INDUCED TRAVEL: A REVIEW OF RECENT LITERATURE AND THE IMPLICATIONS FOR TRANSPORTATION AND ENVIRONMENTAL POLICY

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ABSTRACT

This paper reviews recent research into the demand inducing effects of new transport capacity. We begin with a discussion of the basic theoretical background and then review recent research both in the UK and the US We then procede to examine the influence that verification of these effects is slowly having on both transport and environmental policy in both countries. Changes in policy and implementation of those policies are still occurring and we provide some suggestions on how to move forward in these areas.

INTRODUCTION

Transportation policy has normally been influenced by the desire to provide mobility and efficient access to alternative destinations primarily by alleviating traffic congestion. In the US this has focused around construction of the Interstate Highway System and provision of capital assistance for public transport systems primarily in urbanized areas. The UK has followed a similar approach with a large expansion of the Trunk Road system.[1] Historically the UK has placed great emphasis on cost benefit assessment of road projects to help prioritize projects. Over the last 30-40 years both countries have seen a reduction in public transport usage despite maintaining very different land use planning systems.

Recently both countries have attempted to move towards more integrated transport policies. This began in the US with enactment of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 and subsequent reauthorization as the Transportation Equity Act for the 21st Century (TEA-21) in 1998. In the UK the central government issued a White Paper in 1998 laying out a strategic direction for transport policy (DETR, 1998). The latter reflected research conducted by SACTRA (1994) on the impacts of induced travel as well as environmental concerns over future growth in travel (Goodwin, 1999). In the US capacity enhancing projects are increasingly being challenged as either ineffective at reducing congestion or as likely to result in the continuation of sprawl development patterns and inefficient land use.

This paper analyzes the policy changes that are occurring due to the increased recognition among the public and policy makers that new or expanded roads are not as likely to relieve congestion as once was believed. We begin with a review of the behavioral relationships underlying the theory of induced travel and review recent research that documents and empirically measures induced travel effects. We then examine how transportation and environmental policy is changing in response to the empirical findings both in the US and the UK We suggest areas of improvement in the

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[1] Trunk roads in the UK are the responsibility of the central government and carry the bulk of long distance and through traffic.

decision making process to fully recognize the consequences of induced travel behavior on both transportation and environmental policy.

INDUCED TRAVEL: THEORY AND DEFINITIONS

The underlying theory behind induced travel is based upon the simple economic theory of supply and demand. Any increase in highway capacity (supply) reduces the cost of travel, especially on congested highways, by reducing 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, demand for that good 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 the induced travel 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. 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.[2]

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[2] The relative scale of the effects in Figure 2 do not necessarily represent actual magnitudes.

Induced travel naturally assumes some elasticity of demand associated with travel. That is, as the price (or time cost) of travel changes, the amount of travel demanded changes. Goodwin (1992) reviewed a number of studies of the elasticity of travel with respect to fuel prices. He concludes that elasticities of VMT with respect to gasoline prices range from about –0.16 in the short run up to –0.30 in the long run.[3] However, traffic engineers have traditionally assumed that travel demand has totally inelastic demand implying that total travel will be constant irrespective of changes in the price (or time cost) of travel. This and the attribution of travel growth to exogenous factors is the source of much of the disagreement over the fundamental existence and nature of induced travel effects.

Another common source of disagreement is how to define induced travel. For example, does this just include new trips or should longer trips also be included? Litman (forthcoming), for example, distinguishes between induced traffic and generated traffic, where the latter includes diverted traffic (from other routes), while induced traffic does not include any diverted traffic. We define induced travel to be an increase in VMT, since VMT growth is one of the primary sources of increased environmental and social costs as well as representing the potential benefits of increased mobility. In the simplest terms induced travel (or VMT) can be broadly defined as the increase in VMT attributable to any transportation infrastructure project that increases capacity.

Hills (1996) and Litman (forthcoming) provide 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

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[3] This is distinct from his conclusions on the price elasticity of fuel consumption, which ranges from about –0.25 in the short run up to about –0.8 in the long run.

would not represent induced travel.[4] However, shifts to the peak 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 are hypothesized to have a significant impact on total VMT growth. One long run effect would be increases in household auto ownership levels. Other 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, employees, and businesses will tend to relocate over time often resulting in longer distance trips (Gordon and Richardson, 1994).[5] The concentration of retail activities in "big box" stores or auto-dependent regional shopping centers (rather than centrally located business districts) further increases VMT. Finally, increases in highway capacity may lead to changes in land development patterns within a region.

The theory of induced travel is consistent with Downs (1992) theory of "triple convergence". Downs (1992) formulated this theory to explain the difficulty of removing peak-hour congestion from highways. In response to a capacity addition three immediate effects occur. Drivers using alternative routes begin to use the expanded highway, those previously traveling at off-peak times (either immediately before or after the peak) shift to the peak (rescheduling behavior as defined previously), and public transport users shift to driving their vehicles.

Mogridge (1987) extends this idea to the Downs-Thomson paradox whereby road capacity increases can actually make overall congestion on the road worse. This occurs when the shift from public transport causes a disinvestment in the mode such that the

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[4] Peak shifting that does not noticeably reduce aggregate travel times does suggest that the benefits of most projects are not accurately assessed. This suggests that 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).

[5] While the work of Gordon and Richardson is generally meant to extoll the virtues of suburban land development patterns, their analysis of stability in work travel times while travel speeds increase, provides good empirical evidence for induced travel.

operator either reduces frequency of service or raises fares to cover costs. This shifts additional passengers into cars. Ultimately the system may be eliminated and congestion on the original (expanded) road is worse than before. Arnott and Small (1994) provide a mathematical example of this effect.

Another theoretical framework assumes that total time budgets allocated to travel remain relatively constant over time. This was shown empirically by Zahavi & Ryan (1980) and Zahavi & Talvitie (1980). Gordon and Richardson (1994) show how this has maintained relatively constant average commute travel times. The travel time savings from increased travel speeds tend to be off-set by increased travel distance, rather than actual travel time savings. Thus, individual travel time budgets tend to remain constant. One could argue that full induced travel effects could actually increase the travel time budget if the generalized cost of travel is reduced. However, even without an increase in the travel time budget, a constant travel budget could result in an increase in VMT from capacity additions and the increased travel speeds that are then possible.

