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The Effect of Land Use Policies and Infrastructure Investments on How Much We Drive: A Practitioner's Guide to the Literature

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November
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A White Paper from the National Center
for Sustainable Transportation

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*former affiliation, Institute of Transportation Studies, UC Davis



National Center
for Sustainable
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TABLE OF CONTENTS

Abstract	iv
Introduction	1
How Land Use Planning and Transport System Investments Can Help	2
Evidence from the Literature.....	5
Why are these relationships so difficult to estimate?	6
Correlation between built environment characteristics	6
Self-selection.....	8
Findings from three comprehensive cross-sectional empirical analysis	9
Cervero and Kockelman (1997).....	10
Salon, Boarnet, and Mokhtarian (2014)	12
Bento, Cropper, Mobarak, and Vinha (2003 & 2005)	13
Moving From Evidence to Action: An Example Based on Three Studies	14
Concluding Remarks.....	16
Use studies with contexts similar to decision context	16
For some policy choices, evaluation studies can provide the best evidence.....	16
Focus on studies that control for many aspects of the built environment	17
Studies that inform the likely effect of policy packages are rare	17
Research-based evidence supports action.....	17
References	18

The Effect of Land Use Policies and Infrastructure Investments on How Much We Drive: A Practitioner's Guide to the Literature

Abstract

Policymakers aiming to reduce vehicle miles traveled (VMT) want to know what they should do to reduce the amount people drive, and what evidence suggests that this is the best course of action. The relationships between built environment characteristics and driving have generally been shown to be consistent with expectations. As alternatives to solo driving become available, people drive less. As driving becomes more expensive and less convenient, people drive less. As trip destinations and origins move closer together, people drive less. Based on this evidence, policymakers should not hesitate to enact policies and make prudent investments that encourage less driving.

However, despite an extensive academic literature on this subject, the specific answer to the policymaker's question is not straightforward. There is a wide variety of possible policy actions, and the action(s) that will be most effective in a particular situation depend critically on context: who is driving, where they are going, and what alternative modes and destinations are available. Existing research results can provide guidance but cannot dictate a universally applicable recipe.

This white paper provides a guide for practitioners on how to read, understand, and use results reported in this especially challenging area of the literature: the relationship between the built environment, the transportation system, and driving. It identifies theoretical relationships, highlights the challenges inherent in exploring these relationships using real-world data, and discusses three prominent studies in detail to illustrate how to interpret the results.

Introduction

Carbon emissions from light-duty vehicles account for a significant proportion of total greenhouse gas emissions—approximately 19% in the case of the United States (USEPA 2014), and 22% in California (CARB 2014a). It is now scientifically accepted that greenhouse gas emissions resulting from human activity are causing our global climate to become warmer (IPCC 2013), that this warming is likely to cause a variety of negative impacts (IPCC 2014a), and that it is important to take action toward reducing our emissions of greenhouse gases sooner rather than later (IPCC 2014b). Technological solutions such as improved vehicle and system efficiency together with an expanded role for low carbon fuels are important strategies to meet this challenge. Absent an enormous leap forward in low-carbon transportation technologies, however, successfully reducing transport emissions will require individuals to reduce the amount that they drive (CARB 2014b).

Reacting to these findings, a number of state governments—including California, Washington, and Florida—have recently passed legislation aiming to rein in vehicle miles traveled (VMT), and many cities have independently begun to take action to reduce VMT in their jurisdictions.

The research to date has provided concrete evidence that supports the expected relationships between built environment characteristics and driving. As alternatives to solo driving become available, people drive less. As driving becomes more expensive and less convenient, people drive less. As trip destinations and origins move closer together, people drive less.

The good news is that reducing driving could generate many public benefits in addition to reducing greenhouse gas emissions. These include alleviating traffic congestion, reducing air pollution, reducing our dependence on oil, improving public health through increased exercise, and enhancing interactions within our communities.

