

# **INDUCED TRAVEL: A REVIEW OF RECENT LITERATURE WITH A DISCUSSION OF POLICY ISSUES**

## **INTRODUCTION**

The theory of induced growth in vehicle travel hypothesizes that increases in the carrying capacity of a specific highway corridor or road network will result in an increased level of vehicle traffic. The increase in road capacity results in a decrease in the generalized cost of travel (especially the time costs of travel) and hence an increase in the demand for travel. While this interpretation is intuitively simple and grounded in basic economic theory, it has remained a contentious issue among traffic engineers, transportation planners, and the environmental community. A common engineering approach assumes that demand for travel is derived from exogenous growth in economic activities, and generally does not consider the inter-relationships between highway capacity, relative travel times, and overall regional accessibility.

This paper outlines the behavioral relationships underlying the theory of induced travel and reviews recent research that documents and empirically measures induced travel effects. This research has not only built a strong case for the existence of induced travel effects, but in some cases suggests that a large fraction of growth in vehicle miles of travel (VMT) is directly attributable to increases in road capacity. The paper concludes with a discussion of the additional research needs in this area and the potential implications of this line of research for EPA policies and regulations.

## **INDUCED TRAVEL: THEORY AND DEFINITIONS**

The underlying theory behind induced travel is based upon the generally accepted economic theory of supply and demand. Any increase in highway capacity (supply) results in a reduction in the time cost of travel. Travel time is the major component of variable costs experienced by those using private vehicles for travel. When any good (in this case travel) is reduced in cost, the quantity of the good demanded increases.

Travel supply and demand and the induced travel effect is illustrated graphically in Figure 1. The line S1 is supply before a capacity expansion or other changes that lower the cost of travel. The line S2 is supply after the change in capacity, resulting in a

lower cost of travel, associated with a lower travel time cost. The quantity of travel increases from Q1 to Q2 as the change in supply lowers the cost of travel from P1 to P2. Figure 1 assumes no change in underlying demand. For example, population growth is not depicted in Figure 1. The increase in the quantity of travel from Q1 to Q2 represents the induced travel effect.

In measuring this effect there are many confounding factors that also drive growth in VMT. Population growth, increases in income, and other demographic effects, such as increased numbers of women in the workplace, are often cited (Transportation Research Board, 1997). Figure 2 shows how these effects can be graphically illustrated. The demand curve shifts outward from D1 to D2 because more travel is demanded at a given price when population increases in an area. The demand and supply curves shift simultaneously in Figure 2, and the resulting quantity of travel increases even more than in Figure 1 (to Q3). Empirically, it is difficult to isolate these two concurrent effects, and the relative contribution to VMT growth of different factors. In Figure 2, the induced travel effect is measured along the horizontal axis as the difference between Q2 and Q1, while the effect from exogenous growth is the difference between Q3 and Q2.<sup>1</sup>

Induced travel can be broadly defined as the increase in VMT attributable to any transportation infrastructure project that increases capacity. Hills (1996) provides a useful categorization of the various behavioral effects one can expect from highway upgrades or capacity expansions. Immediate behavioral effects include: changes in the timing of departure due to rescheduling of trips (Small, 1982); switching of routes to take advantage of new capacity; switches between transportation modes such as switching to private vehicle use from transit; longer trips; and an increase in total trips taken. The most visible of these effects (as shown by the difficulty of reducing peak period congestion) tends to be rescheduling behavior that results in travelers returning to their preferred peak travel times. However, this effect does not necessarily result in an increase in VMT and so would not represent induced travel.<sup>2</sup> However, shifts to the peak

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<sup>1</sup> The relative scale of the effects in Figure 2 do not necessarily represent actual magnitudes.

<sup>2</sup> Peak shifting that does not noticeably reduce aggregate travel times does suggest that the benefits of most projects are not accurately assessed. Rather than assessing benefits based on travel times an assessment based on the ability to travel at a preferred time should be done (Small, 1992).

that free up capacity at other times of the day can result in new trips being made at those times that are now less congested.