Clearly, the theoretical understanding and the potential behavioural characteristics for induced travel effects is well established. Clear empirical evidence has, until recently, remained elusive. This is partly due to the difficulty of statistically separating the many effects that also increase total VMT and establishing clear causal relationships. These issues and a review of the empirical work is presented next.

INDUCED TRAVEL: EMPIRICAL STUDIES AND VERIFICATION OF THE THEORY

Two distinct streams of research on induced travel have been pursued over the last several years. These parallel streams occurred in the UK and the US We review both strands of research which provide persuasive empirical evidence for the existence of induced travel.

Studies in the United Kingdom

Research on induced travel effects can be found going back several decades. Goodwin (1996) cites a report done for the UK 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.

The recent spate of empirical work in induced travel was initiated by the SACTRA (1994) investigation and report to the UK Department of Transport. This study included a review of relevant theory and empirical studies. It also included a detailed review of traffic growth within specific corridors that had an increase in capacity, concluding that many corridors had seen greater than expected traffic growth and that this growth was probably not solely attributable to other impacts such as increases in income. In addition, the studies reviewed focused on traffic counts, rather than changes in VMT, which may mask the effect of some trips now be longer than they were previously. On average, actual use during the first year was more than 10% greater than the forecast one year usage. While some of this may simply be due to inaccuracy in the forecasts (other than the lack of accounting for induced travel effects), these studies also showed that traffic flows on parallel routes that the roads were intended to relieve were also either higher or about the same as before.

The SACTRA (1994) report indicates that some of the forecast inaccuracy may be due to underestimates of the rate of increase in GDP (as used by the National Road Traffic Forecast). The UK Department of Transport considered this to be the primary effect of the underestimation of traffic growth on the schemes studied and thus discounted the evidence for induced travel occurring. SACTRA (1994) discounted this argument for several reasons including potential problems with the timing of the measurements (taken only one year after the schemes were completed) and the lack of a broader measurement of total traffic on alternative roads. They also note that forecast traffic on motorways and bypasses was usually larger than for smaller schemes, which would be expected if induced traffic was occurring. The arguments in SACTRA (1994) also hint at the endogeneity of economic growth and highway capacity additions. The latter may have an impact on overall economic growth as we discuss further below. To some extent, however, the potential forecasting errors could be from numerous factors, including lack of accounting for induced travel, therefore it is difficult to draw firm conclusions from this analysis, other than to demonstrate the weakness of current forecasting procedures.

Rodier and Johnston (2001) analyzed errors in various socioeconomic forecasts and the impact on travel forecast error. This was done for the Sacramento, California region. They found that plausible errors in personal income and fuel price forecasts had no significant impact. However, errors in population and employment growth had a significant impact. Therefore it is reasonable to assume that some of the forecast errors reviewed by SACTRA (1994) are from these type of errors, though separating the sources of errors in demographic projections and omission of induced travel effects is questionable.

SACTRA (1994) and Goodwin (1996) derive travel time elasticities with respect to VMT using fuel price elasticities with respect to VMT. This is done for the elasticity range of –0.15 to –0.30 reported by Goodwin (1992). Using an assumption of 6 pence (9 cents) per minute as the value of time, 25 minutes of average time spent traveling and 50 pence (75 cents) spent per day on fuel, he derives an elasticity range of –0.45 to –0.90 (or as he summarizes, nearly –1.00).

While it is not clear how the assumptions on time spent traveling and fuel costs were derived, it is clear that if we use US prices for gasoline, which are about 4 times less than in the UK and assume somewhat lower average vehicle efficiency, we can easily see that elasticity values in the US must be larger. Assuming a gasoline price of $1.25 per gallon, average speed of 30 mph, and fuel efficiency of 27.5 mpg, then US elasticities would range from –0.56 (short run) to –1.18 (long run).[6] The key result must be that if fuel prices are low, then more of a behavioural response can be expected from changes in travel speeds. That is, highway capacity effects will be larger if travel time accounts for a greater fraction of the total generalized cost of travel.

The SACTRA (1994) report had been commissioned to answer specific questions regarding induced travel. The first question was whether induced traffic is a "real phenomenon". They concluded that induced traffic "can and does occur, probably quite significantly, though its size and significance is likely to vary widely in different circumstances." They also concluded that induced traffic can affect the economic evaluation of a road scheme, i.e., affirmatively answering the question of whether induced traffic does matter. They also conclude that it matters most under conditions

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[6] Other assumptions used by Goodwin (1996) are held to be the same.

where the network is operating close to capacity, where demand elasticity is high, and in cases where a specific scheme is likely to result in large changes in travel costs. They were not able to draw any conclusions on which elements of travel behaviour are affected more or less (i.e., generation, distribution, mode choice, land use, etc.). SACTRA (1994) also included recommendations on how to improve appraisal and forecasting methodologies to account for induced travel. We address issues related to this below in our discussion of policy implementation.

One final piece of evidence for induced travel effects was compiled by Cairns et al. (1998). Their study analyzed the impact of highway capacity reductions on traffic, essentially the reverse of adding new capacity. This study was commissioned in response to changes in the goals of transport policy in the UK on finding ways of supporting alternative modes of travel while reducing total vehicle traffic levels. Improvements in public transport, pedestrian and walking facilities often require the reallocation of road space from motor vehicles. Many proposed projects would be avoided due to fears of "traffic chaos" should this occur. Cairns et al. (1998) reviewed both the theoretical evidence and over 40 specific case studies where road space had been either temporarily or permanently removed. There overall conclusion was that "traffic chaos" did not occur, though there may be short-term transitional impacts, and that overall traffic volumes were reduced by removal of road capacity.

Studies in the United States

Shortly after the completion of the SACTRA (1994) report, the Transportation Research Board (TRB) (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 to adequately account for induced travel effects. 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. Johnston and Ceerla (1996a, 1996b) verified this conclusion by modelling various infrastructure improvements in the Sacramento region and comparing results with and without feedback of initial travel time changes. They also showed that the lack of fully accounting for feedback effects could result in different rankings of the projects on their congestion reduction potential.

The TRB report was inconclusive on how induced travel may effect air quality. This issue is complicated by the relationship between traffic dynamics (e.g., such as changes in acceleration characteristics) and emissions. However, the report clearly concludes that reductions in travel time or costs will result in both increased highway use and have a decentralizing effect on urban development.

