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DRIVING AND THE BUILT ENVIRONMENT:
THE EFFECTS OF COMPACT DEVELOPMENT ON
MOTORIZED TRAVEL, ENERGY USE, AND CO_2 EMISSIONS

Key Relationships Between the Built Environment and VMT

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1 INTRODUCTION

This paper critically examines the current literature on the relationships between the built environment and household vehicle miles traveled (VMT). VMT itself is rarely of direct policy interest, but VMT is an important component of greenhouse gas emissions and congestion. Furthermore, policies designed to address these problems will very likely influence VMT as well. Section 4 addresses some of issues involved when other policies besides the built environment are considered. One important issue that this paper does not address is the cost/benefit tradeoffs comparing using the built environment to control VMT compared to more direct carbon or fuel taxes.

One of the key conclusions from this review is that the magnitude of the link between the built environment and VMT is so small that feasible changes in the built environment will only have negligible impacts on VMT. For example, Brownstone and Golob's (2008) results imply that increasing density by 1000 dwelling units per square mile (roughly 40% of the mean density value in their sample) will decrease a representative household's VMT by 1200 miles per year (approximately 5% of the mean sample value). As Downs (2004, Chapter 12) clearly shows, increasing density of an existing metropolitan area by 40% requires extreme densities of new and infill development. Bryan, Minton, and Sarte (2007) have recently developed a consistent historical database of U.S. city and regional densities. These data show that only 30 out of 456 cities increased population density more than 40% between 1950 and 1990, and the median city in this sample decreased population density by 36%. The cities that did increase population density by more than 40% are similar to Santa Ana, California. They experienced large increases in low-income immigrants into very tight housing markets. The increase in densities in these cities was largely accommodated by cramming more people into the existing housing stock. This suggests that more direct fuel and congestion taxes will be more effective for controlling vehicle emissions and congestion.

My standards for accepting empirical conclusions from the literature reviewed here are strict. I only consider results that I would be willing to personally recommend to my local planning agency and defend in the inevitable lawsuits that accompany controversial public policy positions. Studies that were reviewed and not discussed in this paper are listed in the Appendix. This standard makes it difficult to find any reliable quantitative estimates of key elasticities. Many studies are based on aggregate data and therefore subject to self-selection bias described in Section 2. Other studies based on disaggregate data typically include nonlinear discrete choice models but only report coefficient estimates and/or elasticities calculated at mean values of the household explanatory variables. This information is simply not sufficient to judge whether the elasticities are statistically significant and/or large enough in magnitude to be useful for policy purposes. Many studies are only concerned with finding statistically significant effects without any attempt to check whether the precisely estimated coefficients are large enough to be relevant for policymakers. Fang (2008) is a good example of the types of calculations needed to judge policy relevance for these models.

Another important problem with the literature reviewed here is that there is little agreement on what aspects of the built environment are important determinants of VMT. Even when two authors agree on these aspects, they frequently quantify these aspects in different ways that make comparisons across papers difficult. It has also been difficult to get data on many potentially important aspects of the built environment. Therefore many studies just use data from one metropolitan area. This makes it difficult to generalize the results of these studies beyond the particular area studied, so I have given more weight to those studies using nationally representative data. Section 3 addresses these issues.

2 SELF-SELECTION

The most important methodological issue for all studies reviewed in this paper is the self-selection issue. Households choose their residential (and work) locations based, among other things, on their preferences for different types and durations of travel. The observed correlations between higher density and lower VMT may just be due to the fact that people who choose to live in higher density neighborhoods are also those that prefer lower VMT and more transit or non-motorized travel. If this is the case, then forcing higher densities may not lead to anywhere near the reduction in VMT "predicted" by observed correlations.

The "gold standard" for solving self-selection problems is to conduct randomized assignment to treatment and control groups. In the context of the links between the built environment and VMT, then this would require randomly assigning households to different neighborhoods and then observing differences in their VMT. Of course this is rarely possible, so various econometric techniques have been employed to try to correct for this problem.

