Planning for Land-use and Transportation Alternatives: Understanding the Impact of Urban Sprawl on Household Non-work Travel Decisions

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Abstract

Land use and transportation alternatives represent an important yet undervalued opportunity for mitigating climate change. Improved models are still needed to support planning decisions. This study focuses on developing improved indicators of urban form and related travel demand, as well as calibrated analytic models that can facilitate 'what if' analyses of changing land use and transportation circumstances. The empirical relationship between urban sprawl and household non-work travel decisions is examined in Greater Boston Area. The author also identifies the self-selection issue and provides a new solution using the instrumental variables (IV) method based on the land use regulation data set.

Keywords: climate change, land use, transportation, non-work travel behavior, geospatial information infrastructure

1. Introduction

Global climate change has emerged as a major threat to the United States and countries around the world (IPCC, 2007; Gallagher et al., 2007). A growing scientific consensus believes that greenhouse gas (GHG) emissions from burning fossil fuels create significant risks of climate change (Glaser and Kahn, 2008). Overall, transportation is responsible for one-third of the nation's carbon dioxide emissions, and the transportation sector has also been the fastest growing sector. Between 1991 and 2006, transportation accounted for nearly one-half of the growth in U.S. carbon dioxide emissions (Gallagher et al., 2007; Brown et al., 2008). So in the context of reducing oil consumption and greenhouse gas emissions, it is not possible without a significant effort in transforming vehicles, fuels, and transportation generally.

Clearly meeting the climate challenge will require a combination of approaches (Marshall, 2008). Most of the recent proposals for mitigating this crisis have focused on new technologies for saving energy (improving fuel economy), notably on a dramatic increase in average miles per gallon (MPG) of cars and trucks, and GHG performance standards for fuels, such as a gradual switch to low-carbon fuels like ethanol (Ewing et al., 2007; Condon, 2008). Fuel economy and efficiency does deserve attention as improvements in fuels and vehicle technology have the potential to reduce carbon emissions from the transportation sector substantially (Brown et al., 2008). However, in the absence of a strategy to reduce the average number of miles driven by Americans, the gains made through improved fuel efficiency and low-carbon fuels in cars could be swamped by the projected increase in miles driven by Americans (Gallagher et al., 2007; Condon, 2008). Although carbon tax for transportation fuels is also proposed as a policy option, there is unfortunately some recent evidence that drivers are becoming less sensitive to increases in gasoline prices (Hughes et al., 2008; Liddle, 2009). In this sense, the trend of increasing vehicle miles traveled (VMT) is becoming one of the key policy challenges.

Recognizing the unsustainable growth in driving, how can we slow the increasing trend of vehicle miles driven? In fact, not all climate solutions require new technologies. A body of research shows that much of rise in vehicle emissions can be curbed simply by a growth alternative that will make it easier for residents to drive less (Ewing et al., 2007). A more carbon-efficient relationship between land use and transportation, notably better spatial arrangement of buildings and transportation infrastructure in communities and urban systems, can play a significant role in reducing vehicle miles traveled (and corresponding GHG emissions) (Marshall, 2008; Ewing et al., 2007; Condon, 2008). Land use and transportation alternatives might represent an important yet undervalued opportunity for mitigating climate change (Marshall, 2008). While many people are working on modeling GHG, very little of this work focuses on how land use and transportation decisions can be used to mitigating climate change. Models are needed to support planning decisions and generate credible quantitative results when alternative proposals are suggested. Capturing the complex two-way interactions (conditionality as well as causality) between land use, transportation and GHG emissions calls for an integrated model of urban form, activities and energy usage.

In a broader sense, the connection between transportation and land use has long been studied and it is still recognized as complex (Handy, 1993; Yang and Ferreira, 2005; Ewing et al., 2007). There continues to be heated debates on whether the relationship is ‘strong’ or ‘weak’ (Krizek, 2003), largely because land use changes are politically difficult and take time to unfold. So it may take several years before measures that change land use produce significant effects on travel demand (Polzin, 2004; Ewing and Cervero, 2001). Although recent growing concerns about GHG emissions have stimulated renewed interest in land use controls and metropolitan growth management, each study is revealing new and different empirical evidence that previous data, methodology and analysis have not yet answered (Bento et al., 2005; Boarnet and Sarmiento, 1998; Rajamani et al., 2003; Van Ham et al., 2001). As a result, the transportation claims of many land-use planning strategies – such as job-housing balance, new urbanism development, and transit villages - are attractive but still questioned. Many of the shortcomings in the previous studies can be attributed to modeling strategies and data availability. As a recent U.S. National Academy of Science report (TRB, 2007) indicates, the current practice of land use, urban form and transportation modeling requires fundamental change to capitalize on new spatial analysis methods and to model the behavioral changes induced by the new information and communication technologies (ICT). Developing such modeling and analytic capacity is a complex and multi-faceted task that requires innovative strategies and can benefit from a distributed metropolitan information infrastructure.