More recent empirical work has attempted to separate the effects of other exogenous variables using econometric techniques. This recent body of work began with the work of Hansen et al. (1993) and Hansen & Huang (1997). They estimated econometric models using time series data on VMT and lane miles for state highways in California, by county and metropolitan area. The key innovation was the use of a fixed effects model specified as follows, where,

$$\log\left(VMT_{it}\right) = a_i + b_t + \sum_k l^k \log\left(X_{it}^k\right) + \sum_{l=0}^{L} w^l \log\left(SHLM_{it-l}\right) + e_{it}$$

VMT_{it}	is the VMT in region i in year t.
α_i	is the fixed effect for region i,
β_t	is the fixed effect for year t,
X^k_{it}	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 $t-l$.
l^k, w^l	are coefficients which are estimated,
e_{it}	is an error term, assumed to be normally distributed.

Fixed effect models with panel data include dummy (0-1) variables for each cross-sectional unit (less one) and sometimes for each year (again, less one). They are then normally estimated using ordinary least squares regression. 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.

The use of panel data and fixed effects estimation allows estimation of models when the analyst may not have data on all the causal factors that influence the dependent variable (Johnston and Dinardo, 1997). This is of critical importance in the analysis of VMT growth. Many factors have been suggested as drivers of recent growth in VMT.

These include increased female participation in the work force, changing lifestyles amongst individuals, changes in family structure, levels of available public transport, spatial patterns of development, and others which are either unknown or for which data is not easily available. Many of these factors may also be highly correlated with other variables such as per capita income or overall population growth, which can cause problems in estimating standard errors for the coefficients of interest.

As outlined by Johnston and Dinardo (1997), analysis of simple cross-sectional data using ordinary least squares estimation can result in biased estimates due to orthogonality between the independent variables and the time-invariant error term. Panel data allows the time-invariant terms to drop out, thereby removing the bias in estimation. Johnston and Dinardo (1997) point out that "with panel data it is possible to obtain consistent estimates of parameters of interest even in the face of correlated omitted effects when OLS on individuals' cross sections would fail to do so!".

Hansen & Huang (1997) estimate statistically significant coefficients on their lane mile variable using panel data and both OLS and a Prais-Winsten regression. The latter was done to correct for autocorrelated error terms that they found using OLS regression. 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 (2001) 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. In addition, Noland (2001) estimates a growth (or difference) model. This has the beneficial effect of removing virtually any multicollinearity in the independent variables. The resulting lane mile coefficient estimates remain similar, ranging from 0.5 to 0.8, all with high levels of statistical significance.

An analysis of nationwide metropolitan level data by Noland & Cowart (2000) 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.

One criticism of this work has been that it does not resolve the issue of causality, merely showing a correlation between lane mile expansion and VMT growth. Highway planners argue that since they have accurately forecast where individuals desire to travel they expect roads to fill up with travelers after they are built. However, this ignores the fact that they often become more congested more rapidly than initially planned, as Goodwin (1996) and SACTRA (1994) showed for a sampling of projects in the UK. This may partially be a function of analytical forecasting tools that are not accurately capturing induced travel effects. In any case, many planners discount econometric analyses as merely proving that a correlation has been found and that these studies show that planners are putting highways where people want to travel. On the other hand, these studies certainly do not build a case for rejecting the induced travel hypothesis.

One approach for definitively addressing the issue of causality is to use an instrumental variable in the regression with a two-stage least squares estimation procedure. Noland & Cowart (2000) use a two stage least squares regression testing several instruments to use for lane miles per capita. Results are shown in Table 2. Urbanized land is tested as an instrument in model (A). This variable 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. Model (B) removes population density which tends to interact with the dependent variable which is specified as a per capita variable. This reduces the value of the lane mile coefficient. Model (C) which has population / area as an instrument indicates some instability and lack of robustness in the lane mile coefficient. These results, while relatively weak, do suggest a causal linkage between increasing lane miles and increased VMT.

A study by Fulton et al. (2000) used cross-sectional time series county-level data from North Carolina, Virginia, and Maryland and estimated a two-stage least squares model. Their model is specified as a growth model with growth in VMT as a function of growth in lane miles. As an instrument they find that lane mile growth over either 2 years or 3 years is correlated with 1 year growth in lane miles, but not with 1 year growth in VMT. This is used for individual state models and data combined for all three states. Results are quite robust showing an elasticity between 0.3 to 0.5. This model is reproduced in Table 3. Fulton et al. (2000) do not provide an estimate of long-run elasticities but one would expect these to be somewhat higher.

Cervero & Hansen (2001) estimate a two-stage least squares model with instrumental variables using county level data from California. They estimated a statistically significant lane mile elasticity of 0.559, very similar to the results of Fulton et al. (2000). They used various political and demographic variables to help explain the increase in road supply including the party of the governor (lagged by one year) and the proportion of a county’s population that was white. They also found that the supply of lane miles can be explained by VMT, but with a smaller coefficient value of 0.328. Therefore there results suggest that causality may run in both directions but that the effect of lane miles on VMT is greater than the opposite effect. They also conducted a Granger test and found the results consistent with their instrumental variable model. Fulton et al. (2000) also conduct a Granger test with Maryland and Virginia data. While this test is not a basis for causality, they do confirm that VMT growth is preceded by lane mile growth, while the reverse cannot be established.

Overall the results of Fulton et al. (2000) and Cervero & Hansen (2001) are the most persuasive at showing a causal linkage between growth in lane miles and growth in VMT.

Interestingly the work of Noland & Cowart (2000), Fulton et al. (2000) and Cervero & Hansen (2001) using two stage least squares estimation generally produces lower elasticity values than the studies of Hansen & Huang (1997) and Noland (2001), although the latter overlaps at the low end. This may indicate that there is some upward bias in the estimates from the latter two studies.

The studies mentioned above have all used aggregate data to test for statistical significance and to derive elasticity values. This is common practice in the economics literature, but has been criticized by transportation planners. The basis of this criticism is that we need to understand how individuals respond to changes in capacity to truly capture all the behavioural effects that might occur. A disaggregate analysis of this sort would certainly be of interest and is motivated largely by the desire of transportation planners to understand how specific projects may influence the behaviour of specific categories of individuals. This has been a goal of transportation modeling in response to criticisms of using aggregate zonal analysis. However, this does not undermine the benefits of aggregate analysis which is intended to look at aggregate effects and can provide valuable information to policy makers on the overall impact of capacity expansion.