Aggregate studies that just look at bivariate relationships (e.g. Newman and Kenworthy, 1999) typically make no attempt to control for self-selection, so they are the least reliable. Other studies (e.g. Holtzclaw, et. al., 2002) use aggregate sociodemographic variables to try to control for population differences across different zones. Unfortunately the zones used in Holtzclaw et. al. are quite large with an average size of 7000 residents per zone, and there are only limited sociodemographic data available at the zonal level. Most importantly, there are no data on the variability of things like household size and income within each zone. At least for Los Angeles in 2000, the variation of variables like average household income and average household size across traffic analysis zones is a small fraction of the variation of household income and household size for the Los Angeles MSA. Holtzclaw et. al. use smog check odometer readings to get VMT for their zones, but since California exempts new vehicles from smog checks for the first 2 years, this measure systematically biases VMT downwards for zones with large numbers of new vehicles.

Many studies with disaggregate data attempt to control for observable differences between people living in high and low density areas using regression methods. These studies are only valid to the extent that these people differ only on observable characteristics. Therefore studies like Bento et. al. (2005) which includes a rich set of household socioeconomic characteristics should be less affected by self-selection bias.

Finally there are a few more recent studies that jointly model residential location (or at least density) and VMT. These joint models require a lot of assumptions, but if the assumptions are valid then they properly control for self-selection bias. One source of confusion in the literature is the role of instrumental variables, an old econometric technique to deal with endogenous explanatory variables in linear regression models. Boarnet and Sarmiento (1998) were among the first to use instrumental variables to deal with the endogeneity of residential density (caused by self selection) in regressions explaining VMT. More recently Vance and Hedel (2007) used instrumental variables in a two-stage model of car use and VMT conditional on car use. There is frequently an implicit claim that instrumental variables is preferable to explicit joint modeling of density and VMT since instrumental variables makes no explicit assumptions about the variables explaining density, but in fact the requirements for a valid instrumental variable are identical to those required to identify a joint linear model. In particular, a valid instrument must be strongly correlated with density but uncorrelated with car VMT.

Boarnet and Sarmiento (1998) found no stable link between density and VMT after using instrumental variables to control for the endogeneity of density. However, Vance and Hedel (2007) found significant links between commercial density, road density, and walking minutes to public transit and car VMT using similar instruments to Boarnet and Sarmiento (the percentage of buildings built before 1945, the percentage of buildings built between 1945 and 1985, the percentage of residents more than 65 years old, and the percentage of foreign residents). Vance and Hedel did many tests of the validity of these instruments, so the likely reason is differences between the German panel data and the U.S. data used by Boarnet and Sarmiento. Another possible reason is that German cities tend to be denser and have much better transit than U.S. cities, so U.S. cities may not offer enough transit to be a viable alternative to private cars. For example, roughly 30% of the trips recorded in the German travel diaries did not use private cars.

There have been a number of papers explicitly modeling residential location choice and VMT. Brownstone and Golob (2008) build a simultaneous equations model of households' choice of residential density, VMT, and vehicle fuel use using the 2001 National Highway Transportation Survey. Conditional on a rich set of socioeconomic covariates, they find that residential density choice is not determined by VMT or fuel use, but does influence VMT and fuel use. The magnitude of this effect is very small, which suggests that feasible changes in residential density will not have any important effect on VMT or fuel use. The error terms in the estimated system are independent, implying no self-selection bias conditional on the covariates. However, removing any of the covariates from the model leads to self-selection bias which shows the importance of using household level data.

Zhou and Kockelman (2007) use Heckman's treatment-effects model to account for self-selection between CBD and non-CBD in Austin, Texas. They find little impact of self-selection – about 90% of the observed differences in VMT are due to the treatment effect (living in the CBD). Unfortunately the variable they use to identify the system, the number of visitors to the household on the survey day, is quite weak. It is weakly correlated with the decision to live in the CBD, and it is not clear why it can be excluded from variables explaining VMT on the survey day.

Bhat and Guo (2007) build an ambitious model using San Francisco Bay Area data to build a joint model of residential location and number of household vehicles. Their model allows for self-selection effects (correlation between the error terms in their equations), but after controlling for a rich set of covariates they do not find any significant self-selection effects. Similar to Brownstone and Golob (2008), Bhat and Guo find statistically significant but quantitatively small impacts of built environment measures (street block density, transit availability, and transit access time) in vehicle ownership. Bhat and Guo were able to include a large number of covariates in their models since they only worked with one metropolitan area. The only variable that frequently appears in residential choice models that is missing in Bhat and Guo's model is school quality, but that is probably highly correlated with zonal income and zonal housing values which are included in their model.