No single new modeling approach can address the TRB recommendations. It requires collaborative efforts in information collecting, analysis and innovative modeling strategies to be institutionalized as part of the decision making processes, which might take several years. The objective of this paper is to shed light on the new modeling strategies based on the widely available data sets that are not currently satisfied at the desired levels of detail but have a good chance of being refined and replicated as technologies, models and information infrastructures improve. We focus on the use of emerging geospatial processing tools and modern federated database management techniques to develop improved indicators of urban form and related travel demand, as well as calibrated analytic models that can facilitate the ‘what if’ analyses of changing land use and transportation circumstances in metropolitan areas. The study examines the household non-work travel decisions as non-work travel demand has been increasing significantly and we believe household behaviors are possibly influenced by the current land use and transportation infrastructure conditions (Zhang, 2005; Srinivasan and Ferreira, 2002; Bhat and Pozsgay, 2002). The empirical analysis is based on the 1991 household activity-travel survey in Boston Area. Due to the missing information of miles traveled in the survey data, we use vehicle travel time (minutes) as a reasonable approximation. Although there have been a few studies using the same survey data set (Srinivasan and Ferreira, 2002; Zhang, 2004; Zhang, 2005), none of them has addressed the self-selection issue.

The paper is organized as follows. Section 2 discusses the analysis framework and methodology that are used to examine the effects of land use pattern on household non-work travel decisions. Section 3 reports the result of the regression estimates. Section 4 identifies the self-selection problem by revisiting the models and provides a possible solution. Finally, Section 5 discusses the policy implications.

2. Data and Methods

2.1. Research Design

This study is based on 1) a survey that measures the respondents' travel-related behaviors as well as the socioeconomic/demographic factors; 2) A Geographic Information Systems (GIS) inventory that measures the degree of urban sprawl within neighborhood level. The research design in this study is cross-sectional. The emerging geospatial processing tools and federated database management technology, together with the high quality spatial data sets combined at the disaggregated level, help to develop improved indicators of urban form.

The analysis addresses the research question in two steps. A binary logistic regression model is first estimated for all the sampled households, in which the choice of whether or not to make vehicle non-work trips is understood as a probability function of household socio-economic characteristics and neighborhood urban form indicators. Secondly, a linear regression model is estimated for the households who made at least one vehicle non-work trip, in which household travel duration by car is specified as a function of these independent variables.

2.2. Data Sources

The main data set used for this study is the 1991 Boston activity–travel survey conducted by Boston Central Transportation Planning Staff (CTPS). There were 3,854 households surveyed, with a total of 9,281 persons who made 39, 373 trips. The survey population recorded a diary for the outside home activities over a 24-h period. Land use data in 1991, Census 1990 population data and Census Transportation Planning Package (CTPP) 1990 are also collected to measure the neighborhood urban form.

After geocoding the sampled households to the centroids of the census blocks where they live, the final sample for analysis includes 2, 555 households in the database (Figure 1). The travel and socio-economic characteristics for each household are also matched to the urban form indicators of the block group where the households are located. To reduce random activities, the research considers only the home-based non-work trips, whose purposes include pick-up/drop-off, school, shopping, social, recreational, eat out, and banking/personal business[1]. There are 1,753 households who made at least one home-based non-work vehicle trip on the day surveyed. An average household spent 34.7 minutes driving for home-based non-work travel.

[1] All the work and work-related trips were excluded from the data set. The study also excluded the non-home-based trips, neither the origins nor the destinations for which are residence.

