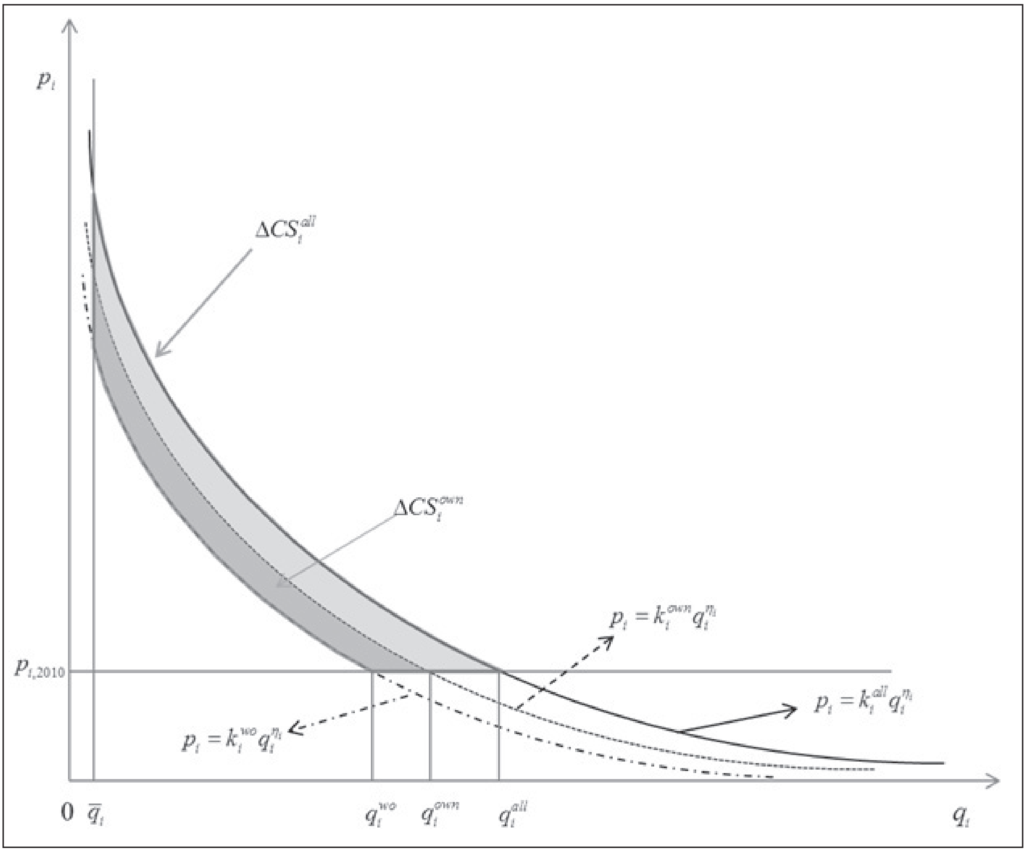
Hypothetical highway demand curves corresponding to, q_i^{wo}, q_i^{own}, and q_i^{all} are shown in Figure 1. The relationships among the demand curves, $q_i^{wo} < q_i^{own}$, $q_i^{wo} < q_i^{all}$, and $q_i^{own} < q_i^{all}$ are hypothesized because we expect ARRA highway disbursements to shift the demand curve for state i to the right, and the vehicle miles traveled with ARRA highway disbursement in all 48 states are expected to increase more than in a given state because of positive spillover effects.

Given the estimated highway demand curves, the benefits of increased vehicle miles traveled for each state due to the ARRA highway disbursement in a given state and in all 48 states were estimated by calculating the additional consumer surplus attributed to the right shifts in the highway demand curves in a state and in all 48 states (shown as ΔCS_i^{own} and ΔCS_i^{all} in Figure 1). The additional consumer surplus due to the ARRA highway disbursements in all 48 states was calculated by integrating the area ΔCS_i^{all}:

$$
\begin{aligned}
(5)\quad \Delta CS_i^{all} &= \left[\int_{\overline{q}}^{q_i^{all}} (k_i^{all} q_i^{\eta_i}) dq_i - p_{i,2010}(q_i^{all} - \overline{q}_i)\right] - \left[\int_{\overline{q}}^{q_i^{wo}} (k_i^{wo} q_i^{\eta_i}) dq_i - p_{i,2010}(q_i^{wo} - \overline{q}_i)\right] \\
&= \left[\frac{k_i^{all}}{\eta_i + 1}\left\{(q_i^{all})^{\eta_i+1} - (\overline{q})^{\eta_i+1}\right\} - p_{i,2010}(q_i^{all} - \overline{q}_i)\right] - \left[\frac{k_i^{wo}}{\eta_i + 1}\left\{(q_i^{wo})^{\eta_i+1} - (\overline{q})^{\eta_i+1}\right\} - p_{i,2010}(q_i^{wo} - \overline{q}_i)\right],
\end{aligned}
$$

where $\overline{q}_i$ is an arbitrarily chosen but reasonably low cutoff value (i.e., vehicle miles traveled corresponding to a price ceiling of 100 times $p_{i,2010}$ in the inverse demand curve $p_i = k_i^{wo} q_i^{\eta_i}$). The area ΔCS_i^{own} was calculated likewise. The decomposition of ΔCS_i^{all} into ΔCS_i^{own}, and $(\Delta CS_i^{all} - \Delta CS_i^{own})$ is meaningful because ΔCS_i^{own} measures the additional consumer surplus in a given state related to the ARRA highway disbursement in that state, while it measures the additional consumer surplus in the given state related to the ARRA highway disbursements in the other states (referred to as "spillover consumer welfare").