The bad news is that although there are many possible strategies that aim to reduce VMT, it is often not obvious which of them will be most effective in a specific neighborhood, city, or metropolitan area. Practitioners aiming to reduce VMT want to know what they should do to reduce the amount people drive, and what evidence suggests that this is the best course of action. As the saying goes, “The devil is in the details.” The policy actions that will be most effective in a particular situation depend critically on the geographic scale of the policy implementation, the physical, socioeconomic, and historical context of the place in which the policy will be implemented, and which related actions are being taken as part of the policy package. Existing research results can also provide guidance, but cannot dictate a universally applicable recipe.

This white paper is written to be a practitioner’s guide to the extensive academic literature that provides evidence of policy effectiveness in reducing VMT. It identifies theoretical relationships between land use planning, transport system investments and services, and VMT, highlights the challenges inherent in exploring these relationships using real-world data, and discusses three

prominent studies in detail with respect to these challenges. The paper concludes with a discussion of how results from this literature can be practically applied to inform policy and planning decisions.

This white paper adds value as a primer for reading, assessing, and using results from the literature to inform policy. The goals of this paper are: (1) to clearly explain why it is impossible to offer specific evidence-based policy advice without knowing the context of the decision being made, (2) to provide criteria that will allow practitioners to independently evaluate whether the results of a particular study will be applicable to the policy decision that they are making, and (3) to argue that the available evidence is sufficient that decision makers should feel comfortable taking reasonable actions to discourage driving.

How Land Use Planning and Transport System Investments Can Help

Before embarking on a journey into the academic literature on the behavioral impacts of land use planning and transport system investments, a framework for understanding the relevant relationships is provided below. Specifically, two questions are discussed here:

1. What are the mechanisms through which changes in the built environment and the transport system can reduce passenger VMT?
2. What are some practical land use and transport system investment strategies for achieving these goals?

Generally speaking, policies affect VMT by changing the underlying price, time, comfort, and overall convenience of travel choices. Land use and transport system investment strategies can affect VMT through (1) reducing trip distances, (2) reducing trip frequencies, (3) enabling/encouraging carpooling, or (4) enabling/encouraging travel via non-car modes. Table 1 presents a matrix illustrating how a variety of policy and investment strategies lead to changes in the built environment that affect VMT in each of these ways. Plus and minus signs indicate the expected directions of the effects. Notice that some changes are likely to affect VMT in more than one way.

The strategies in the action matrix affect VMT through physical changes to the built environment. They work by actually moving origins and destinations closer to one another, and by making alternative modes of transport safer and more convenient. All of these changes to the built environment are expected to reduce VMT, with the exception of highway capacity (which, if increased, is expected to increase vehicle travel by making vehicle travel more convenient).

It is worth noting that other policy options may influence VMT. These include direct behavior change programs and incentives, and increasing the relative price of driving. Many economists and policy analysts suggest that pricing strategies are likely to be the most effective way to reduce VMT and greenhouse gas emissions. However, because pricing strategies tend to be politically unpopular and they raise equity concerns, pricing has not been heavily used to curb driving – at least not in the United States.