Route switching can result in either shorter or longer distances being traveled. If the net effect is more travel this is clearly defined as induced VMT. If speeds are now faster, some additional long trips (perhaps recreational in nature or to more distant shopping centers) are likely to be taken increasing total VMT.

In addition to these short run effects, various longer run effects can have a significant impact on total VMT growth. Long run effects occur due to changes in relative accessibility within an urbanized area and can result in the spatial reallocation of activities. If speeds are higher, many residences and businesses will tend to relocate over time often resulting in longer distance trips (Gordon and Richardson, 1994).

## **RESEARCH EXAMINING THE ISSUE OF INDUCED TRAVEL**

Research on induced travel effects can be found going back several decades. Goodwin (1996) cites a report done for the U.K. Ministry of Transport in 1938 that evaluated a significant increase in traffic on a new road. Much of the historical literature has been based on observational traffic counts within travel corridors. These studies have generally not accounted for other exogenous effects that could also contribute to growth in VMT. Recent work by Goodwin (1996) attempted to control for exogenous factors by selecting a comparable control corridor. In general, he finds significant increases in traffic due to specific highway improvement projects within these corridors.

An early study in the U.S. by Jorgensen (1947) analyzed the traffic generating effects of the newly built Merritt and Wilbur Cross parkways in Connecticut. He found a correlation between traffic growth with gasoline sales for the state of Connecticut. Based upon this, he estimated that the parkways generated 20 to 25 percent more traffic than would have been expected from the expected trend in traffic growth.

Holder and Stover (1972) examined the traffic generating impacts of eight highway projects in Texas. This study examined trend patterns of traffic growth and concluded that there was about a 5 to 21 percent growth in traffic that was induced by the road projects.

The Transportation Research Board (1995) of the National Research Council examined the issue of induced travel and the implications for air quality and energy use. This report provides extensive detail on the behavioral impacts from expanding road capacity. The primary focus of the report was on the capability of analytical models used for forecasting regional transportation growth and emissions of criteria pollutants. The consensus was that most modeling procedures are deficient and probably do not adequately capture induced travel effects or the behavioral and economic development impacts of road projects. The report, however, was inconclusive on how induced travel may effect air quality, an issue complicated by the relationship between traffic dynamics (such as changes in acceleration characteristics) and emissions.

More recent work has attempted to separate the effects of other exogenous variables using econometric techniques. Hansen & Huang (1997) used time series data on VMT and lane miles for state highways in California, by county and metropolitan area, to estimate econometric models. They used a fixed effects model of the following form:

$$\log(VMT_{it}) = \alpha_i + \beta_t + \sum_k \gamma^k \log(X_{it}^k) + \sum_{l=0}^L \delta^l \log(SHLM_{it-l}) + \epsilon_{it}$$

Where,

$VMT_{it}$  is the VMT in region  $i$  in year  $t$ .

$\alpha_i$  is the fixed effect for region  $i$ ,

$\beta_t$  is the fixed effect for year  $t$ ,

$X_{it}^k$  is the value of explanatory variable  $k$  for region  $i$  and year  $t$ ,

$SHLM_{it-l}$  is state highway lane miles for region  $i$  and time  $t-l$ .

$\gamma^k, \delta^l$  are coefficients which are estimated,

$\epsilon_{it}$  is an error term, assumed to be normally distributed.

Other variables included in their analysis are population, personal income, population density, and gasoline prices, all of which are expected to have an effect on VMT growth. Estimates using ordinary least squares and a Prais-Winsten regression result in a statistically significant coefficient on the SHLM variable. Lane mile elasticities (with respect to VMT) of between 0.3 to 0.7 were found for models using county-level data. Elasticities of between 0.5 to 0.9 were found for models using metropolitan level data.

Various lag structures were also tested and a two to four year lag structure resulted in long run elasticities that were greater than those in the unlagged models.