Figure 1: Estimated Demand Curves Without and With ARRA Highway Disbursement in a Given State and in All 48 States



The difference between the predicted vehicle miles traveled with and without ARRA highway disbursements in all 48 states $(q_i^{all} - q_i^{wo})$ was multiplied by \$0.09 per mile (taken directly from Litman and Doherty (2009)—see details in the Study Area and Data section) to calculate the additional implicit cost of negative externalities. Subsequently, the total net benefit for each state from the ARRA highway disbursements was calculated by subtracting the sum of explicit and implicit costs from total additional consumer surplus. The net benefits were aggregated across states to arrive at the total net benefit from ARRA highway disbursements to the 48 contiguous states.

STUDY AREA AND DATA

The cross-sectional data used to estimate the highway demand curves pertain to the 48 contiguous U.S. states for 15 years (1994-2008). Similar cross-sectional data for 2009's ARRA highway disbursements and the other explanatory variables for 2010 were used to simulate the impact of time-lagged ARRA highway disbursements on highway demand in 2010. Data for the 2009 ARRA highway disbursements by state were obtained from www.recovery.gov, the U.S. government's official website (Recovery 2012). The annual retail price of gasoline was obtained from the U.S. Energy Information Administration (U.S. Energy Information Agency 2012); per capita income was collected from the U.S. Department of Commerce, Bureau of Economic Analysis (USDC BEA 2012); and vehicle miles traveled, highway disbursements, length of highways, number of licensed drivers, and fuel tax per gallon were obtained from the Highway Statistics series published by the U.S. Department of Transportation, Federal Highway Administration (USDOT FHWA 2012). Although ARRA disbusements by state were available for 2009, highway disbursements by state were not available for that year. Thus, highway disbursements by state in the absence of the 2009 ARRA disbursements were predicted by each state's time trend using highway disbursement data from 1994 to 2008.

The average opportunity cost of travel time per mile in the United Sates (i.e., \$0.11 per mile) was obtained from Litman and Doherty (2009), as was the per-mile cost of congestion, which was estimated as a weighted average of congestion levels for urban peak, off-peak, and rural areas, multiplied by weighted hourly wages.

The cost of negative externalities from air pollution and traffic congestion (i.e., \$0.09 per mile) (Litman and Doherty 2009) was estimated by summing \$0.04 for the non-greenhouse gas air pollution cost, \$0.02 for the greenhouse gas cost, and \$0.03 for the congestion cost, all per-average vehicle mile traveled. All data, except travel time cost and the costs of negative externalities, were obtained at the state level and all dollar values (i.e., gasoline price, travel time cost, highway disbursements, and per-capita income) were adjusted to 2007 dollars using the consumer price index (U.S. Department of Labor, Bureau of Labor Statistics 2012). Definitions of the variables used in the regressions and descriptive statistics are reported in Table 1.

Annual vehicle miles traveled for each state were used to represent highway demand. The vehicle miles traveled in the United States steadily increased from 2,342 billion miles in 1994 to 2,955 billion miles in 2008 (a 26% increase), with the exception of a slight drop in 2008 during the recession. As shown in Figure 2a, California and Texas stand out as the states with the most vehicle miles traveled during 1994-2008, with 307 and 215 billion miles, respectively, while Delaware, North Dakota, Rhode Island, South Dakota, Vermont, Wyoming, Montana, New Hampshire, and Idaho had the fewest vehicle miles traveled with fewer than 10 billion miles traveled (see Table 2).

The per-mile retail price of gasoline, state-level fuel tax, and opportunity cost of travel time were summed to represent the price of a vehicle mile traveled.[5] The retail price of gasoline has varied across states with a range of around 10% between the highest and the lowest prices. The West Coast and New England are in the higher price range while the Midwest is in the lower price range (see Figure 2b). Over the 15 years, average real gasoline prices for individual states have increased

Table 1: Variable Names, Descriptions, and Descriptive Statistics

Variable†	Description	Mean	Std Dev
Vehicle miles traveled (1995-2008)	Annual vehicle distance traveled by all vehicles (billion miles)	57.731	57.023
Highway disbursement (1994-2007)	Total disbursement for highways from all units of government ($ billion)	2.644	2.309
Price (1995-2008)	Sum of gasoline price and opportunity cost of travel time ($/mile)	0.200	0.012
Per capita income (1995-2008)	Per capita income ($ thousand)	34.608	5.547
Length of highway (1995-2008)	Total highway length (thousand mile)	82.174	50.978
Licensed drivers (1995-2008)	Total number of licensed drivers (million)	3.984	4.057

† All values are across states and across years.