Table 1. How Built Environment Characteristics Impact VMT

Built Environment Characteristic	Policy/Investment Actions (examples)	Auto Trip Distance	Auto Trip Frequency	Carpooling (vehicle occupancy)	Non-Auto Mode
Increase density	<ul style="list-style-type: none"> • Allow multifamily housing development • Increase allowable housing unit density • Encourage urban infill development 	-	+	+	
Mix land uses	<ul style="list-style-type: none"> • Implement mixed-use zoning • Allow vertically-mixed buildings 	-	+	+	+
Increase local access to jobs / Balance jobs and housing	<ul style="list-style-type: none"> • Incentivize development that brings housing to job centers and/or brings jobs to housing centers • Implement mixed-use zoning • Change zoning ordinances to allow more building floor space on each parcel • Reduce parking requirements 	-	+	+	+
Increase regional access to jobs	<ul style="list-style-type: none"> • Bring more jobs to region through host of economic development strategies such as small business incentives and support services and business-enabling zoning changes (e.g. those listed above) 	+/-	-		
Improve physical network connectivity	<ul style="list-style-type: none"> • Reduce block length • Grid network design • Build cut-through streets in developed neighborhoods with low connectivity 	-	+		
Improve public transport access	<ul style="list-style-type: none"> • Add transit routes • Increase service frequency (i.e. reduce headways) • Increase densities around existing transit nodes 				+
Improve public transport service	<ul style="list-style-type: none"> • Add real-time transit vehicle arrival information to stations and stops • Add premium (e.g. faster, more comfortable) service for an additional charge • Provide additional amenities (e.g. wi-fi access) on 				+

Built Environment Characteristic	Policy/Investment Actions (examples)	Auto Trip Distance	Auto Trip Frequency	Carpooling (vehicle occupancy)	Non-Auto Mode
	transit vehicles and at major transfer hubs				
Improve walkability	<ul style="list-style-type: none"> • Implement complete streets • Add and maintain new sidewalks and paths • Implement road diets to improve pedestrian safety • Implement traffic calming measures • Improve pedestrian crossings 				+
Improve bikeability	<ul style="list-style-type: none"> • Implement complete streets • Add and maintain new bicycle lanes and paths • Create bicycle boulevards • Implement road diets to improve cyclist safety • Implement traffic calming measures • Install bicycle parking 				+
Increase highway capacity	<ul style="list-style-type: none"> • Build new roads or widen existing ones • Improve traffic flow on existing roads through traffic management 	+	+	-	-

It is important to notice that the built environment characteristics listed in Table 1 are the variables that are commonly reported in the literature to affect travel choices. However, they are not directly linked to specific policy actions, and most could be affected by multiple policy and investment actions (see column 2 of Table 1 for examples). In these cases, communities will vary both as to which actions will be most effective at causing the physical change and also as to which actions are politically palatable. For instance, many of the relevant actions are to allow and incentivize certain types of development in certain locations. However, developers will likely respond more strongly to such land use regulatory changes in some communities than in others – presumably because the demand would be higher in these places and/or NIMBY (Not In My Backyard) resistance to denser development would be lower.

The remainder of this white paper focuses attention on the built environment characteristics and associated strategies listed in Table 1, with additional estimates of the effect of fuel costs. Policy briefs that summarize findings regarding these strategies and more can be found at <http://arb.ca.gov/cc/sb375/policies/policies.htm>. For a summary of many of these results in a single publication, see Salon et al. (2012).

Evidence from the Literature

There is evidence that land use planning and transportation infrastructure investments can affect VMT substantially. This evidence comes from two prominent types of research: cross-sectional empirical analysis and evaluation studies using before-and-after data collection.

The vast majority of evidence to date is in the first of these categories, and thus this category will be the focus of most of this white paper. Unfortunately, the available evidence from cross-sectional empirical analyses does not translate into easy-to-understand-and-use estimates of how much specific strategies implemented in specific locations are likely to affect VMT. Questions remain about exactly how much each strategy is likely to affect VMT, and which aspects of the specific physical and socio-demographic context affect the effectiveness of these strategies.

Program and policy evaluation methods—where data collected before and after implementation are compared—are just beginning to become more common in travel behavior research, and these methods likely represent a significant improvement over the cross sectional studies. Text boxes in this white paper briefly summarize recent examples of evaluation studies completed by researchers affiliated with the National Center for Sustainable Transportation. It is important to note, however, that even though evaluation studies likely provide improved estimates for the context studied, they may not always generalize to other situations.

