Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions

Technical Background Document

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Study Selection

Research on the effects of highway capacity expansion on vehicle travel focuses on the "induced travel" effect. Induced travel is defined as the increase in vehicle travel that occurs because of capacity expansion. The primary mechanism underlying this effect is an increase in travel speed, which enables more trips and longer distance trips in a given amount of time.

Although research on this topic goes back several decades, a surge of studies in the late 1990s and early 2000s, many focused on California, produced relatively consistent results using somewhat different methods. Included in the accompanying *Policy Brief on the Impact of Highway Capacity and Induced Travel on Passenger Vehicle Use and Greenhouse Gas Emissions* are studies from California and the U.S. that focus on effects on vehicle-miles traveled (VMT) and that control for factors other than capacity expansion that influence VMT. Six studies published between 1997 and 2011 were included (see Table 1). The brief excludes studies that focused on traffic counts or average daily traffic (ADT) (e.g. Mokhtarian et al. 2002) or on the relationship between VMT and changes in travel time (i.e. travel-time elasticities) (e.g. Barr, 2000), as they do not have a direct relationship with greenhouse gas emissions.

No systematic studies of the effect on VMT of permanent capacity reductions in the U.S. were identified. Hunt et al. (2002) describe the challenges associated with studying the effects of permanent capacity reductions.

Methodological Considerations

The six selected studies all use a combined cross-sectional and time-series approach with aggregate data, though with different units of analysis (Table 1). Several studies analyze effects at the level of metropolitan regions (e.g. Noland and Cowart, 2000; Hansen and Huang, 1999) or counties (e.g. Cervero and Hansen, 2001 and 2002; Hansen and Huang, 1999). One study analyzes effects at the state level (Noland, 2001), while another examines effects for projects (Cervero, 2003). Region- or county-level analysis may be most effective in capturing the effect of the shifting of travel from one roadway to another in determining the net effect of capacity expansions (Cervero and Hansen, 2002).

Table 1. Descriptions of Selected Studies

Study	Study location and years	Unit of analysis and sample Roadway types	Method	Dept Var	Indept Var	Fixed effects	Instru-ments	Controls	Lags
Duranton and Turner, 2011	US 1983 – 2003	Metro Areas: 192 MSAs with urban interstates at three time points Interstate Highways	Multiple models. Final model: Two-stage least-squares regression with instrumental variables	VKT	Lane km	Decade	Historic routes	Population, geographic variables, census division variables,	n/a
Cervero, 2003	California 1980 - 1994	Freeway projects: 24 projects at 15 time points Projects in small- and medium-sized cities in suburban areas	Path model accounting for speed and development as mediating variables	VMT	Lane miles	Project Year	n/a	Population density, employment density, race/ethnicity	7-8 years
Cervero and Hansen, 2002	California 1976 - 1997	Counties: 34 urban counties at 22 time points State-owned roadways	Multiple models: simultaneous equation analysis (three-state least squared regression); distributed lag model	VMT	Lane miles	County	n/a	Population, income per capita, fuel price, employment density	1 to 5 years
Noland, 2001	US 1984-1996	States: 50 states at 13 time points All roadway types as reported by US DOT in *Highway Statistics*	Multiple models: fixed-effects ordinary least squares models, distributed lag models; for all roads and disaggregated by road type	VMT	Lane miles per capita	State	n/a	Population, income per capita, fuel cost	2 and 5 years
Noland and Cowart, 2000	US 1982 - 1996	Metro areas: 70 areas at 15 time points Freeways and arterials	Multiple models: distributed lag model, two-stage least-squares regression with instrumental variables	VMT per capita	Lane miles per capita	Metro area Year	Urbanized land area, population density	Population density, income per capita, fuel cost	1 year
Hansen and Huang, 1997	California 1973 – 1990	Counties: 30 counties at 19 time points Metro areas: 14 metro areas at 19 time points State-owned highways	Multiple models: fixed-effects ordinary least square models, distributed lag models with fixed effects	VMT	Lane miles	County/ metro area Year	n/a	Population, population density, income per capita, fuel price	2 and 4 years

