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The impact of residential density on vehicle usage and fuel consumption: Evidence from national samples☆

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ABSTRACT

This paper investigates the impact of residential density on household vehicle usage and fuel consumption. We estimate a simultaneous equations system to account for the potential residential self-selection problem. While most previous studies focus on a specific region, this paper uses national samples from the 2001 National Household Travel Survey. The estimation results indicate that residential density has a statistically significant but economically modest influence on vehicle usage, which is similar to that in previous studies. However, the joint effect of the contextual density measure (density in the context of its surrounding area) and residential density on vehicle usage is quantitatively larger than the sole effect of residential density. Moving a household from a suburban to an urban area reduces household annual mileage by 18%. We also find that a lower neighborhood residential density induces consumer choices toward less fuel-efficient vehicles, which confirms the finding in Brownstone and Golob (2009).

1. Introduction

How does urban sprawl affect household travel behavior? This paper addresses this question by investigating the impact of land use density on household annual mileage traveled and fuel consumption. Following previous studies (Boarnet and Crane, 2001; Brownstone and Golob, 2009), we use land use density as the measure of urban spatial structure (or urban sprawl). Although urban sprawl is not simply low density, land use density is highly correlated with almost all measures of urban sprawl (see Badoe and Miller, 2000). Most of the previous studies that attempt to measure the influence of urban spatial structure on vehicle usage focus on specific regions in order to guarantee geographic homogeneity (Bhat and Guo, 2007; Boarnet and Crane, 2001; Brownstone and Golob, 2009; Salon, 2009). This study analyzes national level data, so we control for geographic heterogeneity by including a set of urban/rural dimension dummies (the contextual density measure) and rail transit dummies.

The most important econometric issue is possible residential self-selection, and this occurs if residents of high-density areas differ in some unobservable characteristics that influence travel behavior. One possible behavior that leads to self-selection bias would be households who dislike automobile travel locating in dense urban areas with good transit. Unless residential self-selection is controlled, the estimated influence of land use density on travel behavior may be spurious. We follow the same methodology as in Brownstone and Golob (2009) to correct for the self-selection bias by specifying a simultaneous equation model where residential density, household mileage traveled, and fuel consumption are jointly endogenous. These three endogenous variables are assumed to be influenced not only by other endogenous variables but also by a rich set of socio-demographic variables. Among various socio-demographic variables, education dummies are key variables to identify the simultaneous equations system. In particular, our final model is consistent with the assumption that education only impacts fuel use and not vehicle miles traveled or density conditioned on number of workers, children, income, race, number of drivers, and urban structure. This is equivalent to assuming that education only impacts the choice of fuel efficiency. This assumption is partially tested using overidentification tests described in Section 3. Our final model also assumes that density is exogenous to miles traveled or fuel use, which is consistent with the behavioral assumption that households first choose residential location (and therefore density) and then choose their vehicle type and use conditional on this choice. This assumption is consistent with other disaggregate studies conditioning on a broad set

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of socioeconomic variables (Bento et al., 2005; Bhat and Guo, 2007) but is tested in this paper using various tests described in Section 3.

The other econometric issue that may result in biased coefficients is the non-random missing data in the key endogenous vehicle fleet characteristics (needed to compute fuel use). To correct for the bias caused by this problem, weights are estimated to compensate for the higher probability of missing data for households owning many vehicles and weighted estimation is used. The wild bootstrap method is used to estimate standard errors that are robust to heteroscedasticity.

Although we mostly adopt the methodologies that were used in Brownstone and Golob (2009), our study is more extensive in two aspects. First, we use national level data from the 2001 National Household Travel Survey (NHTS) instead of just the California subsample. The big advantage of using national level data is that with the increased sample size, we can specify a larger, more accurate model. We can also check whether travel behavior in a specific region is unique or not by comparing those two results. We provide comparisons between the results of this paper and those in the California analysis of Brownstone and Golob (2009), which share the same specifications. We do not use the more recent 2009 NHTS survey because this survey did not collect vehicle miles traveled using dual odometer readings. The 2009 NHTS then imputed vehicle miles traveled based on a single odometer reading and self-reported miles traveled for each vehicle using an imputation model based on the 2001 NHTS data. Our preliminary work with the 2009 NHTS vehicle miles traveled data show that this imputed variable is less reliable.

This paper further extends Brownstone and Golob (2009) by including various geographic control variables such as census region, MSA category, urban/rural dimension and rail transit dummies. Since these variables are included, we can investigate the effects of certain geographic or institutional conditions, such as the supply of rail transit, on travel behavior. We find that the urban/rural dimension variables have a large impact on vehicle usage. Our results are consistent with the view expressed in Transportation Research Board (2009) that changing density without changing other aspects of urban structure has very little impact on vehicle and fuel usage. However, our simulation results in Tables 8 and 9 show substantial impacts from changing urban structure (as measured by our urban/rural dimension variables).