*Box 1: Travel impacts of the Metro Exposition light rail line, Los Angeles, CA
(Boarnet et al. 2013)*

Los Angeles is known for—among other things—its car-dependent transportation system. But the city is working to change this; between 2012 and 2020, six new rail lines will open in LA. The first of these to open was Phase 1 of the Exposition Line. Marlon Boarnet (University of Southern California) led an extensive before-after data collection effort to evaluate the effect of the new transportation infrastructure on the travel choices of neighborhood residents. Findings include evidence that the new transit line reduced VMT substantially among households living within a half-mile of a station, but interestingly, that there was not as large of an increase in transit ridership.

Why are these relationships so difficult to estimate?

The literature that focuses on estimating how the strategies in Table 1 affect travel choices is truly vast, including peer-reviewed journal articles, books, and reports. The researchers who contribute to this literature aim to identify the extent to which a change in the environment will lead to change in behavior. One reason for the extent of the literature is that the questions it asks are important and interesting, but another reason is that these questions are difficult to answer.

Many changes to the built environment and transportation system occur over long periods of time. It often takes multiple years to add significant capacity to rail transit systems, and it can take decades for the built environment effects of land use policy changes to be fully realized. Collecting data before and after a policy change that takes multiple years to take effect may not be practically feasible, and the quasi-experimental power of the evaluation research approach is reduced by the fact that many things in addition to the policy will have changed. This is one reason that evaluation studies have been rare in this literature.

Most studies in this literature are based on cross-sectional data, i.e. data collected at one point in time. Using these data, it is impossible to measure the effect on VMT of an actual change in a policy or in the built environment. To do this, we would need data collected before and after the change. Analyses of cross-sectional data rely on the variability across the sample in policy implementation and built environment characteristics to estimate the relationship between these variables and VMT. While this is a good use of available data, it has two major limitations. First, it requires the use of a large number of variables in the analysis, many of which are highly correlated with one another. This is necessary because estimates might be biased if key variables are not controlled for through inclusion. Second, it makes it difficult to determine causal impacts. Is it the land use pattern that influences VMT, or do people who prefer to, for example, use transit more and drive less choose to live in transit-oriented developments?

Correlation between built environment characteristics

Many built environment characteristics are closely correlated with one another. This means that they vary relative to each other according to a specific pattern (e.g. when one is high, the other is often high). Among closely correlated variables, statistical analyses of cross-sectional

data cannot tell us which variable(s) are the “real” drivers of behavior, which presents a problem for using results from this literature to inform policy actions. When many correlated built environment characteristics are included, estimates of the relationship between any one of them and VMT become less precise and can become statistically insignificant. This challenge is called multicollinearity. When built environment characteristics are left out of the analysis that are associated with VMT and correlated with characteristics remaining in the analysis, the estimates of the relationships between those that remain and VMT will be biased. This problem is called omitted variable bias.

Box 2: Shopping travel impacts of a Target retail store, Davis, CA (Lovejoy et al. 2013)

Before 2009, the City of Davis, CA did not allow big-box retail stores. After a controversial referendum vote, the City allowed a Target store to open for business near the outskirts of town. A before-after data were collected to evaluate the effect of the new store on the shopping travel patterns of Davis residents. Results showed that total shopping travel for Davis residents was measurably lower one year after the Target store opened than immediately before the store’s opening in 2009. The likely explanation for this is that prior to the store’s opening, Davis residents were traveling to neighboring cities to do their big-box shopping. Although this result is not directly generalizable to other cities, the methods used and lessons learned are transferable.

Existing estimates of the relationship between residential density and VMT showcase both problems. Places that have higher population densities usually have a mix of commercial and residential land uses, sometimes more transit service, and at times smaller blocks and amenities that facilitate non-car travel. Numerous studies have estimated the effect of residential density on travel choice. However, there is little theoretical support for the hypothesis that residential density itself significantly affects travel. Instead, it is the fact that density is correlated with multiple other variables that do affect travel that makes it appear to be important. Most researchers who estimate the relationship between density and VMT realize this, and argue that their estimates of this relationship should be viewed as proxies for the relationship between more theoretically grounded drivers of behavior (e.g. job density, retail density, mixed land uses, the availability of alternative modes, and even parking price and availability) and VMT (e.g. Frank and Pivo 1994, Cervero and Kockelman 1997, Salon 2009). Residential density in these statistical analyses represents a suite of correlated variables.