Noland (forthcoming) estimated a number of similar panel regression models using nationwide data at the state level. In general, Noland finds similar elasticity values ranging from 0.3 to 0.6 in the short run and from 0.7 to 1.0 in the long run. The models estimated by Noland include a disaggregation of the data by road facility type (i.e., interstates, arterials, and collector roads by urban and rural road categories). These are estimated using Zellner's seemingly unrelated regression and with a distributed lag (thereby allowing the derivation of a long run elasticity). Results for one of these models is displayed in Table 1.

An analysis of nationwide metropolitan level data by Noland & Cowart (1999) tells the same story. Long run elasticity values of 0.8 to 1.0 are derived using a distributed lag model estimated for VMT and lane miles specific to interstates and arterial road capacity. Another study by Fulton et al. (1999) used cross-sectional time series county-level data from North Carolina, Virginia, and Maryland to estimate both short run and long run elasticities. Their results are consistent with previous studies showing a short run elasticity of 0.1 to 0.4 and a long run elasticity of 0.5 to 0.8.

One issue that is not completely resolved is the issue of causality. Highway planners argue that since they have forecasted where individuals desire to travel they expect roads to fill up with travelers after they are built. However, this does not explain the fact that new highway capacity often becomes more congested more rapidly than initially planned. Goodwin (1996) compares forecast and actual rates of traffic growth (from a sampling of projects in the UK) and finds that the forecasts are generally too low. This may partially be a function of analytical forecasting tools that are not accurately capturing induced travel effects. In any case, many planners discount the work of Hansen & Huang (1997) and Noland (1999) as merely proving that a correlation has been found and that these studies show that planners are putting highways where people want to travel. These arguments, however, do not fully consider the degree to which the use of a fixed effects model minimizes simultaneity bias in the regressions.

One approach for more definitively addressing the issue of causality is to use an instrumental variable in the regression. Noland & Cowart (1999) use a two stage least

squares regression using urbanized land area as an instrument for lane miles per capita. Results for a two stage least squares analysis using urbanized area are shown in Table 2. Urbanized land area is not strongly correlated with per capita VMT but is significantly related to total lane miles per capita (increasing urbanized land area results in lower lane miles per capita). Model (A) has coefficient values very similar to ordinary least squares, while model (B) shows somewhat of a reduced effect. Overall, these results tend to support the hypothesis of a causal linkage between increasing lane miles and increased VMT.

Given that the hypothesis of induced travel is supported by the results of the recent empirical studies, the next relevant question is how important is the induced travel effect compared to other drivers of VMT growth. Both Noland (forthcoming) and Noland & Cowart (1999) estimate the relative contribution of induced demand to overall VMT growth. Noland (forthcoming) applies the distributed lag model in Table 1 to forecast VMT growth out to 2010. He finds that if current trends in both lane mile increases and demographic variables continue, VMT will grow at about 2.65% annually. If lane mile growth is set to zero, this reduces VMT growth to about 1.9% annually. In other words, the induced travel effect accounts for about 28% of annualized growth in VMT. Noland & Cowart (1999) estimate this effect to average 45% of annualized VMT growth (on interstates and arterials) for metropolitan areas. This result strongly suggests that forecasting VMT growth (and the environmental impacts of that growth) needs to include some measure of transportation infrastructure as a determining factor.

Another key research question is under what circumstances might induced travel be larger or smaller. For example, one would expect induced travel effects to be larger in a congested area. Chu (1999) developed a model to try to estimate elasticity changes for different levels of underlying congestion. In deriving his theoretical model of travel demand and highway supply he determines that incremental expansion in highway capacity will have smaller effects on vehicle travel. In testing this hypothesis, he uses data from the Nationwide Personal Transportation Survey (NPTS) and estimates the following model:

$$\log(q/C) = \mathbf{b}_0 + \mathbf{b}_1 \log(X^k) + \mathbf{b}_2 \log(C) + \mathbf{b}_3 (\log(C))^2 + \mathbf{e}$$

where  $q$  is vehicle travel (VMT),  $C$  is a measure of capacity (lane miles),  $X^k$  refers to other variables included in the estimation, and  $\varepsilon$  is an error term. Using a cross-sectional database of metropolitan areas derived from the NPTS, Chu finds significant coefficients on both the  $b_2$  and  $b_3$  terms. He concludes that capacity does influence total traffic albeit with a diminishing effect as specified in his theoretical model.