There are also a number of studies which deal with self-selection by trying to directly measure preferences through attitude surveys (Kitamura et. al., 1997 and Bagley and Moktarian, 2002, and Frank et. al., 2007). These studies typically find that attitudes explain most of the variation in VMT across households, and the regression model fits (as measured by R^2) improve significantly relative to models without attitude measures. The most likely reason for the greatly improved fit is that the attitudes are jointly determined by the outcome variables. People who live in dense urban areas tend to express positive attitudes about urban characteristics, and people who commute long distances are likely to express positive attitudes about large lots and open spaces. If this is the case then these attitudes cannot be treated as exogenous and stable, and their inclusion in models will bias all of the results. It is also possible that the measured attitudes will change with the built environment, and this would invalidate the results from these models.

Krizek (2003) attempts to control for self-selection by looking at changes in travel behavior for households that moved between consecutive years in the Puget Sound Transportation Panel Study. This approach is only valid if households only move for reasons that are unrelated to their preferred type of neighborhood, such as to change jobs or accommodate a change in household size. If a household moves because they were dissatisfied with the characteristics of their initial neighborhood, then Krizek's analysis of movers would be invalid. Looking at changes in panel surveys has become the standard approach to self-selection problems in labor economics (see Heckman and Vytlacil, 2007), but these methods require massive data sets and complex methodology. For example, Krizek considered 6,144 households over 10 years of the panel, but only observed 403 households that moved. Since some of these households moved because of changes in household composition, it is sometimes not clear how to define the household across these moves. Nevertheless using modern dynamic panel data methods and collecting the required panel data is the best way to finally resolve the self-selection issue.

Recent studies with disaggregate data find no impact of self-selection after controlling for rich sociodemographics. This suggests that it is critical to carefully control for sociodemographics when building models of household VMT, and therefore results from studies using aggregate data are likely subject to serious self-selection biases. Although recent studies use state-of-the-art methods, they all have weaknesses in the scope and accuracy of the underlying data. In particular, there is little agreement on the geographic scope or the definition of appropriate measures of the built environment. It is therefore possible that studies using different measures may find significant impacts of self-selection.

3 KEY FEATURES OF BUILT ENVIRONMENT

There are potentially many aspects of the built environment that could affect households' travel behavior. Naturally research has concentrated on those aspects that are easy to measure. Since most measures of the built environment are highly correlated, it may only be necessary to include a few key characteristics to capture the effects. Most national level studies only use residential and/or employment density since these are the easiest to obtain. One study that put a lot of effort into measuring various aspects of the built environment is Bento et. al. (2005). They generated measures of road density, rail and bus transit supply, population centrality, city shape, jobs-housing balance, population density, land area, and climate and merged these with 1990 NPTS survey respondents living in MSAs. They found that their measure of population centrality was a significant factor explaining vehicle ownership, but not a significant factor explaining VMT conditional on vehicle ownership. Consistent with other recent studies using disaggregate data, Bento et. al. (2005) found that the magnitude of the impact of any of their built environment measures was too small to support any policy relevance. They concluded their paper with some simulations using their estimated model to examine the counterfactual experiment of "moving" people from Atlanta to Boston. Even though the impact of any single built environment factor is small, the cumulative impact of changing many factors is sufficient to explain the observed differences in VMT between the two cities. Of course, the cost of making Atlanta look like Boston is prohibitive.

Ewing and Cervero (2001) conducted an extensive review of the literature on the links between travel and the built environment. They argue that elasticities are the best way to summarize the quantitative conclusions from these sorts of studies, and they built an extensive table (Table 8) giving average elasticities for many of the best studies. Even though these elasticities for the nonlinear models are incorrect (they need to be averaged over the sample, not simply evaluated at sample means of the explanatory variables), the numbers in Table 8 are mostly all below 0.1 in absolute value. Standard errors are not provided, but it is likely that the hypothesis that they are all equal to zero cannot be rejected. The largest elasticities (around 0.3) are reported for regional accessibility measures, but as the discussants pointed out these measures are very difficult to change with feasible zoning/planning tools. Ewing and Cervero (2001) also provide a summary table (Table 9) showing that elasticities of vehicle trips and VMT with respect to density, diversity, and local design are all below 0.05.