This issue of high correlation between built environment characteristics is important for other variables as well, and findings can be quite sensitive to what is and is not actually included in the analysis. Studies that investigate the effects of only a small number of built environment characteristics on VMT will likely report results for included variables that are biased (upward or downward). These results cannot be used as reliable quantitative estimates of associations between the variables.

Studies that investigate the effects of a large number of built environment characteristics on VMT will necessarily report results that are less precisely estimated, meaning that they will

have relatively large margins of error around the best-guess point estimates (i.e. they will have large estimated standard errors, or confidence intervals). These results are not afflicted by the problem of omitted variable bias, but practitioners need to be mindful of the confidence intervals that are reported along with the point estimates.

Self-selection

It is clear that people who live in different types of neighborhoods drive different amounts. However, it is not clear how much of this observed choice difference is due to physical differences between the neighborhoods and how much is due to the fact that different types of people live in different types of neighborhoods. Studies that have attempted to measure the physical environment effect separately from the individual effect find—not surprisingly—that both effects are occurring (see Cao, Mokhtarian, and Handy 2009 for a review).

This issue is referred to as “self-selection” in the literature. The fact that self-selection does occur means that the effect on VMT of changes to a neighborhood’s built environment will be staged in time. The immediate effect will be the direct effect of the change on the choices made by existing neighborhood residents and visitors. The longer-term effect will be the result of residential sorting (people moving into and out of a neighborhood in response to a built environment change according to their preferences and constraints) and possibly also shifting preferences of existing residents that will happen over time.

These effects can either reinforce each other or work in opposing directions. First, consider the example of a neighborhood that is becoming an increasingly important employment center. The immediate effect of an increase in local job opportunities will be to reduce some local residents’ commutes. Over time, some of the people who took the new jobs and lived outside the neighborhood will move in, and they will also have short commutes, further reducing the average VMT among local residents.

Now consider the example of a new rail station built in a working class neighborhood that was not previously served by rail transit but had working bus service. The immediate effect of the new rail access will be that some local residents will be able to use the rail line to get places that they need to go. If they used to drive to those places, VMT will drop. If they used to take the bus or bike, VMT will remain unchanged. A second important effect likely to occur immediately is that property values in the vicinity of the rail station will rise in response to the improved access. Over time, both wealthier households and households for whom the rail access is important will move in. If the former group dominates, the result may be that neighborhood average VMT actually rises. If the latter group dominates, the new residents will use the rail service, and average neighborhood VMT is likely to drop. In some cases, newcomers may be both wealthier *and* value rail access. Which of the groups dominates will depend on a host of other factors.

For policymakers who aim to reduce regional VMT, the relevant question is about the net effect—both for the neighborhood that experienced a change in its built environment and for the region as a whole. In the case of the new job center, taking a regional perspective could change

the result of the net VMT change calculation. From a regional perspective, it is critical to consider how the commutes of the non-local employees have changed—a new employment center near the outskirts of a metropolitan area could easily reduce its neighborhood VMT while increasing regional VMT.

Even these simplified stories are complex. But these are examples of real policy questions. Decision makers who are aiming to reduce VMT in their neighborhoods and regions would do well to think through the storylines of how specific actions they are considering could affect driving, both immediately and over time.