Fulton et al. (1999) also attempted to determine whether population density and/or existing traffic congestion can result in different elasticity estimates. They include an interaction term for areas with low, medium, and high volumes of traffic per lane mile and also for low, medium, and high population densities. One would expect that those areas with more congestion or higher population density would have relatively larger elasticities. Fulton et al. (1999) were unable to find any statistical differences in the lane mile coefficients. Noland & Cowart (1999) also examined this issue using both the size of the metropolitan area and an index of traffic congestion as interaction terms. They found no statistical differences in the lane mile coefficients other than for medium sized metropolitan areas having a larger elasticity.

Additional research is currently being conducted to examine the development impacts of increasing highway capacity and additional attempts to statistically estimate causal linkages. The Department of Transportation is also incorporating measures of induced travel demand into their Highway Economics Requirement System which attempts to determine total financial needs for the U.S. highway system using a cost benefit analysis approach.

## **FUTURE RESEARCH NEEDS AND POTENTIAL IMPLICATIONS FOR EPA**

The theoretical basis for induced travel effects and the empirical research reviewed above could have implications for how EPA undertakes its responsibilities under the National Environmental Policy Act (NEPA) and the Clean Air Act (CAA). These include, respectively, EPA's role in the review of Environmental Impact Statements and conformity determinations under the CAA.

However, additional research is needed in order to ascertain the potential range of environmental impacts resulting from induced travel. Much of the empirical research

reviewed above indicates that on a regional or national basis, additions of highway capacity are associated with increases in the total amount of vehicle miles of travel.

These increases in vehicle miles of travel have yet to be measured in terms of their impacts upon air quality (e.g., criteria air pollutant and greenhouse gas emissions). The conversion from vehicle miles traveled to air quality impacts is not as straightforward as it may appear. For example, with the construction of a new highway, there may be more traffic “induced” onto the highway, but the flow characteristics of the traffic may be altered. Depending upon what happens to average speeds and whether the travel is “stop and go” or smooth flowing, emissions per vehicle may increase or decrease. The two effects---total travel and the characteristics of that travel---will interact to determine the emissions implications of the highway expansion. Further, additional vehicle miles of travel have impacts upon water quality, for example by affecting the amount of stormwater runoff from highways and other impervious surfaces.

Since the recent studies reviewed above rely upon aggregate analysis of vehicle miles of travel at the county, metropolitan, and state levels, the empirical results may not directly convert into specific elasticities for individual transportation corridors or individual highway projects. Additional research may be needed at the corridor-specific and project-specific level empirically measuring induced travel effects, resultant environmental impacts, and the conditions under which they occur.

#### National Environmental Policy Act

One of EPA’s major roles<sup>3</sup> is to review and comment on Environmental Impact Statements for Federal projects as specified by NEPA. The role of the Environmental Impact Statement (EIS) is to provide information to decision-makers and the public about the environmental impact of projects and possible alternatives.

The stated goal of many transportation projects is to reduce congestion; however, the studies cited above suggest that forecasts of congestion reduction resulting from added highway capacity may be overestimated to the extent that they do not account for induced travel. In addition, regulations promulgated by the Council on Environmental

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<sup>3</sup> EPA’s role in the NEPA process is defined in Section 309 of the Clean Air Act.

Quality (CEQ, 1987) require the assessment of cumulative and secondary impacts of highway projects, some of which may be related to induced travel effects.

Another potential implication of the research results is that if congestion reduction forecasts of additional highway capacity are overstated, then alternative approaches to capacity additions may be more effective at reaching the goal. For example, congestion pricing on existing road capacity has been proposed as an alternative to new capacity construction (Transportation Research Board, 1994). Provision of transit services and redevelopment of existing land (e.g. brownfields and infill development) may also lead to less regional congestion.