Figure 2a: Average Vehicle Miles Traveled During 1994-2008 (million miles)

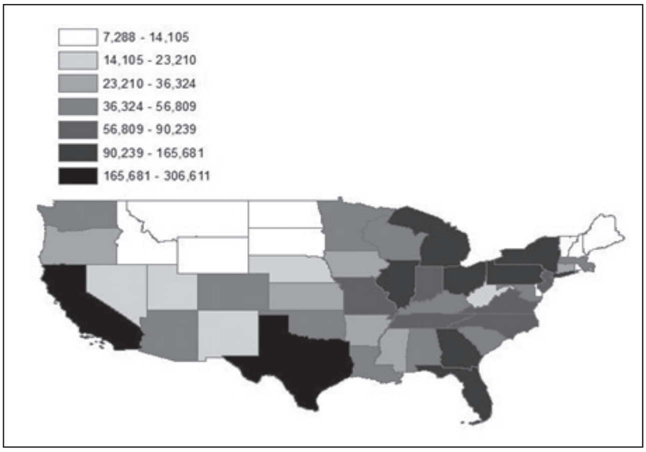
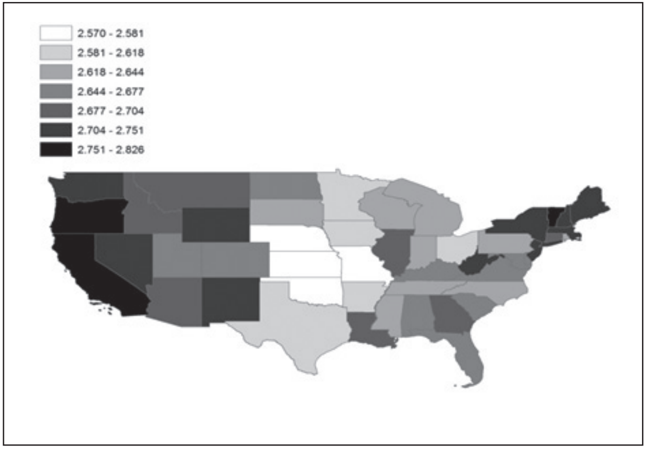


Figure 2b: Gasoline price Per Gallon in 008 ($ per gallon)



between 131% and 179% (U.S. Energy Information Agency 2012). Fuel taxes that add to the price of gasoline differed in 2008 from $0.36 per gallon in West Virginia to $0.08 per gallon in Georgia.

In the estimation, highway disbursement is total investment in highways by federal, state, and local governments (e.g., capital outlay, maintenance and services, administration, and research and planning). Between 1994 and 2008, highway disbursement in 2007 dollars increased by 50% from $88 billion to $132 billion for the aggregate 48 states. Highway disbursements were highest in California, Texas, and New York (over $6 billion per year) on average over the 15 years, while Vermont, Rhode Island, and North Dakota had the lowest highway disbursements (less than $0.4 billion per year). The allocation among states of the $27 billion in ARRA highway disbursement amounted to between 12.6% and 47.5% of each state's highway disbursement in 2008. Correlation between state highway disbursements in 2008 and state ARRA highway disbursements was 0.96, indicating that the share of the total ARRA disbursement was distributed according to each state's existing share of highway disbursement (see Figures 3a and 3b for the distribution of highway disbursement in 2008 and ARRA highway disbursement, respectively).

Figure 3a: Highway Disbursement in 2008 ($ million)

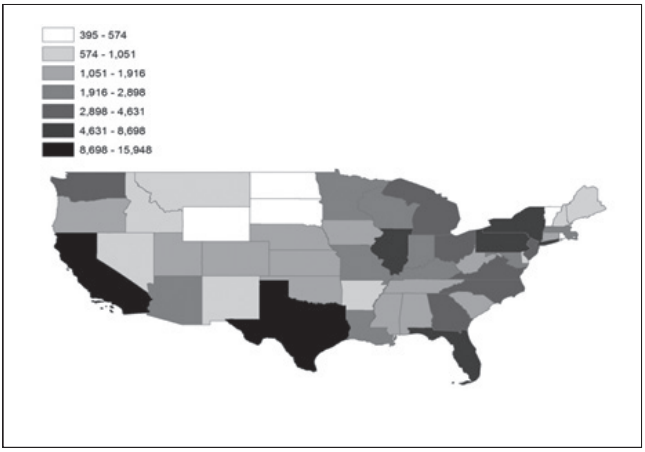


Figure 3b: ARRA Highway Disbursement in 2009 ($ million)

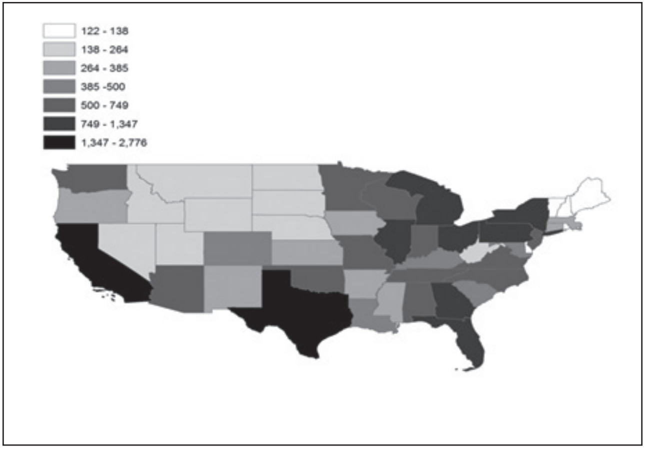


Table 2: Average Vehicle Miles Traveled During 1994-2008, Gasoline Price Per Gallon in 2008, Highway Disbursement in 2008, ARRA Highway Disbursement in 2009