Findings from three comprehensive cross-sectional empirical analysis

Three of the most comprehensive studies in the literature are discussed and compared here in order to illustrate the challenges inherent in trying to make use of the evidence base in the literature. These studies are comprehensive in the sense that each estimates the effect on VMT of a variety of land use and infrastructure characteristics simultaneously. This is important because it means that the reported results are less subject to the bias discussed above that can occur due to key omitted variables. That said, these studies are not perfect; no single study surmounts all of the challenges inherent in explaining how the strategies in Table 1 affect VMT.

Although all three of these studies use disaggregated information about travel choices (at the individual and household levels), each characterizes the built environment based on data from different geographic areas and at different geographic scales. Cervero and Kockelman's (1997) analysis is based on averages of parcel-level built environment characteristics from 50 selected neighborhoods (each composed of one or two census tracts) in the San Francisco Bay Area. Salon, Boarnet and Mokhtarian (2014) use built environment characteristics averaged to the geographic level of the census tract for all of the census tracts in California. Bento *et al.* (2005) base their findings on built environment characteristics measured for metropolitan areas from across the United States.

A summary of results for each study (Tables 2 through 4) is included below. For each study, statistically significant marginal effects and elasticities of built environment characteristics are reported, and additional variables included and/or tested in the analyses are listed. Marginal effects are the change in VMT estimated to occur if an independent variable (i.e. built environment characteristic or fuel price) were to increase by a set amount. An elasticity is the *percent change* in VMT estimated to occur if an independent variable were to increase by 1%. Elasticities are usually reported at the means of the relevant variables (so the increase evaluated is 1% of the mean of the built environment characteristic, and the increase reported is the percent of the mean of household VMT for the sample).

It is readily apparent that the three studies discussed here use almost completely distinct sets of variables to represent the relevant aspects of the built environment and transportation system that we think affect travel behavior. There are two main reasons for this. The first is related to the variation in the geographic scale of measurement of the built environment discussed above; relevant built environment characteristics are simply different at different

geographic scales. For instance, the built environment measures that characterize entire cities used by Bento *et al.* (2003 and 2005) are not relevant for studies of behavior within one city.

The second is a basic data availability issue. Researchers studying a few small geographic areas (e.g. Cervero and Kockelman 1997) can collect extremely detailed built environment data, including variables such as sidewalk provision and width, bike infrastructure availability, and details of parking availability and cost. Researchers studying many larger geographic areas are more limited in their ability to collect data at this level of detail due to research resource constraints—even when it would make sense to do so. Compromises are made in which available data is used to allow study of a larger geographic area. For example, Salon, Boarnet and Mokhtarian (2014) restricted their built environment variables to those that were possible to calculate at the census tract-level for California without conducting original physical data collection.

Regardless of the explanations for it, the difference in built environment variables across studies makes comparing results challenging. The remainder of this white paper will focus on each of the three papers in turn. Major methodological differences are highlighted and an interpretation of results in regards to policymaking is provided. The goal is to provide guidance as to how these sorts of studies could be useful to those within the policy realm.

Cervero and Kockelman (1997)

Cervero and Kockelman (1997) is one of the most cited papers in this literature. It is the source of the concept of the built environment “D’s” that influence travel behavior, identifying density (people, jobs, or activities in a given area), diversity (extent to which activities and/or land uses are mixed), and design (physical characteristics of built environment, such as shade trees, street furniture, or placement of parking) as potentially important factors.

The analysis method used to estimate the effect of built environment characteristics on VMT is ordinary least squares (OLS) regression, making the results accessible to researchers and practitioners alike. However, use of this method does not control for residential self-selection, meaning that any results will be a combination of the effect of residential neighborhood selection and the effect of the built environment characteristics of that neighborhood on car ownership and travel choices. From a policy perspective, this means that their results may overestimate or underestimate the effect that changing the current built environment characteristics would have on the VMT of people in their current neighborhoods.

Table 2 summarizes the analysis results from this paper. Cervero and Kockelman’s overall conclusion was that the built environment has a modest effect on VMT. They found that job access was the only built environment variable to have a statistically significant and negative effect on household VMT. Looking at non-work VMT, they found that their intensity factor (a composite measure of multiple types of density), vertical mixing (mixed use within a single multi-story building), and the percent of intersections that are four-way all had negative effects.