#### Clean Air Act Conformity Determinations of Transportation Plans

The Clean Air Act requires transportation plans to be in conformity with State Implementation Plans for meeting the National Ambient Air Quality Standards (NAAQS). Under this law and its associated regulations, states and metropolitan planning organizations must forecast the impact of transportation plans (i.e., a collection of many different projects) on total emissions of criteria pollutants (NO<sub>x</sub>, VOC, CO, and PM-10).

Regional transportation planning agencies (or the states) generally maintain a system of models to forecast and evaluate the impact of transportation projects and plans. These models may be deficient in accurately forecasting emissions (TRB, 1995) partly because they do not adequately account for both short run and long run induced travel effects.

Some EPA regions are working with metropolitan planning organizations to improve the state of the practice in the modeling of transportation impacts, in particular the impacts on land development. Various modeling packages are available to provide estimates of land development changes induced by transportation and accessibility changes. Improved modeling of these impacts would provide decision makers with far better information on the short-run and long-run emissions impact of alternative transportation plans and are critical for developing State Implementation Plans that will actually help bring a region into attainment of the NAAQS.

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Table 1 Seemingly Unrelated Regression by Road Type and Urban/rural area: distributed lag model

Dependent variable is log of VMT by road type Lane miles are by road type per capita	urban interstates	urban arterials	urban collectors	rural interstates	rural arterials	rural collectors
LN(VMT, lagged one year)	0.464 (17.981)	0.370 (12.915)	0.528 (20.251)	0.669 (30.774)	0.485 (16.658)	0.649 (21.658)
LN(urban interstate lane miles, per capita)	0.439 (17.136)					
LN(urban arterial lane miles, per capita)		0.498 (18.002)				
LN(urban collector lane miles, per capita)			0.513 (15.097)			
LN(rural interstate lane miles, per capita)				0.234 (6.473)		
LN(rural arterial lane miles, per capita)					0.369 (10.621)	
LN(rural collector lane miles, per capita)						0.407 (6.726)
LN(population)	0.625 (9.561)	0.652 (10.279)	0.690 (6.645)	0.250 (4.057)	0.509 (8.159)	0.307 (2.950)
LN(per capita income)	0.748 (12.227)	0.489 (9.788)	0.328 (3.545)	0.531 (9.858)	0.630 (11.450)	0.313 (4.387)
LN(cost per BTU of fuel)	-0.085 (-4.191)	-0.047 (-2.308)	-0.019 (-0.478)	-0.064 (-3.590)	-0.035 (-1.746)	-0.033 (-1.106)
Constant	-9.149 (-9.479)	-5.908 (-7.864)	-6.219 (-4.907)	-4.702 (-6.574)	-7.349 (-10.093)	-3.350 (-2.786)
N	583	583	583	583	583	583
<b>Long run elasticities</b>						
Lane miles per capita	0.819	0.790	1.087	0.707	0.717	1.160
Population	1.166	1.035	1.462	0.755	0.988	0.875
Personal income	1.396	0.776	0.695	1.604	1.223	0.892
Gasoline price	-0.159	-0.075	-0.040	-0.193	-0.068	-0.094

**Table 2**  
**Instrumental Variable (2 Stage Least Squares) Regressions**

	(A)	(B)	(C)
LN(vmt per capita)	Instrument = LN(area)	Instrument = LN(area)	Instrument = LN(population / area)
LN(lane miles per capita)	0.760 (18.092)	0.289 (2.873)	1.944 (6.035)
LN(per capita income)	0.315 (6.198)	0.557 (8.051)	-0.135 (-0.798)
LN(fuel cost)	-0.005 (-0.179)	-0.023 (-0.713)	0.135 (2.186)
LN(population density)	-0.160 (-7.077)		
Constant	0.476 (0.887)	-3.193 (-4.701)	3.595 (2.224)
N	1050	1050	1050
Adjusted R <sup>2</sup>	0.975	0.967	0.902