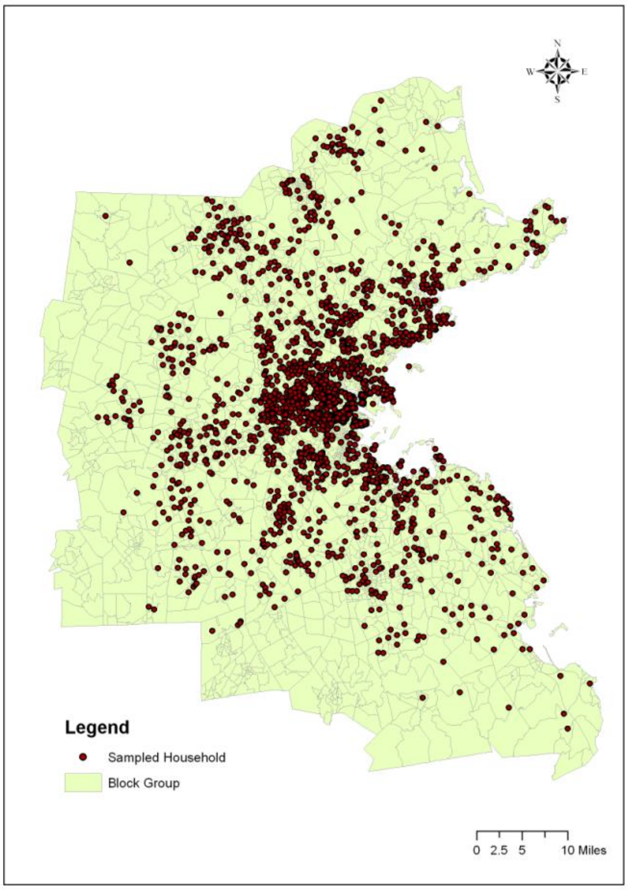

Figure 1 Location of Sampled Households

2.3. Urban Form Measures

Urban form indicators at the neighborhood level (block group) are constructed incorporating the Smart Growth American's urban sprawl definition (Ewing et al., 2003b). Neighborhoods are assessed in four urban form dimensions: residential density, land use type and mix, accessibility and urban design features (Srinivasan, 2002; Song and Knaap, 2004).

Residential density is defined as the population per unit area of residential lands (single-family housing, multifamily housing). Land use mix measures the degree to which land uses are mixed and balanced within block groups. The degree of land use mix is captured by the commonly used measure - land use diversity entropy - a logarithmic index that considers the number of different land use types and the proportion each use (Srinivasan, 2002). Two regional accessibility variables representing the accessibility to community center (Figure 2) and accessibility to neighborhood center (Figure 3) are considered in the analysis. This study adopts Levinson and Kumar's (1994) gravity model-based measurement.

$$A_i = \sum_j O_j f(C_{ij})$$

Where Ai, Accessibility for i; Oj, measurement of retail opportunities presented at destination zone j; this study uses the square feet of the community shopping centers or neighborhood shopping centers in each zone as the retail opportunities measures. f(Cij), impedance function between the zone i is located in and destination zone j, which may take various mathematical forms. This study uses the CTPS matrices of the 24-h average zonal travel times by auto as travel impedance data. An exponential function, shown below, is calibrated for the impedance calculations.

$$f(C_{ij}) = \exp(C_{ij} * \beta)$$

where β is an empirically determined parameter (0.2) that best explains variations in distance for all trips (Handy, 1993; Kitamura et al., 1997; Zhang, 2005). Besides the two regional accessibility variables, three local accessibility variables are also considered in the analysis: distance to CBD (based on subsets stratified by Boston's geographic rings), distance to major roads and the presence of subway station within ½ miles of residence. Finally, the local street pattern is used as proxy measures for the 'traditionalness' of the neighborhood and other urban design amenities (Krizek, 2003).