	Average vehicle miles travelled during 1994-2008 (million miles)	Gasoline price per gallon in 2008 ($ per gallon)	Highway disbursement in 2008 ($ million)	ARRA highway disbursement in 2009 ($ million)
Alabama	56,342	2.669503	1,916	620
Arizona	50,961	2.681059	2,806	585
Arkansas	29,824	2.605943	1,051	367
California	306,611	2.80529	14,697	2,776
Colorado	42,225	2.665651	1,695	445
Connecticut	30,278	2.704172	1,370	300
Delaware	8,559	2.652169	683	122
Florida	165,681	2.664688	8,698	1,347
Georgia	102,556	2.69069	3,817	904
Idaho	13,939	2.703209	802	194
Illinois	102,733	2.688764	6,299	939
Indiana	69,706	2.629056	2,732	657
Iowa	29,464	2.618463	1,505	358
Kansas	27,952	2.57609	1,487	349
Kentucky	45,543	2.666614	2,404	448
Louisiana	42,046	2.684911	2,488	435
Maine	14,105	2.740767	739	138
Maryland	51,291	2.657947	2,747	447
Massachusetts	52,456	2.717654	2,898	385
Michigan	97,176	2.632908	3,269	896
Minnesota	52,200	2.598239	2,352	557
Mississippi	36,324	2.626167	1,346	355
Missouri	65,806	2.572238	2,545	640
Montana	10,244	2.698394	651	264
Nebraska	18,037	2.570312	1,352	230
Nevada	18,084	2.725358	906	221
New Hampshire	12,243	2.713802	681	130
New Jersey	68,290	2.71958	3,921	679
New Mexico	23,210	2.716691	860	306
New York	128,855	2.723432	7,537	957
North Carolina	90,239	2.643501	3,584	744
North Dakota	7,288	2.677207	471	184
Ohio	106,521	2.59535	4,631	936
Oklahoma	43,736	2.580905	1,634	565
Oregon	33,508	2.825513	1,364	300
Pennsylvania	102,703	2.642538	5,956	1,035
Rhode Island	7,947	2.629056	419	137
South Carolina	45,431	2.665651	1,470	500
South Dakota	8,382	2.632908	451	214
Tennessee	65,384	2.640612	1,771	749
Texas	214,964	2.612685	15,948	2,263
Utah	22,895	2.675281	1,229	224
Vermont	7,411	2.820698	395	129
Virginia	75,544	2.659873	3,875	691
Washington	53,249	2.75136	3,901	578
West Virginia	19,356	2.721506	1,208	212
Wisconsin	56,809	2.642538	2,392	562
Wyoming	8,398	2.730174	574	185

Average vehicle miles traveled in 1994-2008 and highway disbursement in 2008 from USDOT-FHWA (2012) Gasoline price per gallon in 2008 from U.S. Energy Information Agency (2012). ARRA highway disbursement in 2009 from Recovery (2012).

EMPIRICAL RESULTS

Regression Results

The parameter estimates and direct, indirect, and total effects of the SDMP are shown in Table 3. The positive and significant spatial lag parameter (ρ) suggests a spatial spillover effect of vehicle miles traveled, which is consistent with the results of the spatial LM, Wald, and LR tests discussed in the Empirical Model section. Specifically, a 1% increase in vehicle miles traveled in the neighbors yielded a 0.20% increase in the own state's vehicle miles traveled on average.

Table 3: Regression Results of the SDMP Model with Spatial-Fixed Effects and Neighbors Defined by *HW1*

Variables	Parameter estimates	Direct effects	Indirect effects	Total effects
Intercept	2.132*			
	(0.842)			
ln (Highway disbursement), *t*-1	0.028*	0.029*	0.031	0.060*
	(0.008)	(0.008)	(0.019)	(0.021)
ln (Price)	-0.997*	-0.957*	0.763*	-0.194*
	(0.227)	(0.220)	(0.227)	(0.034)
ln (Per capita income)	0.252*	0.257*	0.160	0.417*
	(0.060)	(0.058)	(0.075)	(0.054)
ln (Length of highway)	0.026	0.041	0.331*	0.372*
	(0.039)	(0.038)	(0.061)	(0.066)
ln (Licensed drivers)	0.302*	0.324*	0.466*	0.790*
	(0.038)	(0.037)	(0.069)	(0.072)
*HW1**ln (Highway disbursement), *t*-1	0.020			
	(0.016)			
*HW1**ln (Price)	0.841*			
	(0.229)			
*HW1**ln (Per capita income)	0.082			
	(0.076)			
*HW1**ln (Length of highway)	0.272*			
	(0.051)			
*HW1**ln (Licensed drivers)	0.328*			
	(0.064)			
*HW1**ln (Vehicle miles travelled), ρ	0.201*			
	(0.048)			
Adjusted R^2	0.8277			

*Denotes $\rho < 0.05$

All non-lagged explanatory variables except the length of highway are significant. The signs of all the significant variables are in agreement with expectations, which shows that the states with higher highway disbursements, per capita incomes, and numbers of licensed drivers tend to use highways more. The spatially lagged explanatory variables that are positive and significant (i.e., price, length of highway, and number of licensed drivers) reflect positive spatial spillover effects on vehicle miles traveled.