Rodier et al. (2001) use disaggregate data from the Sacramento, California region to examine induced travel effects. Their study uses the integrated land use / transportation model, MEPLAN, to analyze the impact of various scenarios in the Sacramento region. They analyze the effect of holding some modeling elements constant, such as changes in land use and trip distribution. What they find is that allowing these inputs to be endogenous results in an elasticity of VMT with respect to lane miles of 0.8 for a forecast out to 2015 and 1.1 for a forecast out to 2040. If land development is held constant this is reduced to 0.6 and 1.0 respectively. Holding population and employment location constant reduces these values to 0.4 and 0.6 respectively. This latter is equivalent to the state of the art in regional travel demand models where trip distribution is derived through feedbacks and multiple iterations. Without feedback of the trip distribution step, which is more common amongst state of the practice travel demand models, results in inelastic travel demand, i.e. an elasticity of 0.0 (for both future forecast years).

Rodier et al. (2001) make several major contributions. First, the range of elasticity values derived using a disaggregate regional integrated land use and travel demand model gives elasticities similar to the aggregate studies discussed previously. In fact, their elasticities are even higher than those studies that employ two stage least squares to account for causality. Second, they show that state of the art improvements to regional travel demand models can capture about 50% of the induced travel effect relative to current practice capturing no effect. Obviously, this latter result has important implications for assessment of alternative projects (which is discussed further below). Lastly, their analysis is based on individual behavioural elements establishing a clear causal link between behaviour and induced travel. Rodier et al. (2001) also show that about 50% of the long term induced travel effect is not captured by the use of travel demand models; in order to fully account for induced travel, regions would have to capture both travel and land use changes interactively.

Most recently, Strathman et al (2000) combined the 1995 Nationwide Personal Transportation Survey (NPTS) data for 12,009 households with the Texas Transportation Institute (TTI) data (Schrank and Lomax, 1997) on road capacity in 48 metropolitan areas in order to produce a system of equations that include both a wide range of exogenous variables and four endogenous variables (commute mode, workplace density, residential density, and vehicle miles of travel). In addition they use three instrumental variables (likelihood of payment for parking at work, commute distance, and vehicle ownership). In this study, per capita roadway capacity was found to have a significant effect upon mode choice, residential density, workplace density, and vehicle miles of travel. Given an increase in roadway capacity, the cross-sectional analysis indicated that persons within the metropolitan area tended to be more likely to drive alone to work, live and work at lower densities, and generate higher VMT.

The direct effect of a ten percent increase in per capita roadway capacity is estimated to be a 2.9 percent increase in VMT, when all other variables are controlled for. This elasticity is consistent with the findings of Noland (2001), Noland and Cowart (2000), and Fulton et al. (2000). Interestingly, this value is similar to Barr's (2000) estimate of travel time elasticities using the same nationwide data (see discussion below). In addition to the direct effect of roadway capacity on vehicle miles of travel, Strathman et al. (2000) also found an indirect effect, through residential density and employment density. Interestingly, the estimations showed that reduced residential density results in higher vehicle miles of travel while reduced employment density results in lower vehicle miles of travel. This latter result may appear counter-intuitive unless one considers that lower density employment locations may in some cases be closer to residential areas than higher density urban cores, though they would also tend to be less accessible by public transit. The net change of these two counteracting forces, was an estimated indirect elasticity of 0.033 between roadway capacity and VMT, which was about one-tenth of the magnitude of the direct effect.

Barr (2000) used disaggregate household data from the 1995 NPTS to examine induced travel effects. His study included 27,409 individuals from the NPTS. His key variable of interest was the amount of time spent traveling by each household. This was calculated by deriving the average travel speeds from the reported length of journeys and their reported duration. The inverse of the speed was used to derive the key variable of interest which was the average travel time. While this study uses only a cross-sectional database it can only describe correlation and not causation. The use of reported measures of time and distance may also introduce potential inaccuracies in the data. However, some interesting observations can be drawn from Barr's study. Travel time elasticities ranged between -0.3 and -0.4. This is below the range suggested by Goodwin (1996). Barr (2000) also shows that elasticities are higher in urbanized areas compared to non-urbanized areas. This could be explained by higher congestion in these areas and greater access to alternative modes. While he states that urbanized areas have a higher elasticity (-0.36), it is really not much higher than for non-urbanized areas (-0.32). This may indicate no significant difference and his result that elasticities do not vary with metropolitan area size would tend to support the insignificance of the difference in these elasticities. He does show interesting elasticity differences for different family life cycles but suggests that much of this difference is due to higher income elasticities. Clearly, Barr's work shows that disaggregate analysis can offer additional information to policy makers on how capacity additions will impact various demographic groups.

A similar result on the effect of metropolitan area size was shown by Noland & Cowart (2000). They forecast the contribution of capacity additions to VMT growth for metropolitan areas of different size and areas with different congestion indexes as ranked by the Texas Transportation Institute (Schrank & Lomax, 1997). The forecasts showed that there was no difference in the contribution of capacity additions to new VMT between the different categories. EEA (1999) analyzed elasticity differences assuming that the ratio of VMT over lane miles was a good proxy for congestion levels (using the same data as Fulton et al., 2000). They could not show any significant difference in elasticity values for the different models. These results are quite interesting as one would expect more congested areas to have larger elasticities. It is possible that this could indicate that land use and development effects play a larger role than existing congestion in inducing new VMT. Noland & Cowart (2000) suggest that this may be the case by analyzing the difference in the contribution of new capacity to forecast VMT growth between metropolitan areas. They conclude that areas with proportionally greater growth in lane miles can attribute more of their VMT growth to induced travel.

Chu (2000) 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 also uses data from the Nationwide Personal Transportation Survey (NPTS) and estimates the following model:

$$\log(q/C) = b_0 + b_1\log(X^k) + b_2\log(C) + b_3(\log(C))^2 + e$$

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 ε is an error term. Using a cross-sectional database of metropolitan areas derived from the NPTS, Chu (2000) 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.

Not all the studies cited have been able to show that induced travel is larger or more extensive when congestion is present. Chu’s (2000) model provides the most convincing evidence of some correlated effects. While the empirical analysis is weak, theoretically we would generally expect more induced travel when congestion is higher and also more induced travel when land use and development controls are weak thereby allowing the market to respond to changes in the highway network. SACTRA (1994) came to the conclusion that when large changes in generalized travel costs occur, induced travel is likely to be significant, based largely on theoretical grounds.