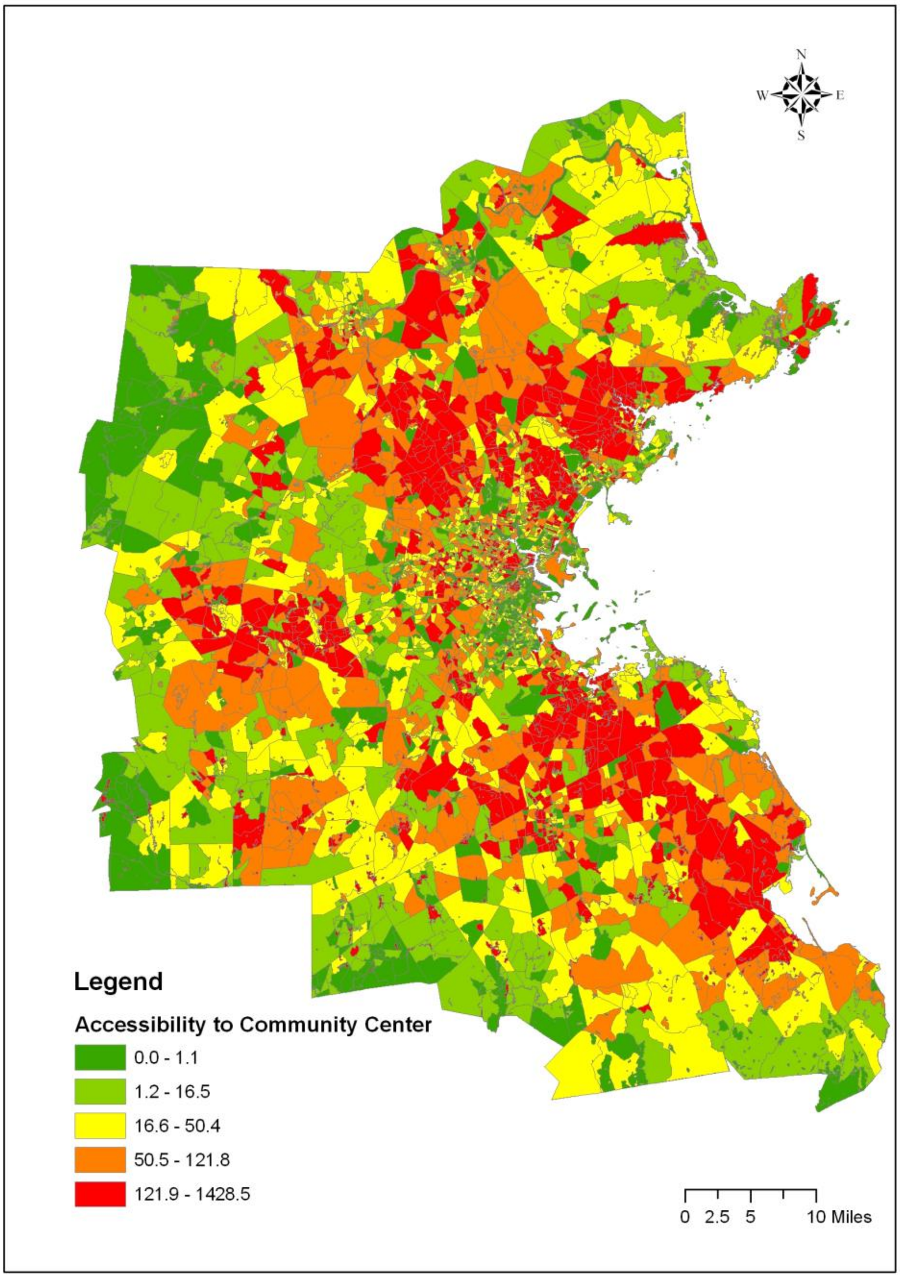

Figure 2 Accessibility to community center

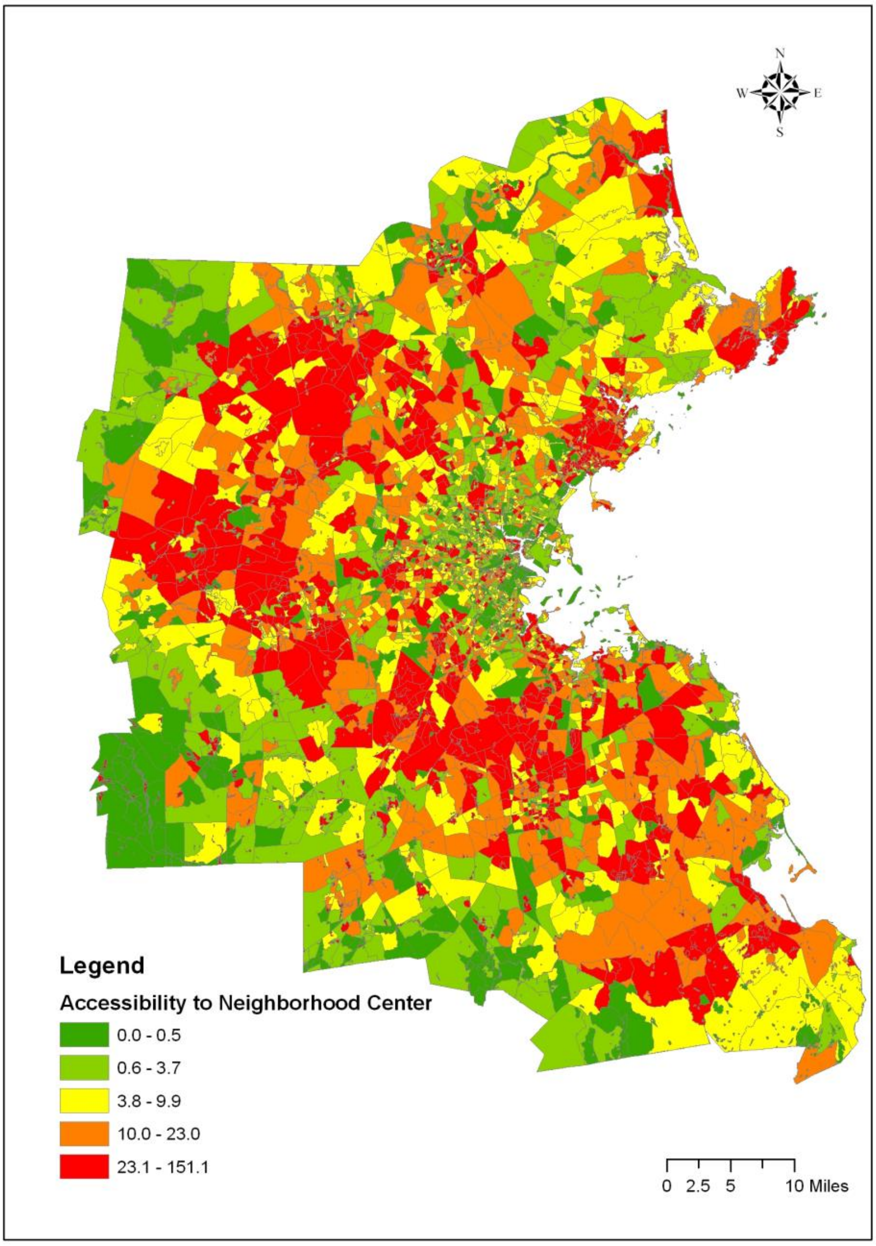

Figure 3 Accessibility to neighborhood center

3. Regression Estimates

The section estimates the regression models in which household non-work travel decision is specified as a function of household socio-economic factors and neighborhood spatial form characteristics. It assumes the household non-work travel decision as two-step choices: first to determine whether or not to make vehicle non-work trips and then to decide the in-vehicle non-work travel duration for those making trips. All models were estimated using the statistical package STATA 10.

Model specifications: TB = f (X, UF) + e
TB: travel behavior. It refers to whether or not to make vehicle non-work trips in the first set of models or non-work travel duration by car in the second set.
X: household socio-economic characteristics, including household size, household income level, number of children under 5, number of licensed drivers, number of vehicles, employment (full time), employment (part time), number of enrolled students and some dummy variables representing the household types.
UF: urban form indicators (Residential density, Land use mix, Accessibility and Local street pattern)
e: error term, including all other unobserved factors, like price, travel attitude

3.1. Model Estimates: Household Choice of Whether or Not to Make Vehicle Non-work Trips

The first set of the models were estimated based on the entire sample of 2, 555 households, in which the household choice of whether or not to make vehicle non-work trips was specified as a function of the independent variables. Binary logistic regression was used to estimate the data. The dependent variable is a set of two choices, 1 if the household made at least one vehicle non-work trip and 0 otherwise. Two regression models were developed: model 1 included only the household socio-economic variables, and model 2 included all the variables defined previously. Table 1 shows the regression results.

- The improvement of goodness of fit from model 1 to model 2 is not significant. It indicates the impacts of most urban form indicators on household choice are not significant.

- The interpretation of the weak relationship between urban form indicators and household choice means that household socio-economic factors dominant the household decisions of whether or not to make non-work trips by car.
- Household size, number of vehicles and fulltime employment are the most important predictive factors.

3.2. Model Estimates: Household In-vehicle Non-work Travel Duration

The second set of the regression models were estimated based on the 1, 753 households who made at least one vehicle non-work trip, in which household in-vehicle non-work travel duration was considered as a function of the same independent variables. Two linear regression models were developed: model 1 included only the household socio-economic variables, and model 2 included all the variables defined previously. Table 2 shows the regression results.