An increase by 1% in a state's one-year lagged highway disbursement increases vehicle miles traveled inside the state by 0.03% and across all states by 0.06%. These results suggest that government investment in highways perhaps enhances either the quantity or quality (or both) of highways and thus increases highway usage. The larger total effect than direct effect of the highway disbursement suggests that a state-level shock in highway disbursement has an even larger effect on demand for the regional highway network. The results explicitly predict that the 2009 ARRA highway disbursement increased highway usage.

The price per mile has direct, indirect, and total effects on vehicle miles of -0.96, 0.76, and -0.19, respectively. These results suggest that the positive indirect effect moderated the close-to-unit-elastic demand for highway usage to yield an inelastic regional highway demand based on the total effect. The positive indirect effect suggests that an increase in the price of highway usage in a state increases vehicle miles traveled in other states. This finding implies that highway usage in one state is a substitute for highway usage in neighboring states.

The direct and total effects of per capita income on vehicle miles traveled suggest that a 1% increase in per-capita income in a state increased vehicle miles traveled by 0.26% and 0.42% in the state and the regional highway systems, respectively. These findings suggest that highway usage is a necessity, implying that highway usage does not decrease appreciably during economically tough times.

The indirect and total effects of highway length are both positive and significant. These results suggest that a 1% increase in highway length in a state increased vehicle miles traveled outside of the state and in all 48 states by 0.33% and 0.37%, respectively. These results imply that an increase in highway miles within a state increased the accessibility of the highways in neighboring states, inducing greater highway use in those states, resulting in an increase in regional highway demand.

The direct, indirect, and total effects of the number of licensed drivers are all positive and significant. This variable plays a crucial role in the regression to control for the effects on vehicle miles traveled of the large variation in population size across states. The estimates suggest that a 1% increase in the number of licensed drivers in a state increased highway usages in the state, outside the state, and in the regional highway system by 0.32%, 0.47% and 0.79%, respectively. The higher indirect effect than the direct effect implies a greater effect on vehicle miles traveled in other states than within the state.

Simulation Results

The predicted effects of the 2009 ARRA highway disbursement on vehicle miles traveled, consumer surplus, costs, and net benefits in 2010 are presented in Table 4. Results suggest that the ARRA highway disbursement increased vehicle miles traveled in the 48 states by 36 billion miles, which amounts to a 1.2% increase (i.e., final row of the $(q_i^{all} - q_i^{wo})$ column in Table 4). In each state, the predicted increase in vehicle miles traveled with the ARRA highway disbursement (see "$(q_i^{all} - q_i^{wo})$" column in Table 4) is greater than the predicted increase with state *i*'s own disbursement alone (see "$(q_i^{all} - q_i^{wo})$" column in Table 4), i.e., $q_i^{wo} < q_i^{own} < q_i^{all}$. The findings support the hypotheses that the ARRA highway disbursement shifted the demand curve for highway use upward, and vehicle miles traveled in a state increased more when the ARRA highway disbursement was distributed throughout all states than if its distribution were limited within that state because of the positive spillover effect.

The increase in vehicle miles traveled in a given state, resulting from that state's ARRA highway disbursement (see "$(q_i^{all} - q_i^{wo})$" column in Table 4), ranged from 38 million miles for Delaware to 1.99 billion miles for California, whereas increases in vehicle miles traveled in a given state with the ARRA highway disbursement distributed throughout all states (see "$(q_i^{all} - q_i^{wo})$" column in Table 4) ranged from 78 million miles or Delaware to 3.83 billion miles for California. These increases in vehicle miles traveled generated additional consumer surplus between \$43 million for Delaware and \$2.22 billion for California (see "ΔCS_i^{own}" column in Table 4) when the ARRA disbursement was for a given state, and between \$87 million and \$4.27 billion (see "ΔCS^{all}" column in Table 4) when the ARRA disbursements were distributed to all states. Given the implicit costs of negative externalities by state between \$7 million and \$337 million (see "Implicit cost" column in Table 4) and explicit costs of between \$122 million and \$2.78 billion (see "Explicit cost" column in Table 4), total net benefits ranged from –\$132 million for New Jersey to \$1,158 million for California, which summed to \$8.24 billion over the 48 states (see "Total net benefit" column in Table 4). As a result, the net benefit per dollar spent ranged from –\$0.34 for Delaware to