Our conclusion from the relevant literature is that the theory of induced travel can certainly not be refuted and is largely confirmed. Table 4 summarizes the elasticity estimates from the studies discussed above. These coefficient values, while estimated with different data sets and different techniques, seem to suggest that lane mile elasticities are in the range of 0.3-0.6 with larger elasticities for long run effects.

A major relevant question is how important is this effect compared to other drivers of VMT growth, or as SACTRA (1994) asked, "does it matter?". Both Noland (2001) and Noland & Cowart (2000) estimate the relative contribution of induced demand to overall VMT growth. Noland (2001) 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 (2000) estimate this effect to average between 15-40% of annualized VMT growth (on interstates and arterials) for metropolitan areas. The lower range is probably more precise as this was the better of the models that they estimated. Heanue (1998) uses data from Milwaukee, Wisconsin to estimate the contribution of induced travel to VMT growth. Using Goodwin (1996) and Hansen & Huang's (1997) elasticity estimates, Heanue (1998) determines that between 6-22% of VMT growth is due to capacity additions. Still, 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 issue is the impact of added highway capacity on economic development. Some have argued that public infrastructure (of which highways are a major element) result in larger productivity growth than investments in private capital (e.g. Aschauer, 1989). In essence this is an argument that highway development will generate additional travel which would be a result of new economic development that would not have otherwise occurred. Subsequent analysis, however, challenged the conclusion of Aschauer with regard to the relative magnitude of productivity effects from public versus private capital (e.g. Tatom, 1991; Kelejian & Robinson, 1994). Nadiri & Mamuneas (1998) find that highway capital has a positive effect on total productivity (although less than the effect of private capital). Boarnet (1997) attempts to reconcile the literature on development impacts from highway projects. He suggests that while from a regional perspective highway projects may have little if any growth inducing impacts, they may have significant impacts within specified corridors or sub-regional areas. The result is that highway projects may simply redistribute existing growth within a metropolitan area. To a large extent, this growth will be in ex-urban areas that are receiving gains in accessibility at the expense of downtown or older suburban areas. The overall welfare impacts of this redistribution are not explored but could be important. Both Boarnet (1998) and Chandra & Thompson (2000) estimate models that demonstrate that the spatial allocation of development is affected by road infrastructure.

The theory of induced travel, whether by immediate behavioural travel adjustments or longer term land use impacts, appears to be clearly justified. Transportation planners have been reluctant to accept this conclusion that essentially challenges the notion that transportation projects can substantially reduce traffic congestion. However, the implication should not be that transportation projects have no benefit. It merely implies that the benefits cannot be attributed to changes in travel time. Going back to basic urban economic theory, induced travel effects imply that the changes in behaviour are translated through changes in land price valuation (i.e., the bid-rent curves of urban economics, see for example, Mills & Hamilton, 1994). This conclusion changes the context of transportation policy from congestion reduction to one of directing the growth of urbanized areas. We turn to a discussion of these issues and changes taking place both in the UK and the US.

INDUCED TRAVEL AND CHANGES IN TRANSPORTATION AND ENVIRONMENTAL POLICY

Transport and Environment Policy in the UK

In 1998 the UK Department of Environment, Transport and the Regions established a new direction for UK transport policy with the publication of the government's transport White Paper, *A New Deal for Transport: Better for Everyone* (DETR, 1998a). One of the key directives of this policy was that the government would no longer attempt to accommodate traffic growth through a strategy of "predict and provide." That is, road construction would not continue to meet forecast traffic growth. The level of forecast infrastructure needed to meet an unconstrained growth assumption was seen as unsustainable both environmentally and financially.

Goodwin (1999) states that this allows the recognition that alternative options, such as increased public transport and non-motorized modes are increasingly important. Integration of all modes of transport was seen as a key goal while simultaneously reducing the need for motorized transport. An emphasis on maintaining existing road infrastructure, rather than increasing its capacity, was another key element. The recognition that some road pricing options would be desirable, both for moderating demand, and for raising revenue for alternatives was another key conclusion.

Goodwin (1999) outlines much of the historical context and incremental changes that preceded the publication of the White Paper. Growing concerns about the environmental impact of road transport were seen as a primary driver. These included concerns about the health costs of air pollutants, climate change impacts, acid rain and ecological impacts. The SACTRA (1994) report on induced traffic played a major role in changing the perspective on whether "predict and provide" was an economically sensible policy and has led to changes in the process of road appraisal in the UK

The new appraisal process seeks to simplify the task for the decision maker by summarizing key information in a tabular format (DETR, 1998b). Price (1999) provides an overview of the new appraisal system, the purpose of which is to more clearly highlight environmental concerns (which tended to be lost in the volume of the detailed environmental impact assessments) against traditional cost benefit approaches which have been used in the UK since the 1970's. The cost benefit approach embodied by the COBA model measures travel time savings, changes in vehicle operating costs, and changes in accident rates. A review of planned trunk road schemes was carried out using the new appraisal methods. Of 68 schemes considered for the Targeted Program of Improvements for trunk roads laid out in DETR (1998c), 37 were withdrawn or deferred for further analysis after the new appraisal methods were applied. Nellthorp & Mackie (2000) analyzed how various appraisal factors affected the decision of whether to withdraw a scheme or not. They concluded that many of the environmental factors (excluding air quality) were influential in the decision. Interestingly, they included that the cost benefit assessment (from COBA) was not significant in the decisions taken.

The SACTRA (1994) reported recommended new procedures of cost benefit analysis of road projects to account for induced travel effects. Interim guidance on this was published simultaneously with the SACTRA report (DETR, 1994). These procedures were updated in 1997 with an updated section of the UK Design Manual for Roads and Bridges (Highways Agency, 1997). This provided interim elasticity methods to account for induced travel effects; DETR continues to do research on updating four step modeling procedures for more complex schemes.[7]

Some analysis has been conducted on the differences in cost benefit results with and without the inclusion of induced travel effects. Small induced travel effects of 5-10 percent have been found to reduce the benefits of a scheme by anywhere from 20 to nearly 40 percent.[8] It is not clear whether any specific road schemes have either been abandoned or undergone major design changes in response to changes in the appraisal methods. However, the overall policy approach of abandoning a "wish list" of projects and announcement of a Targetted Programme of Improvements outlined in DETR (1998c) undoubtedly are in response to new qualitative knowledge on induced travel effects.