The dependent variable in most studies is vehicle-miles of travel (VMT), though one study uses VMT per capita (Noland and Cowart, 2002) and one uses vehicle-kilometers of travel (VKT) (Duranton and Turner, 2011). Similarly, capacity is measured as lane miles, lane miles per capita (Noland and Coward, 2000; Noland, 2001), or lane kilometers (Duranton and Turner, 2011). Most studies focus on state-owned or maintained highways (including federal highways as well as state highways), but the Duranton and Turner (2011) study includes only interstate highways, and Noland (2001) uses data for all roadway types. In all cases, the log or natural log of both VMT and lane miles are used in estimating the statistical model, so that the coefficient for lane miles is equivalent to the elasticity of VMT with respect to lane miles.

The studies employ similar econometric techniques in estimating statistical models, though with notable variations, as described in more detail below. All six studies pool data for multiple places and points in time and then estimate models with fixed effects for geography and/or for time. Including fixed effects in the model (in the form of a dummy variable for geography or time) compensates for the lack of information on all of the factors that might influence VMT. The models generally control for factors other than capacity expansion that may influence changes in VMT, such as population, income per capita, and fuel price.

However, the studies use different approaches to addressing simultaneity bias, the possibility that VMT growth causes capacity expansions at the same time that capacity expansions cause VMT growth. Most common is the use of two-state least squares regression with instrumental variables (Noland and Cowart 2000; Duranton and Turner 2011). This approach involves “instrumenting” the independent variable of interest (i.e. lane miles) with an estimator based on exogenous variables that do not directly affect the dependent variable (i.e. VMT) (Hansen and Huang, 1997). For example, Duranton and Turner (2011) use three instrumental variables: miles of routes of major expeditions of exploration between 1835 and 1850, major rail routes in 1898, and proposed routes of interstate highways in preliminary plans. The analysis used these three variables to predict lane kilometers in cities, then used this estimate in a second equation to predict the effect of road capacity on VMT. Finding appropriate instrumental variables for which data are available is challenging, however (Hansen and Huang, 1997; Duranton and Turner, 2011).

Several other methods to address simultaneity bias have also been used. Cervero and Hansen (2002) estimated simultaneous equation models (equivalent to a three-stage least squares model) to account for the bi-directional relationship between capacity expansion and VMT. They also used a Granger test of time precedence to further confirm that capacity expansion precedes VMT growth, but VMT growth also precedes capacity expansion.

The question of short-term versus long-term effects is addressed in some studies through the inclusion of lagged effects in the models (e.g. Cervero and Hansen, 2002). “Lagged effects” refers to the lag between the timing of the capacity expansion and the timing of the observed effect. In the studies reviewed, the lags range from 1 year to 8 years, with lags of 1 to 2 years considered “short term” and lags of 4 years or more considered “long term.” Cervero (2003) used a path model to demonstrate both short-term effects resulting from increases in travel speed and long-term effects resulting from impacts of capacity expansion on speed as well as development patterns. Distributed lag models were used in several studies to estimate long-term elasticities (Noland and Cowart, 2000; Noland, 2001; Hansen and Huang, 1997). In this approach, VMT per capita lagged by one year is included in the model as an independent variable; the coefficient for lagged VMT is then used to adjust the short-term elasticity (as represented by coefficient for unlagged VMT) to get a long-term elasticity. Hansen and Huang (1997) tested several different lag periods and found that a two-year lag was appropriate for counties, while a four-year lag was appropriate at the metropolitan level.

Notable aspects of specific studies (starting with the most recent study) are as follows:

Duranton and Turner (2011): This study uses data for metropolitan regions in the U.S. at three points in time. Similar to other studies, this study used two-stage least squares regression with instrumental variables, but the use of the three instrumental variables described above overcomes problems with those used by other researchers, according to the authors. Through a multitude of analyses, this study provides estimates of the effect of increasing capacity for one road type on other road types and examines the relationship between vehicle travel and public transit service. The analysis controls for population, physical geography, and census division indicators.