Table 4: Costs and Benefits of ARRA Highway Disbursement

States	Own		Total		Spillover consumer welfare $\Delta CS_i^{all} - \Delta CS_i^{own}$ (\$ million)	Implicit cost (Negative externality) (\$ million)	Explicit cost (\$ million)	Total net benefit (ΔCS_i^{all} – Implicit cost – Explicit cost) (\$ million)	Net benefit per dollar spent (\$)
	$q_i^{own} - q_i^{wo}$ (million mile)	ΔCS_i^{own} (\$ million)	$q_i^{all} - q_i^{wo}$ (million mile)	ΔCS_i^{all} (\$ million)					
Alabama	536	565	1,004	1,058	493	88	620	349	0.56
Arizona	314	348	656	727	379	58	585	84	0.14
Arkansas	258	271	486	509	238	43	367	100	0.27
California	1,986	2,217	3,826	4,271	2,054	337	2,776	1,158	0.42
Colorado	300	320	619	660	340	54	445	161	0.36
Connecticut	182	200	356	392	192	31	300	60	0.20
Delaware	38	43	78	87	45	7	122	-41	-0.34
Florida	800	833	2,321	2,419	1,586	204	1,347	868	0.64
Georgia	929	988	1,747	1,859	871	154	904	801	0.89
Idaho	110	120	211	229	110	19	194	17	0.09
Illinois	523	554	1,208	1,279	725	106	939	234	0.25
Indiana	458	486	880	933	447	77	657	198	0.30
Iowa	193	204	397	420	216	35	358	27	0.08
Kansas	171	182	370	394	212	33	349	12	0.04
Kentucky	273	290	591	628	338	52	448	129	0.29
Louisiana	284	299	607	639	339	53	435	150	0.35
Maine	80	87	170	185	98	15	138	31	0.23
Maryland	287	317	532	588	271	47	447	94	0.21
Massachusetts	186	209	546	612	403	48	385	179	0.47
Michigan	677	714	1,256	1,325	611	111	896	319	0.36
Minnesota	361	384	795	848	463	70	557	220	0.40
Mississippi	274	291	584	621	329	51	355	214	0.60
Missouri	411	430	884	925	495	78	640	207	0.32
Montana	109	117	207	222	105	18	264	-60	-0.23
Nebraska	104	112	252	269	158	22	230	17	0.08

Table 4: continued

States	Own		Total		Spillover consumer welfare	Implicit cost (Negative externality) ($ million)	Explicit cost ($ million)	Total net benefit	Net benefit per dollar spent ($)
	$q_i^{own} - q_i^{wo}$ (million mile)	ΔCS_i^{own} ($ million)	$q_i^{all} - q_i^{wo}$ (million mile)	ΔCS_i^{all} ($ million)	$\Delta CS_i^{all} - \Delta CS_i^{own}$ ($ million)			(ΔCS_i^{all} – Implicit cost – Explicit cost) ($ million)	
Nevada	112	128	224	255	127	20	221	15	0.07
New Hampshire	80	91	157	178	87	14	130	35	0.27
New Jersey	253	270	558	595	325	49	679	-132	-0.19
New Mexico	203	211	365	380	169	32	306	41	0.13
New York	467	501	1,232	1,323	822	108	957	258	0.27
North Carolina	533	587	1,235	1,359	772	109	744	506	0.68
North Dakota	80	85	153	163	78	13	184	-35	-0.19
Ohio	618	662	1,210	1,296	634	106	936	253	0.27
Oklahoma	406	429	698	738	309	61	565	111	0.20
Oregon	206	236	410	472	235	36	300	136	0.45
Pennsylvania	515	563	974	1,064	501	86	1,035	-56	-0.05
Rhode Island	70	79	102	116	37	9	137	-31	-0.22
South Carolina	432	463	764	820	357	67	500	253	0.51
South Dakota	102	109	169	181	72	15	214	-48	-0.22
Tennessee	732	773	1,187	1,254	481	104	749	400	0.53
Texas	1,200	1,245	3,005	3,117	1,872	264	2,263	590	0.26
Utah	113	121	287	308	187	25	224	58	0.26
Vermont	70	78	106	117	39	9	129	-22	-0.17
Virginia	425	452	874	930	477	77	691	162	0.23
Washington	282	326	621	720	393	55	578	87	0.15
West Virginia	92	100	196	212	113	17	212	-17	-0.08
Wisconsin	375	406	742	805	398	65	562	177	0.31
Wyoming	86	91	155	163	72	14	185	-36	-0.19
Sum over the 48 states	17,295	18,589	36,005	38,664	20,076	3,168	27,257	8,239	0.30

\$0.89 for Georgia, with a weighted average net benefit of \$0.30 per dollar spent across the 48 states (see "Net benefit per dollar spent" column in Table 4).

The total increase in vehicle miles traveled for the 48 states $\left(\sum_{i=1}^{48}\left(q_i^{all} - q_i^{wo}\right)\right)$ of 36.01 billion miles generated \$38.66 billion in additional consumer surplus $\left(\sum_{i=1}^{48}\Delta CS_i^{all}\right)$. About 50% is attributed to benefits received by states other than the one receiving the ARRA disbursement i.e., 17.30 billion miles generated \$18.59 billion in additional consumer surplus $(\Delta CS_i^{all} - \Delta CS_i^{own})$. The considerable differences between the increases in predicted vehicle miles traveled in a given state from the ARRA disbursement in that state and the predicted vehicle miles traveled when the ARRA disbursement is made to all 48 states imply the ARRA highway disbursement had a sizable spatial spillover impact on highway demand.