In the area of land use policy the UK has historically been able to preserve land and avoid the sprawl development patterns of the US (though there are certainly examples of US style sprawl in the UK). Planning Policy Guidance 13 on Transport (Department of the Environment, 1994) was instituted to provide Local Authorities with guidance on better coordinating land use and transport planning. The aim is to reduce reliance on private vehicles, encourage modes with less environmental impact, and reduce both the number and length of motorized journeys. The promotion of development in centralized and accessible areas (by modes other than private cars) is explicitly stated. These sort of policies are certainly consistent with the goals of the White Paper.

Interestingly, if land use policy were completely effective one would expect capacity enhancements to result in less induced travel. This assumes that land use planning can effectively disconnect the response of developers to changes in the transport

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[7] In the US the National Cooperative Highway Research Program (project number 25-21) is conducting similar research geared at looking at the air quality impacts of changes in traffic flow. The proposed methodologies are quite comprehensive and will be equivalent to updating four step travel demand models and integrating them with land use and modal emissions models to account for induced travel effects and changes in vehicle dynamics.

[8] Parliamentary Record of the House of Commons, Hansard column 808 - 6 December 1996, HMSO: London.

network. Induced travel impacts would then be limited to changes in the number of trips, routes, destinations, and modes. Some relocation of activities could still occur, but one wouldn't expect major sprawl development to occur (unless this is part of the land use plan). In theory, one could argue that effective land use planning would allow capacity enhancements to capture travel time reduction benefits more effectively. As shown previously, Rodier et al. (2001) estimate that 50% of induced travel effects occur if land use does not change in reaction to expanded capacity.

In July 2000 the UK government released a 10 year transport plan (DETR, 2000) following up on many of the policy documents issued in recent years. The plan outlines the proposed investment strategy for surface transport over the next 10 years. While the text of the document is generally consistent with the integrated transport policy of the original 1997 Transport White Paper, an analysis of the actual expenditure plan is not quite consistent with the White Paper's policy. Of about £121 Billion of public expenditure proposed over the 10 year period, over 45% is devoted to trunk and local roads and slightly more devoted to rail and public transport (annex 1 of DETR, 2000). While not all of the road spending is devoted to new capacity, there is an explicit target of widening 5% of the trunk road network, construction of 30 bypasses, and 80 major schemes to reduce congestion. The Transport Plan acknowledges that construction of new road capacity is not the solution to congestion problems, but the overall investment focus appears to disregard potential induced travel effects (including stating that congestion reduction is a specific goal).

Despite this major increase in spending on road projects, the Transport Plan also includes increases in rail and public transport expenditures. Local Authorities will also be required to develop integrated Local Transport Plans, improving of planning that focused around specific schemes. In addition, these Plans provide a mechanism for using transport funding to help address the needs of Air Quality Improvement Plans also required of Local Authorities.

The Transport Plan also allows Local Authorities to plan and implement congestion charging and/or workplace parking schemes. The Greater London Authority has also been empowered to implement a congestion charging scheme for which active planning is currently in progress. These ideas are consistent with a recognition of the need to price demand to relieve congestion without inducing new travel.

Overall the 10 year Transport Plan attempts to distribute substantial increases in public spending to many beneficiaries. While increases in road spending are significant, public transport and rail systems also are receiving substantial increases. Other than the potential for various congestion charging schemes, the overall plan does not appear to fully integrate much of the knowledge of induced travel effects developed in recent years.

Transportation and Environmental Policy in the US

Within the last decade, the general trend in policies of the US Federal government has been to better integrate transportation policy with environmental policy. This trend began with passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991. Perhaps the two most significant examples of the integration of transportation and environmental policy has been the establishment of the Congestion Mitigation and Air Qualtiy program which dedicates specific funding for projects that improve air quality. In addition, the Clean Air Act Amendments (CAAA) of 1990 strengthened the requirement that metropolitan transportation investment programs "conform" with state implementation plans for achieving the National Ambient Air Quality Standards. This requires that the mobile source emissions "budget" can not be made worse by the planned transportation system. Naturally this involves forecasting and modeling of transportation systems and has spurred much research into developing models that can actually measure and estimate these effects.

More recently the Transportation Equity Act for the 21st Century (TEA-21) of 1998 has continued both the CMAQ program and the transportation air quality conformity requirements. In addition this legislation required the US Department of Transportation to institute a "streamlined" process for transportation project facilitation and delivery. The Department of Transportation has interpreted these "streamlining" provisions as a means to encourage earlier consideration of environmental issues in the transportation planning and project development process.

Review of the environmental impact of Federal projects is one of EPA's major roles as specified by the National Environmental Policy Act (NEPA) of 1970. Environmental Impact Statements (EIS) for Federal projects are developed by the lead agency (the Federal Highway Administration in the case of highway projects) but reviewed by EPA (as well as the general public). The role of the EIS is to provide information to decision-makers and the public about the environmental impact of projects and possible alternatives. The alternatives analyzed are generally minor (e.g. changes in routing or alternative mitigation strategies). Major decisions on project scope have already been pre-determined at earlier phases of the transportation planning process, often without undergoing significant environmental review. Projects are often delayed due to the inadequacy of early stages of decision making that preclude the consideration of a broad range of alternatives. This is the element that the "streamlining" provisions are aimed at correcting.

Environmental Impact Statements specify and define the goal for the specific project.[9] The goal of many transportation projects is to reduce congestion; however, the studies cited above strongly suggest that adding highway capacity will not be an effective solution for achieving long-term congestion reduction goals. Alternative approaches may be far more effective than merely adding more capacity. For example, a more realistic approach to actually controlling congestion would be to propose congestion pricing on existing road capacity (as an alternative to new capacity construction). Provision of transit services and redevelopment of existing land (e.g. brownfields and infill development) may also lead to less regional congestion, while also serving the needs of economic development (albeit on different parcels of land).

The research reviewed above suggests that adding highway capacity will facilitate development either on previously undeveloped land or more intensive development near the proposed project. The linkage of development impacts to specific transportation projects requires an analysis of the cumulative and secondary impacts of the project. Regulations promulgated by the Council on Environmental Quality (CEQ, 1987) require the assessment of cumulative impacts. Many Environmental Impact Statements for highway projects currently do not conduct a high quality analysis of cumulative effects (i.e., the land development impacts that are induced by the project). In addition, many highway projects are analyzed in segments, rather than as an entire corridor which would tend to underestimate the potential cumulative effects in the long run.