The estimation results show that residential density has a statistically significant but economically modest influence on vehicle usage and fuel consumption, which is similar to that in other previous studies. However, the joint effect of the urban/rural dimension variable (contextual density measure) and residential density is much greater than the sole effect of residential density. A simulation moving a household across the urban/rural dimension affects household annual mileage traveled and fuel consumption significantly. This result suggests that residential density in a wider geographic scope, which takes into account of density of surrounding areas, is important in influencing household travel behavior. Compared to the California subsample result of Brownstone and Golob (2009), the influence of residential density on mileage traveled is slightly higher. However, the impact of residential density on vehicle type choice, i.e. tendency toward more fuel efficient vehicle choices for households in denser area, is quantitatively smaller than that in the California subsample.

1.1. Literature review

Studies of the effects of land use density (or other measures of urban spatial structure) on vehicle usage can be divided into aggregate and disaggregate studies. Transportation Research Board (2009) reviews many of these studies, and Ewing and Cervero (2010) carry out a meta-analysis of some disaggregate studies. Aggregate studies use spatially defined averages for all variables. One of the most cited papers is Newman and Kenworthy (1999), where the authors implemented a global survey of 37 cities to assess automobile dependence cost. The results indicate that cities with more car use, road provision, and urban sprawl have higher automobile dependence, which causes direct and indirect costs in terms of higher road expenditures, more time spent on commuting, and higher external costs from road deaths and emissions.

Disaggregated studies use household observations of vehicle usage and either city-wide, zonal, or neighborhood averages for urban form variables. Bento et al. (2005) specify disaggregate models of commute mode choice, automobile ownership and annual vehicle miles traveled (VMT). They construct diversified measures of urban form and transit supply: measures of city shape, density of the road network, spatial distribution of population, jobs-housing balance, and bus route and rail miles supplied. Using the 1990 National Personal Transportation Survey, they find that the impacts of any of the urban form measures on travel behavior are frequently insignificant and small in magnitude.

Although disaggregate studies (Bento et al., 2005) that include a rich set of socioeconomic control variables are less subject to residential self-selection bias, it is still possible that residents in high density areas differ in some unobservable characteristics that influence their travel behavior. The only way to deal with this possibility is to construct a joint model of residential density and travel behavior. One of the first to do this is Boarnet and Crane (2001). They specify a demand function for travel in which the number of trips of different travel modes are influenced by the relative time costs (price of travel) and various socio-demographic "taste" variables. By comparing models where land use density is endogenous and exogenous, they find that the measured influence of land use on travel behavior is very sensitive to how endogeneity is treated.

Bhat and Guo (2007) specify a joint mixed multinomial logit model of residential location and number of household vehicles. Their model allows for residential 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 effects of residential self-selection. This result implies the necessity of including a rich set of socio-demographic variables to control for residential self-selection. Using San Francisco Bay Area data, they find statistically significant but quantitatively small impacts of built environment measures (street block density, transit availability, and transit access time) on vehicle ownership. Salon (2009) also addresses the simultaneity concern by modeling the joint choice of residential location, car ownership, and commute mode. Salon (2009) estimates her model using samples from New York City residents.

Finally, Brownstone and Golob (2009) directly model the joint choice of residential density and vehicle usage to control for potential residential selectivity. Unlike other previous studies, they also explicitly model vehicle fuel consumption to account for the possibility that residents of high density areas choose more fuel efficient vehicles. Additionally, by adopting a weighting approach, they correct for the bias caused by systematic missing data problems. Using the California subsample of the 2001 NHTS, they find a statistically significant but quantitatively small impact of residential density on household vehicle usage and fuel consumption.

Unlike the previous studies using subsamples of a specific region, this paper uses national level data from the 2001 NHTS. While this paper follows the methodology used in Brownstone and Golob's (2009), our empirical model additionally includes various geographic control variables that are necessary in analyzing national level data. We first confirm the finding in the previous studies that residential density has a statistically significant and economically modest influence on vehicle usage. A new finding in this paper is that the urban/rural dimension dummies have considerable influences on household annual mileage and fuel consumption. Our findings suggest that the effect of density in a small geographic scope is limited but the joint influence of density and densities of surrounding areas are economically significant.

This paper is organized as follows. Section 2 discusses the data used in the study. Section 3 describes the empirical model and the