CONCLUSIONS

This study evaluated the impact of the 2009 ARRA highway disbursement on vehicle miles traveled, reflecting a shift in highway demand, in the framework of a cost-benefit analysis. We estimated a highway demand equation that employed SDMP based on panel data pertaining to the 48 U.S. contiguous states for the 1994-2008 period. The estimates from the equation supported the hypothesis that different state-level ARRA highway disbursements resulted in different upward shifts in the highway demand curves across states. The different effects on the state-level demand curves resulted in increases in vehicle miles traveled that were different for each state, generating a wide range of predicted increases in consumer surplus across states. The estimated figures and explicit and implicit costs associated with the additional highway usage were used to estimate total net benefit and net benefit per dollar spent for each state and for the 48 states. Our estimates found a total net benefit of \$8.2 billion summed across the 48 states resulting from the \$27.2 billion 2009 ARRA highway disbursement, which yielded a weighted average of \$0.30 in net benefits per dollar spent.

Besides the core finding of a positive net benefit of the ARRA highway disbursement, another key finding is that about half of the increased vehicle miles traveled resulting from the ARRA highway disbursement was due to the spatial spillover impacts on vehicle miles traveled in states neighboring the states where the funds were disbursed. This result implies that about half the benefits from improving a state's highway system are disseminated outside the state to the users of multistate highway networks.

The approach used in this study does not address the question about whether the ARRA was beneficial in rehabilitating the deeply depressed economy. However, given the assumptions of the SDMP and the e*x post* simulated welfare calculations, our estimates suggest a positive national net benefit from the ARRA disbursement emanating from increased highway demand.

Another implication of this study is that the dollar value of the ARRA highway disbursement is not the only element that determines the net benefit per dollar spent for a given state. For example, Georgia received the highest estimated net benefit per dollar spent of \$0.89, whereas its ARRA highway disbursement ranked 9th among the 48 states. This finding shows that a state's neighborhood structure also affects its net benefit per dollar spent. Thus, directing funds toward improving neighborhood structures could be considered to improve states' returns per dollar spent when future highway funds are disbursed.

A caveat should be noted. The cutoff value $\overline{q}_i$ when integrating the area shown as ΔCS_i^{all} in Figure 1 is an arbitrary value corresponding to a price ceiling of 100 times $p_{i,2010}$. Sensitivity analyses were performed to test the sensitivity of $\left(\sum_{i=1}^{48}\Delta CS_i^{all}\right)$ to changes in $\overline{q}_i$ by assuming $\overline{q}_i$'s corresponding to price ceilings of 150 and 50 times $p_{i,2010}$, which are respectively denoted as $\overline{q}_{i,+50\%}$ and $\overline{q}_{i,-50\%}$. The resulting total net benefits are \$11.9 billion and \$2.0 billion, respectively, yielding average net benefits per dollar spent of $0.44 and $0.07, respectively. The rank order of state net benefit per dollar spent was not substantially changed by varying $\overline{q_i}$. For the cutoffs q+50 and q-50 provided the same ranks with the original cutoffs in 40 and 38 of the 48 states, and no state changed more than three ranks. The sensitivity analysis implies some confidence in determing which states received greater benefits from the 2009 ARRA highway disbursement than others, and that positive net benefits per dollar spent are likely. Nevertheless, the aforementioned sensitivity to the cutoff value suggests caution when interpreting the magnitude of the additional consumer surplus generated by the 2009 ARRA disbursement.

Endnotes

1. In the United States, an entitlement program is a kind of government program that offers individuals personal financial benefits to which an indefinite number of potential beneficiaries have a legal right whenever they meet eligibility conditions that are specified by the standing law that authorizes the program (Johnson 2013).

2. In fact, equation (2) embraces four different model specifications depending on whether those unobserved effects exist; i) both effects do not exist ($\mu_i = 0$, and $\lambda_t = 0$), ii) only state-specific effects exist ($\mu_i \neq 0$, and $\lambda_t \neq 0$), iii) only time-specific effects exist ($\mu_i = 0$, and $\lambda_t \neq 0$), and iv) both effects exist ($\mu_i \neq 0$, and $\lambda_t \neq 0$).