- The improvement of the adjusted R^2 from model 1 to model 2 verifies the assumption that the appearance of urban form variables explains a larger proportion of variance in household non-work travel duration.
- There are three urban form variables whose coefficients are significantly different from zero. All of them belong to the accessibility dimension.
- After controlling for the other factors, the presence of subway station within ½ miles would reduce the household vehicle travel duration by 2.2 minutes.
- Every additional 1 km further away from the major roads is associated with 2-minute increase in non-work travel time by car.
- Higher accessibility to neighborhood centers leads to longer travel time by car for non-work purpose.

4. Model Revisited: Self-selection Issue

If we revisit the models in the previous section, we are aware of the “self-selection” issue as many other literatures have pointed out, which is prior self-selection of residents into a built environment that is consistent with their predispositions toward certain travel preferences. If self-selection exists, we would say travel behaviors are not determined by the place where they live, but by their preferences (if they live elsewhere, they might have the same travel behaviors). Therefore, urban form indictors become endogenous, reflecting the travel preferences of the self-selected residents at a more or less extent.

We can go back to re-examine the model specifications.
TB = f (X, UF) + e
We made the exogenous assumption: E(e|X,UF) = 0, which means the error term (e) is not correlated with the urban form indicators (UF). However, in fact, e includes all the other unobserved factors, for example, travel attitude and preference (AT). Therefore, e (AT) might be correlated with UF, which violates the exogenous assumption. In this case, we might already overestimate the urban form effects. So the new problem is that how we can split the UF effects from the AT?

Literature review indicates that we have several possible solutions (Krizek, 2003; Cao et al., 2006; Handy et al., 2006).

- Natural experiment: relocating households to random places
- Longitudinal designs: assuming that attitudes do not vary over time $\Delta TB = f(\Delta X, \Delta UF) + e$
- Sample selection models

Obviously, all the methods require additional data collecting, which is a big effort. Although the state-of-art information and communication technology might help the data collecting process, we are here interested only in what we can do based on the currently available data. So we turn to the fourth method: instrumental variables (IV) model.
Instrumental variables model is also called two-stage least square regression (2SLS). It involves first modeling UF as a function of instrumental variables, say, IV, they are not correlated with e, and then replacing the observed UF in the second equation with its predicted value from that model (McFadden, 2000; Cao et al., 2006).

$$UF = b(IV) + g(AT)$$

$$TB = F(X, \widehat{UF}) + e(AT)$$

where $\widehat{UF} = \hat{b}(IV)$

We need to choose instrumental variables that are significantly correlated with UF, but not corrected with travel preferences (e). In this way UF represents an influence of the UF that is purged of the self-selection attitudinal component. So the point is that when the households decide their residential locations, they consider many factors, of which some are related to travel preferences, some are not. We need to find those not related to travel attitudes.

McFadden (2000) suggested that good instruments are often created by exogenous policy changes, geographic differences in the application of standards (i.e., different states implement different passing standards for a common exam) or generic randomness. To address this possibility, we turn to a new data set collected by the Pioneer Institute for Public Policy Research on land use regulations in greater Boston. The data set contains land use restrictions including lot size, wetlands regulations, septic rules, zoning distincts and subdivision requirements, for 187 cities and 2 towns within greater Boston area (Glaser, 2008). For many of the regulations, the data set also includes the dates when the regulations were imposed so that it is possible to match the time frame of the survey data. We picked up growth management, cluster zoning (dummy), minimum lot size, number of overlay zoning distinct over that of regular zoning distinct, number of residential zoning distinct over that of regular zoning distinct as well as residential density and geographical ring from the original GIS data to instrument the urban form indicators. These variables represent the degree of efforts the local municipals implemented to prevent urban growth from sprawling. If we believe these measures did take effect, they should have strong connection with the urban form influenced by these regulations, while they are less likely to affect the travel preferences of the residents.

Table 3 shows the 2SLS model estimates.

- The coefficients for the urban form indicators remained in the model do decrease as expected. It indicates some of the previous estimated UF effects resulted in fact from prior self-selection.
- After controlling for the other factors, the presence of subway station within ½ miles would reduce the vehicle travel duration by 1.1 minutes.
- Every additional 1 km further from the major roads is associated with 0.3-minute increase in non-work travel duration by car.
- The impact of accessibility on non-work travel duration is unclear. Higher accessibility to neighborhood still leads to longer travel time for non-work purpose in this model.