Badoe and Miller (2000) also surveyed the literature on the interactions between land use and transportation. They tend to be more critical of the existing literature, and mainly conclude that most studies they surveyed suffered from methodological and/or data weaknesses. Their tables also show that regional accessibility measures are important, and they stressed the importance of socioeconomics as determinants of travel behavior. The best way to incorporate socioeconomic impacts is to use household level data, but Badoe and Miller point out that using these disaggregate models for forecasting then requires very detailed forecasts of the socioeconomic variables.

Given that there is no clear consensus about which feasible measures of attributes of the built environment are important, it is almost certain that all of the studies reviewed in the paper suffer from measurement error. If this measurement error is large, then the coefficients on these variables will be biased downwards. Although this could explain the inability of most studies to find substantively and statistically significant links between the built environment and VMT, the main impact of measurement error is to increase the variability of the coefficient estimates. Since recent studies using disaggregate data have found statistically significant but substantially very small links between some aspects of the built environment and VMT, it is likely that measurement error is not the main problem.

Another possible reason for the weak links between the built environment and VMT is that there are non-linearities in the relationship, and the U.S. data is primarily in the range where density and other aspects do not have much impact. Some aggregate studies (Newman and

Kenworthy, 1996 and 2006) including foreign cities have found evidence of these non-linearities (or "inflection points"), but as discussed in Section 2 these studies are subject to serious self-selection biases. In particular, many dense foreign cities have much lower incomes and therefore much lower automobile ownership rates than in the U.S. This is a more likely explanation of the inflection point found in these aggregate studies.

4 OTHER POLICIES THAT AFFECT VMT

It is not clear why controlling VMT should be a policy goal. The worldwide spread of the private automobile (and VMT) shows that people place a high value on increased mobility. Vehicle use is associated with externalities – especially polluting emissions and congestion, and economists have long advocated using Pigouvian taxes as a more efficient policy tool to deal with these problems. Given current technology, taxing greenhouse gas emissions is equivalent to taxing gasoline. The best recent studies (see Small and Van Dender, 2007) suggest that raising gasoline taxes will reduce emissions primarily by inducing people to buy more efficient vehicles. Given current U.S. incomes and gasoline price levels, VMT is not strongly affected by modest tax increases. Larger gasoline tax increases are beyond the range of observed data, but we can speculate that they would have a direct impact on VMT and also a longer-term impact on the built environment.

Households attempting to lower their VMT will try to move residences and/or job locations. This will impact land rents and the demand for public transit (as well as better bicycle and walking facilities), and may in the end accomplish the same types of changes in the built environment advocated by "smart growth" proponents.

Congestion taxes directly tax VMT in certain locations, and are also likely to provide incentives for households to move to reduce their tax bills. The exact impact of congestion taxes depends on their implementation. For example the London toll ring has increased the demand for housing inside the ring, since tolls are only collected at the ring boundaries. HOT facilities similar to the SR91 and I-15 corridors in Southern California may induce lower income households (who are more sensitive to the tolls) to move closer to their job locations.

Although it is simple to increase fuel taxes, implementing optimal congestion taxes can be technically difficult and costly. Fortunately parking charges can be used together with simple cordon congestion pricing schemes to come close to what could be achieved with optimal pricing (see Calthrop, Proost, and Van Dender, 2000). Of course deliberately restricting parking and/or deliberately under-sizing roads to create congestion are also effective at reducing local VMT, but these can never be as efficient as pricing. If parking is restricted then it is possible that congestion and VMT will increase as drivers search for available parking spaces. These negative impacts can be somewhat mitigated by better information. For example, Lucerne, Switzerland, has large electronic information signs at all of the entrances to the city center showing the number of free parking spaces in all of the main parking garages.

Fuel and congestion taxes and parking fees all have the advantage that they work much faster than we could feasibly change the built environment, and there is no doubt that they will reduce emissions and congestion. In order to be effective these taxes will need to be high enough to generate substantial revenue, and some of this revenue could be used to improve transit service (as was done in London).

5 CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

There are not enough reliable studies that control for enough socioeconomic characteristics to avoid self-selection bias, cover a representative sample of households and geographic area, and use common measures of built environment to support strong quantitative conclusions. There is evidence that there is a statistically significant link between aspects of the built environment correlated with density and VMT. Very few studies provide enough detail to judge whether this link is large enough to make manipulating the built environment a feasible tool for controlling VMT, but those that do suggest that the size of this link is too small to be useful.