3. The log-likelihood function for equation (3)——in the following illustration our notation subsumes lagged highway disbursements into the vector of other regressors $\mathbf{X}_{i,t}$—is expressed as:

$$\text{(a)}\quad \ln L = -\frac{NT}{2}\ln(2\pi\sigma^2) - \frac{1}{2\sigma^2}\sum_{i=1}^{N}\sum_{t=1}^{T}\left[Q_{i,t} - \rho\sum_{j=1}^{N} w_{ij}Q_{j,t} - \mathbf{X}_{i,t}\boldsymbol{\beta} - \sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\boldsymbol{\Phi} - \mu_i\right]^2 + T\ln\left|I_N - \rho W\right|,$$

where the last term on the right hand side of the equation is the Jacobian term that addresses the endogeneity of the spatially lagged dependent variable $\sum_{i=1}^{N} w_{ij}Q_{j,t}$ (Anselin 1988). Taking the derivative of equation (a) with respect to μ_i and solving for μ_i gives:

$$\text{(b)}\quad \mu_i = \frac{1}{T}\sum_{t=1}^{T}\left[Q_{i,t} - \rho\sum_{j=1}^{N} w_{ij}Q_{j,t} - \mathbf{X}_{i,t}\boldsymbol{\beta} - \sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\boldsymbol{\Phi}\right].$$

The log-likelihood function (a) is re-expressed by replacing μ_i with the right hand side of equation (b):

$$\text{(c)}\quad \ln L = -\frac{NT}{2}\ln(2\pi\sigma^2) - \frac{1}{2\sigma^2}\sum_{i=1}^{N}\sum_{t=1}^{T}\left[Q^*_{i,t} - \rho\left(\sum_{j=1}^{N} w_{ij}Q_{j,t}\right)^* - \mathbf{X}^*_{i,t}\boldsymbol{\beta} - \left(\sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\right)^*\boldsymbol{\Phi}\right]^2 + T\ln\left|I_N - \rho W\right|,$$

$$Q^*_{i,t} = Q_{i,t} - \frac{1}{T}\sum_{t=1}^{T} Q_{i,t}$$

$$\left(\sum_{j=1}^{N} w_{ij}Q_{j,t}\right)^* = \sum_{j=1}^{N} w_{ij}Q_{j,t} - \frac{1}{T}\sum_{t=1}^{T}\left(\sum_{j=1}^{N} w_{ij}Q_{j,t}\right),$$

$$\mathbf{X}^*_{i,t} = \mathbf{X}_{i,t} - \frac{1}{T}\sum_{t=1}^{T}\mathbf{X}_{i,t},$$

$$\left(\sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\right)^* = \sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t} - \frac{1}{T}\sum_{t=1}^{T}\left(\sum_{j=1}^{N} w_{ij}\mathbf{X}_{j,t}\right).$$

Estimates of β, Φ, ρ and σ^2 and maximize the full log-likelihood function (c) and were obtained following Elhorst's (2003) two-step procedure using the concentrated maximum likelihood function.

4. As an illustration, the marginal effects of a change in the price of highway usage in the first state (i = 1) at a point in time are derived to demonstrate differences in demand curves among states. For simplicity, we transform equation (3) into N dimensional matrix form:

   (d) $\boldsymbol{Q} = \rho W\boldsymbol{Q} + \alpha \boldsymbol{j}_N + \mathbf{X\beta} + W\mathbf{X\Phi} + \boldsymbol{\mu} + \boldsymbol{\varepsilon}$,

   where j_N is an $N \times 1$ vector of ones. Equation (d) can be re-expressed as:

   (e) $\boldsymbol{Q} = \rho W\boldsymbol{Q} + \boldsymbol{P}\beta_p + W\boldsymbol{P}\phi_p + \mathbf{A}$,

   where $\boldsymbol{P}$ is an $N \times 1$ price vector, β_p and ϕ_p are scalar parameters, and $\mathbf{A}$ contains the other terms in equation (d) that are not involved in calculating the marginal effects. The total marginal effect of a price change on highway demand for the given state (i = 1) is:

   (f) $$\frac{\partial \boldsymbol{Q}}{\partial P_{i=1}} = (I - \rho W)^{-1}(\boldsymbol{i}_1\beta_p + W\boldsymbol{i}_1\phi_p),$$

   where $\boldsymbol{i}_1' = [1, 0, \cdots, 0]_N$. Equation (f) can be re-expressed as:

   (g) $$\frac{\partial \boldsymbol{Q}}{\partial P_{i=1}} = (I - \rho W)^{-1}\begin{bmatrix} \beta_p + w_{11}\phi_p \\ w_{21}\phi_p \\ \vdots \\ w_{n1}\phi_p \end{bmatrix}.$$

   Let v_{ij} be an (i, j) element of $(I - \rho W)^{-1}$, then equation (g) can be solved as:

   (h) $$\frac{\partial \boldsymbol{Q}}{\partial P_{i=1}} = \begin{bmatrix} v_{11}\beta_p + \phi_p \sum_{k=1}^{n} v_{1k} w_{k1} \\ v_{21}\beta_p + \phi_p \sum_{k=1}^{n} v_{2k} w_{k1} \\ \vdots \\ v_{n1}\beta_p + \phi_p \sum_{k=1}^{n} v_{nk} w_{k1} \end{bmatrix}.$$

   The first element of the vector in equation (h) denotes the direct effect of P on Q for a given state (i = 1), the other elements of the vector represent the indirect effects on Q for the other states ($i \neq 1$) and the sum of all elements in (h) is the total marginal effect across the 48 states. The marginal effects of P in (h) vary across states because the elements in $(I - \rho W)^{-1}$ and the elements in W differs in value depending on the spatial unit where an initial shock occurs.

5. The gasoline-price data in \$/gallon were converted to \$/mile using approximation of an average mileage rate of 25 miles/gallon according to the report by Litman and Doherty (2009).

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