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[9] EIS terminology defines project goals under the "purpose and need" of an EIS.

Long run development impacts also suggest that project goals should be defined exclusively with regard to land development objectives, not congestion reduction. This type of justification is normally avoided by transportation agencies. An assessment of transportation projects based upon their land development impacts obviously creates more political tension in the promotion of transportation projects. The business community and developers are generally very active in many localities in promoting projects that increase access to undeveloped land and resulting economic development on that land. A more detailed analysis of how transportation projects interact with land development is essential information that is needed to improve decision-making and the environmental outcomes of specific projects.

If congestion relief is not the stated goal of a project this would also imply that alternatives to capacity expansion might be more appropriate. For example, if broad economic development and sustainability goals are stated as goals within a corridor EIS, then the possible range of solutions may expand well beyond the analysis of highway options or even beyond other transport options.

As mentioned previously, the CAAA requires transportation plans to be in conformity with State Implementation Plans for meeting the National Ambient Air Quality Standards (NAAQS). What this means is that 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_x, 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 are usually deficient in accurately forecasting emissions (TRB, 1995) partly because they do not adequately account for both short run and long run induced travel effects. This can be partly corrected by building feedback mechanisms into the models to at least account for some of the short-run impacts (Johnston & Ceerla, 1996a). Air quality regulations already require this step for conformity analysis, though actual practice has generally not kept pace with the regulatory requirement.

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 (none of which are ideal) are available to provide estimates of land development changes induced by transportation and accessibility changes.[10] 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. Project selection criteria would also be vastly improved, as shown by Johnston and Ceerla (1996a, 1996b).

The Department of Transportation is also incorporating measures of induced travel demand into their Highway Economics Requirement System (HERS) which attempts to determine total financial needs for the US highway system using a cost benefit analysis approach (US DOT, 1999). This model includes travel demand elasticities of 1.0 in the short run and 1.6 in the long run with respect to total user costs. These are used as elasticities for individual links on the highway network and therefore include route shifts that may not represent induced VMT effects. Previously the HERS model had used a short run elasticity of 0.8 and a long run elasticity of 1.0. These adjustments were made in the most recent report after an external review of the model was conducted. US DOT (1999) states that they would expect network elasticities to be lower. The inclusion of these user cost elasticities in the HERS model allows estimated VMT growth to respond to changes in recommended investment levels. For example, average annual VMT growth (over 20 years) for large urbanized areas is estimated to be 1.66% if annual average investments are $46.3 Billion while an investment level of $94.0 Billion could result in VMT growth of 2.06% annually. It is unclear, however, how this analysis actually influences the allocation of investment from the Federal government. While TEA-21 authorized spending levels for transportation, subsequent annual appropriations of funds have been linked to annual gasoline tax revenues with no consideration of how investment levels may affect VMT growth. In fact, US DOT (1999) suggests that investment needed to maintain current conditions, estimated using the HERS model, is generally higher than actual investment by both the Federal and State governments.

Therefore, while the theoretical basis of induced travel effects appears to be acknowledged by the US DOT, the actual investment of Federal dollars is still largely

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[10] A good review of these models is contained in Parsons Brinckerhoff Quade & Douglas (1999).

driven by political imperatives (such as demands for congestion reduction) and the levels of revenue collected by the Federal gasoline tax. US DOT does not make decisions on specific projects since these are made by state Departments of Transportation and sometimes by local Metropolitan Planning Organizations. However, the availability of funding and the incentives this provides to state governments by providing an 80% match to local funding can certainly bias decision making.

Boarnet & Haughwot (2000) suggest that radical reform of the Federal role in highway funding might be an effective policy for changing urban development patterns. They suggest that if local metropolitan areas spent local money (rather than Federal or even state money), that cost benefit analysis would be conducted and that ultimately local decision-makers would choose better projects.

Even without this type of radical reform, the science and economics of induced travel effects are being recognized at the project level through the requirements of NEPA and the CAAA conformity requirements. These statutory and legal requirements are beginning to have an impact on policy for certain specific projects. While Federal money may currently distort decision-making, Federal regulations may be able to improve decision-making (Downing & Noland, 1998).

The US debate on these issues is fundamentally tied to issues of community livability and sprawl development. Suburban congestion has been linked to sprawl development patterns by those promoting “livability”. It is clear from much of the induced travel research that increasing road capacity tends to encourage sprawl development while also being ineffective at solving congestion problems. Despite this clear linkage, TEA-21 still authorizes tremendous resources to new highway construction, potentially undermining other efforts to achieve “livability” goals.

CONCLUSIONS

The research evidence on induced travel effects clearly shows that behavioural responses are real and can have significant impacts on the congestion reduction benefits of capacity expansion projects. Both in the US and the UK research efforts are underway to improve modeling and assessment tools to measure the impacts of these effects. Transport policy is also gradually changing in both countries. UK policy appears to have been more influenced by this research, primarily through the abandonment of forecasting based on a "predict and provide" philosophy. In the US, national policy has aimed to be more inter-modal in perspective, but in practice funding incentives and political inertia have made major change difficult. Much of the change in US policy is actually beginning to occur due to more detailed analysis at the project level of induced travel and induced development impacts. In both countries, these changes are being driven by environmental concerns. In the US environmental statutes are enabling much of the change at the project assessment level rather than from directives specified by the Federal government.

Overall, the new knowledge being developed of how infrastructure affects travel behaviour and land use patterns will hopefully lead to actual implementation of improved policies and project selection allowing greater choices for individuals using the transport network.