Cervero (2003): This study focuses on freeway expansion projects that occurred in small- to medium-size cities in suburban settings in California. The analysis uses a path model structured according to a proposed conceptual model that accounts for the mechanisms by which capacity expansion leads to increased VMT: increases in speed, and changes in development patterns. The estimated elasticity in the short term (0.10) is the product of the change in speed relative to the change in lane miles (0.42) and the change in VMT relative to the change in speed (0.24). The estimated elasticity in the long term (0.39) is the sum of the effect from lane miles to speed to VMT (0.25), the effect from lane miles to speed to development to VMT (0.07) and the effect from lane miles to development to VMT (0.07). The author argues that the estimated elasticities are smaller than estimates in other studies because not all speed improvements are attributable to capacity expansion.

Cervero and Hansen (2002): This study used 22 years of observations for 34 urban counties in California. The analysis employed simultaneous equation modeling with both induced travel demand (VMT) and induced road investment (i.e. supply, measured as lane-miles) as endogenous variables in order to account for their reciprocal relationship. The analysis examined different lagged structures to account for the fact that effects are not instantaneous for either supply or demand. The analysis controlled for operating cost and gas prices, county population, population by race, population and employment density, personal income, average fuel efficiency, geography/weather, air quality, and political party affiliations. Fixed-effects for time were not included in the model, as the inclusion of population, which increased steadily over the study period in California, serves a similar role, according to the authors. The findings showed strong reciprocal relationships between road investment and travel demand, but the elasticity estimates were similar to those from previous single-equation studies.

Noland (2001): This study is unique in analyzing effects at the state level. As a measure of capacity, this study used lane-miles per capita rather than lane-miles, to account for the wide variation in population by state. In addition to a fixed-effects ordinary least squares model, the study employed distributed lag models, in which one-year lagged VMT per capita was included as an independent variable in the model. The study also disaggregated the analysis by road type, e.g. whether interstate, arterial, or collector, and whether urban or rural. The seemingly unrelated regression method was used to account for the interrelationships between VMT on various road types, including urban versus rural roadways. The study controlled for state population, per capita income, and cost per energy unit of gasoline.

Noland and Cowart (2000): This study analyzed VMT per capita as a function of lane miles per capita, the latter a proxy for traffic congestion and thus travel time. In calculating the elasticity (the ratio of the change in VMT per capita to the change in lane miles per capita) based on this model, the “per capita” element cancels out, leaving an elasticity equivalent to those of other studies. The elasticities reported in the brief are from the distributed lag model. The study also estimated two-stage least squares regression models with urbanized area and population density as instrumental variables, but the authors concluded that these instruments were less than ideal. The study controlled for population density, income per capita, and fuel cost.

Hansen and Huang (1997): This study focused on counties and on metropolitan areas in California but examined VMT on state highways only. The study estimated fixed-effects models using ordinary least squares regression as well as the Prais and Winsten method. In addition, distributed lag models with fixed effects were estimated, and several different lag periods were tested. The study did not use two-stage regression with instrumental variables, as the researchers could not identify appropriate instruments for which data were available. The analysis controlled for population and personal income per capita.

A seventh study was considered for inclusion in the brief. Fulton, et al. (2000) used an approach similar to Noland and Cowart (2000) and Duranton and Turner (2011) in a study of the induced travel effect in counties in the mid-Atlantic region. However, this study used growth in lane miles over two or three years as the instrument for current (one-year) growth in lane-miles, arguing that “this variable is both highly correlated with the growth in lane miles and not correlated with the growth in VMT.” Given the tenuousness of this assumption, this study was excluded from the brief. The effect size estimated in this study falls within the range of estimates from the other studies, however.

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