**Figure 1**  
**Induced Travel**

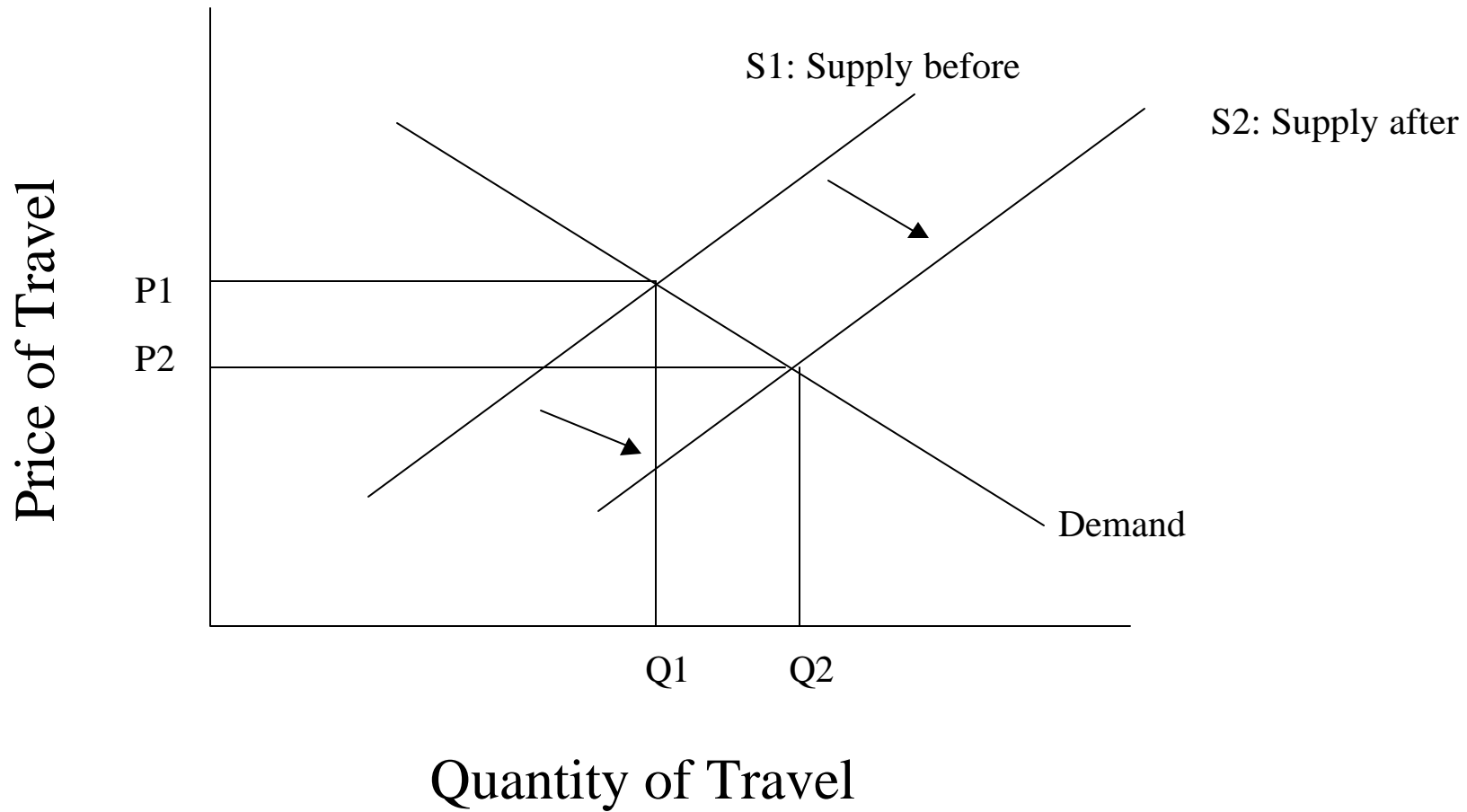


Figure 2

Induced Travel During Period of Underlying Growth in Demand