5. Conclusion

The regression estimates also have some policy implications. If we assume the models are perfect and the results are reliable, what kind of meaningful change can we make?

The study indicates that subway accessibility can result in 1.1 minutes reduction in non-work travel durations by car per household per day after controlling the other factors, which accounts for 4% of the total non-work travel duration by car per household per day. It also shows major roads accessibility improvement can provide 0.3 minutes (1%) reduction at most. However, the effects of retail-housing mixing are still far from clear because the study indicates high accessibility to neighborhood centers might increase total travel duration (due to more frequent visits).

Compared to many other studies, this study indicates the individual change in urban form has only modest effects on the travel duration. This is not necessarily the case if we could change the different aspects of urban form simultaneously. A study by Bento et. al. (2005) shows that although individual elasticity is small in terms of absolute value, moving sample households from a city with the characteristics of Atlanta to a city with the characteristics of Boston reduces annual VMTs by 25%.

So far, we have not yet touched the question as whether work or non-work travel is the critical one that attributes to congestion? It remains far from entirely resolved. Without answering that question, we know at least transit supply is effective in reducing both work and non-work travel durations by car based on literature review and this study. However, it is hard to compare which land-use strategy yields greater reductions in vehicle travel without answering that question: improving the proximity of jobs to housing or bringing retail and services closer to residential areas?

How can we achieve the goal of reducing the greenhouse gas emissions by 50% at the 1990 level by 2050? Where shall we locate the additional 465,000 residents estimated by the MetroFuture study in Greater Boston by 2030 (MAPC, 2008)? What kind of meaningful strategies can we recommend to regional planning or neighborhood design?

- Improving transit access
- Job-housing balance

- Retail-housing mixing: Bringing Retail and other community services, close to residential areas. It is still not clear whether we should instead have some large shopping malls? So that people might make longer trip like, per week, instead of many short trips.
- Improved school access: It is the similar situation as the retail-housing mixing. It might be the case that we can locate schools close to work places.

This study does confirm the effectiveness of a few policy options, however, more empirical studies are still needed for improved decision making.

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Table 1 Logistic Regression Models of Household Choice of Whether to Make Vehicle Non-work Trips

Variables	Model 1				Model 2			
	B	Wald	Sig.	Exp(B)	B	Wald	Sig.	Exp(B)
Household Socio-economic								
Household size	**0.357**	**5.718**	**0.017**	**1.429**	**0.337**	**4.820**	**0.028**	**1.401**
Number of children under 5	0.078	0.242	0.623	1.081	-0.031	0.037	0.847	0.970
Number of licensed drivers	0.064	0.557	0.456	1.066	0.124	2.000	0.157	1.132
Number of vehicles	**1.023**	**141.180**	**0.000**	**2.780**	**0.777**	**74.611**	**0.000**	**2.176**
Household income level	0.039	0.722	0.396	1.040	0.079	2.715	0.099	1.082
Employment (full time)	**-0.519**	**8.702**	**0.003**	**0.595**	**-0.491**	**7.442**	**0.006**	**0.612**
Employment (part time)	-0.145	0.678	0.410	0.865	-0.063	0.123	0.726	0.939
Number of enrolled students	-0.042	0.226	0.635	0.959	0.046	0.258	0.612	1.047
All-working Household	**-0.774**	**3.868**	**0.049**	**0.461**	**-0.626**	**3.434**	**0.059**	**0.535**
Non-working household	0.100	0.061	0.805	1.105	0.267	0.415	0.519	1.306
One-worker one-adult household	0.146	0.088	0.767	1.157	0.063	0.015	0.901	1.065
One-worker two-adult household	**-0.623**	**4.401**	**0.036**	**0.536**	-0.484	2.531	0.112	0.617
One-worker two-adult with kids household	-0.223	0.297	0.586	0.800	-0.161	0.155	0.694	0.851
One-worker three-adult with kids household	0.256	0.217	0.641	1.291	0.420	0.569	0.451	1.522
Two-worker two-adult household	0.009	0.001	0.979	1.009	-0.072	0.038	0.846	0.930
Two-worker two-adult with kids household	**1.116**	**5.491**	**0.019**	**3.053**	**1.062**	**4.787**	**0.029**	**2.891**
Urban Sprawl Measures								
Residential density (1/km^2)					0.000	1.919	0.166	1.000
Land use mix					-0.129	0.339	0.560	0.879
Accessibility to community center					0.000	0.001	0.976	1.000
Accessibility to neighborhood center					0.000	0.008	0.930	1.000
Presence of subway station within 1/2 miles					**-0.918**	**31.188**	**0.000**	**0.399**
Distance to major road (m)					0.000	0.802	0.371	1.000
Geographic ring					-0.009	0.019	0.891	0.991
Average block perimeter (m)					0.000	0.179	0.672	1.000
Constant	-0.807	2.348	0.125	0.446	-0.129	0.049	0.824	0.879
Other Statistics								
N				2555				2555
Nagelkerke R^2				0.377				0.390
-2 Log likelihood				2451.024				2344.388