Almost all of the studies surveyed in this paper are cross-sectional analyses from the last 2-3 decades, so the conclusions drawn from these studies are only valid to the extent that common background variables do not change. The most obvious problem is energy prices, which have recently almost doubled from their previous stable levels. If these high energy prices persist or a serious carbon tax is imposed, then households will adjust by reducing their VMT, moving to denser neighborhoods, increasing utilization of mass transit, and changing work locations. Existing studies also cannot account for the possible impacts of new travel demand management measures like congestion pricing. Putting a toll ring around a major city (as London has recently done) will cause households to switch to transit and possibly move to more dense neighborhoods. Small (2005) points out that congestion pricing can greatly improve bus service (by improving bus speeds), and this synergistic effect will further shift more households to transit. The only other study that looks at this issue is Cambridge Systematics Inc. (1990), but this only considers large suburban activity centers. The existing detailed disaggregate models can simulate the impacts of an ageing population and continued immigration, but this requires good forecasts of the underlying sociodemographic variables.

The built environment influences far more than just VMT, so a full analysis of the impacts of the built environment must consider all possible outcomes. The literature suggests that density and diversity are correlated with more walking and bicycle trips, which in turn may reduce obesity (see Frank et. al., 2007). There is also evidence that density has a quantitatively small impact on the number and types of vehicles owned by households. However, it is important to remember that there are many reasons for the decreases in residential density and increases in VMT over at least the last 50 years. Some of this may be caused by failure to properly price the externalities associated with vehicle usage, but some of it is also due to household’s preferences. Unless justified by some market failure, policies that force people into higher density areas will very likely reduce welfare (see Brueckner, 2001 and Bento and Franco, 2006).

My review of this literature does have implications for future research. The most obvious and non-controversial is that we need better data. In particular we need good samples from the relevant population that contain accurate and detailed data on household socioeconomics, travel behavior, and built environment measures. Travel behavior data should be collected using GPS data loggers, since diary collection is burdensome and leads to missing and inaccurate observations. Since many policies work at least partially by altering the number and types of vehicles, it is also crucial to obtain detailed make/model information for all household vehicles (as in the 2001 NHTS survey). Built environment data also needs to be collected in a uniform fashion across geographic areas. This would be much easier if metropolitan planning agencies could agree on definitions and collection methods for key variables. This effort could be helped by coordination and possibly some money from the U.S. Department of Transportation.

Section 2 of this paper highlighted the problems caused by self selection. This implies that there is not much use in continuing to study the links between the built environment and transportation behavior using aggregate data. Another implication of the literature reviewed in Section 2 is that transportation behavior is strongly correlated (and probably caused by) households' socioeconomic characteristics. This implies that using disaggregate models for forecasting requires forecasting socioeconomic characteristics. This difficult task is made even harder by that changes caused by immigration and aging will lead to changes in the built environment and possibly changes in the built environment will cause migration that will alter the socioeconomic makeup of the city. The best way to study these important issues is to collect panel data that follow households over time. These data are very expensive, and the only examples I could find are the German Panel data used by Vance and Hedel (2007) and the Puget Sound Panel Study used by Krizek (2003). A more feasible option would be to try to include transportation behavior questions in an existing U.S. panel study like the Michigan Panel Study of Income Dynamics.

Even though Vance and Hedel (2007) and Krizek (2003) had panel data, they did not exploit the potential of panel data to analyze the dynamics of household responses to changes in prices and built environment. These panels are probably too short (10 years) to observe many changes in the built environment, but hopefully they will continue the panels and eventually this will enable very interesting research.

Finally, many studies (especially more recent ones using complex models) simply do not provide enough information to judge whether their results are useful for policy analysis. Many studies only give tables of parameter estimates which typically can only be used to find out the sign and statistical significance of a variable. Some studies give elasticities, but these are typically evaluated at the means of the "exogenous" variables and almost never include any measures of statistical significance. Hopefully editors and referees will be more careful about requiring more thorough description of model output.

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7 APPENDIX: STUDIES NOT EXPLICITLY CITED

This section lists studies that were reviewed but not cited explicitly in the text. These studies are typically similar to studies that were reviewed, and they do not meet the criteria set out at the beginning of this paper for providing reliable and/or complete empirical results.

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