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

Table 3
Instrumental Variable Regressions (with fixed effects)

Dependent Variable: Growth in VMT	*All States*		*Maryland*		*North Carolina*		*Virginia*	
	Instrument = growth in lane miles over two years	Instrument = growth in lane miles over three years	Instrument = growth in lane miles over two years	Instrument = growth in lane miles over three years	Instrument = growth in lane miles over two years	Instrument = growth in lane miles over three years	Instrument = growth in lane miles over two years	Instrument = growth in lane miles over three years
Growth in Lane Miles	0.505 (4.823)	0.457 (2.796)	0.397 (1.972)	0.290 (0.948)	0.638 (6.491)	0.479 (3.705)	0.288 (4.405)	0.444 (4.958)
Growth in Population	0.031 (0.234)	0.031 (0.214)	0.251 (0.864)	0.219 (0.726)	0.166 (0.589)	0.387 (1.293)	0.120 (1.998)	0.114 (1.694)
Growth in per capita income	0.002 (0.037)	-0.028 (-0.372)	0.255 (1.923)	0.292 (2.047)	0.114 (1.423)	0.133 (1.573)	0.088 (2.232)	0.080 (1.959)
Constant	-0.003 (-0.148)	-0.004 (-0.176)	0.009 (0.451)	0.008 (0.396)	0.038 (1.900)	0.038 (1.824)	0.040 (3.098)	0.043 (3.222)
N	1980	1760	598	575	1000	900	2400	2304
Adjusted R^2	0.031	0.024	0.112	0.089	0.060	0.060	0.172	0.199

T-stats are in parentheses

County and time specific constants are omitted for brevity.

Table 4
Summary of Elasticity Estimates

Citation	Travel time elasticity	Lane mile elasticity	Type of model	Data used
Goodwin (1996); SACTRA (1994)	-0.5 - -1.0			Derived from gasoline price elasticities
Hansen & Huang (1997)		0.3 – 0.7	Time-series cross-sectional fixed effects	California County-level data
		0.5 – 0.9		California Metropolitan-level data
Noland (2001)		0.3 – 0.6 (short-run)	Time-series cross-sectional fixed effects	State-level data
		0.7 – 1.0 (long-run)		
		0.5 – 0.8	Difference model with fixed effects	
Noland & Cowart (2000)		0.8 – 1.0 (long-run)	Time-series cross-sectional fixed effects	Nationwide metropolitan-level data
		0.3	2 stage least squares with weak instrument	
Fulton et al. (2000)		0.3 – 0.5	2 stage least squares with good instrument	County level data from Maryland, Virginia, North Carolina, and DC
Cervero & Hansen (2001)		0.559	2 stage least squares with good instrument	County level data from California
Rodier et al. (2001)		0.8 – 1.1	Disaggregate modeling study	Sacramento regional data and modeling system
Strathman et al. (2000)		0.29	Cross-sectional model	NPTS data, individual-level, nationwide
Barr (2000)	-0.3 - -0.4		Cross-sectional model	NPTS data, individual-level, nationwide

Figure 1

Induced Travel

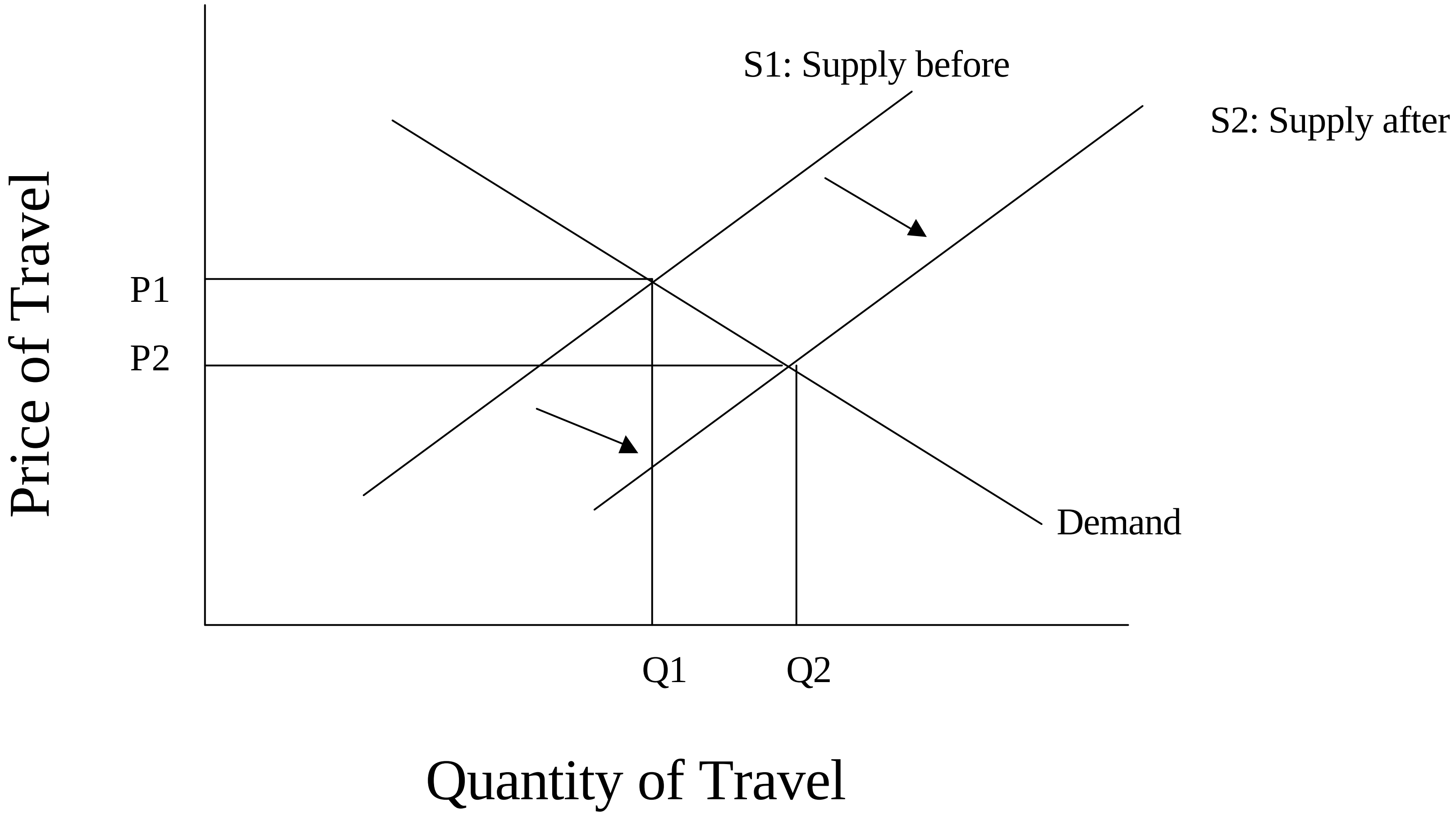

Figure 2

Induced Travel During Period of Underlying Growth in Demand