Percent correctly predicted	76.2	78.2

Table 2 Regression Models of Household In-vehicle Non-work Travel Duration (Households Making at Least One vehicle Non-work Trip)

Variables	Model 1			Model 2		
	B	t-stat.	Sig.	B	t-stat.	Sig.
Household Socio-economic						
Household size	**8.630**	**7.189**	**0.000**	**8.638**	**7.168**	**0.000**
Number of children under 5	0.767	0.432	0.666	0.748	0.421	0.674
Number of licensed drivers	**2.471**	**2.538**	**0.011**	**2.497**	**2.562**	**0.010**
Number of vehicles	**2.037**	**2.152**	**0.032**	**1.823**	**1.878**	**0.061**
Household income level	0.538	1.225	0.221	0.497	1.126	0.260
Employment (full time)	**-5.270**	**-3.564**	**0.000**	**-5.245**	**-3.543**	**0.000**
Employment (part time)	0.054	0.036	0.972	0.089	0.058	0.953
Number of enrolled students	1.142	1.111	0.267	1.166	1.128	0.260
All-working Household	0.530	0.142	0.887	0.642	0.172	0.863
Non-working household	**3.714**	**2.247**	**0.025**	**3.86**	**1.818**	**0.067**
One-worker one-adult household	0.366	0.077	0.939	0.698	0.146	0.884
One-worker two-adult household	3.269	1.083	0.279	3.438	1.135	0.257
One-worker two-adult with kids household	-4.871	-1.099	0.272	-4.951	-1.117	0.264
One-worker three-adult with kids household	**7.035**	**1.875**	**0.064**	**6.64**	**1.681**	**0.096**
Two-worker two-adult household	0.523	0.136	0.892	0.545	0.142	0.887
Two-worker two-adult with kids household	-0.180	5.009	0.971	-0.204	-0.041	0.967
Urban Sprawl Measures						
Residential density (1/km^2)				-1.10E-05	-0.08	0.936
Land use mix				-0.62	-0.224	0.823
Accessibility to community center				-0.001	-0.264	0.792
Accessibility to neighborhood center				**0.076**	**2.113**	**0.035**
Presence of subway station within 1/2 miles				**-2.159**	**-2.630**	**0.009**
Distance to major road (m)				**0.002**	**2.079**	**0.038**
Geographic ring				-0.678	0.913	0.458
Average block perimeter (m)				0	0.126	0.899
Constant	6.627	1.557	0.120	6.148	1.216	0.224
Other Statistics						
N			1753			1753
Adjusted R^2			0.352			0.387
F			63.23			43.74
P			<0.000			<0.000

Table 3 2SLS Model Estimate

Variables	2SLS			
	B	t-stat.	Sig.	B
Household Socio-economic				
…				
Urban Sprawl Measures				
Residential density (1/km^2)				-1.10E-05
Land use mix	-1.570	-0.09	0.929	-0.62
Accessibility to community center	.009	0.20	0.820	-0.001
Accessibility to neighborhood center	.051	1.78	0.075	**0.076**
Presence of subway station within 1/2 miles	-1.084	-1.87	0.063	**-2.159**
Distance to major road (m)	0.0003	1.65	0.098	**0.002**
Geographic ring				-0.678
Average block perimeter (m)	-3.38E-05	0.000	1.000	0
Constant	5.435	0.67	0.500	6.148
Other Statistics				
N			1753	
Adjusted R^2			0.368	

Instrumented: land use mix, Accessibility to community center, Accessibility to neighborhood center, Presence of subway station within 1/2 miles, Distance to major road (m), Average block perimeter (m)

Instruments: growth management, cluster zoning (dummy), minimum lot size, number of overlay zoning distinct over that of regular zoning distinct, number of residential zoning distinct over that of regular zoning distinct, residential density, geographical ring