Table 2: Estimates of Built Environment Variable Elasticities and Marginal Effects from Cervero and Kockleman (1997)

	All VMT		Nonwork VMT	
	Elasticity	Marginal Effect	Elasticity	Marginal Effect
Intensity Factor ¹	Not Included	Not Included	-0.06	-3.45
Proportion of Commercial Parcels with Paid Parking	Not Significant	Not Significant	Not Included	Not Included
Accessibility Index ²	-0.27	-0.08	Not Included	Not Included
Vertical Mixing	Not Included	Not Included	-0.14	-11.21
Percent 4-Way Intersections	Not Included	Not Included	-0.59	-34.34
Percent Quadrilateral Blocks	0.18	9.86	0.46	19.51
Transit Service Intensity	Not Significant	Not Significant	Not Significant	Not Significant
Control Variables for all VMT: # Vehicles, # Workers, Income				
Control Variables for Nonwork VMT: # Vehicles, # Workers, Household Size				
¹ The Intensity Factor was calculated from 6 variables: Population Density, Retail Store Density, Activity Center Density, Retail Intensity, Park Intensity, and Walking Accessibility. ² The Accessibility Index is a gravity model-based calculation of a location's employment accessibility.				
NOTE: The following additional built environment variables were tested and found to be statistically insignificant in models of VMT. They are not included in the above models. Walking Quality Factor (a combination of Sidewalk Provision, Street Light Provision, Block Length, Planted Strips, Lighting Distance, and Flat Terrain), Employment Density, Dissimilarity Index of Land Use Mix, Entropy Measure of Land Use Mix, Proportion of Commercial Parcels with Paid Parking, Road Density, Average Street Width, Average Arterial Speed Limit, Distance to Downtown, Distance to Freeway, Distance to Transit, Proportion of Blocks with Bike Lanes, Proportion of Blocks with Mid-Block Crossings, Proportion of Intersections with Signals, Average Sidewalk Width, Bike Lanes Per Developed Acre, 3 Types of Activity Center Mixture Variables, PLUS: <ul style="list-style-type: none"> • Commercial Intensities for: Convenience Stores, Supermarkets, Eateries, Entertainment and Recreational Uses, Auto-Oriented Services, Mixed Parcels • Per-Developed-Acre Intensities of Land Use for Residential, Commercial, Office, Industrial, Institutional, Parks and Recreation • Proportions of Developed Acres and Residential Acres within ¼ Mile of Convenience Store and Retail-Service Use • Proportion of Commercial-Retail and Service Parcels with: Off-Street Parking, Off-Street Parking between Store and Curb, On-Street Parking, On-Site Drive-In/Drive-Thru 				

Two important variables used by Cervero and Kockelman are actually combinations of built environment characteristics, combined using factor analysis. From a research perspective, data combination using factor analysis is attractive. The method can extract the important information from multiple related built environment characteristics and create a single variable that is then tested for significance in statistical models. Cervero and Kockelman created two such variables: an “Intensity Factor” and a “Walking Quality Factor”. The Intensity Factor, which was significant in explaining non-work VMT was composed of six measured variables:

Population Density, Retail Store Density, Activity Center Density, Retail Intensity, Park Intensity, and Walking Accessibility.

From a practitioner’s perspective, however, the use of factor variables and other variables based on complex calculations is not helpful. These results do not answer the practitioner’s question of which policies to enact because these factor variables are not easy to connect to concrete policy actions.

Salon, Boarnet, and Mokhtarian (2014)

Salon, Boarnet, and Mokhtarian (2014) is the most recent of the studies discussed here. This study is unique in its focus on estimating different effect sizes for different subpopulations within the dataset. The purpose of its focus on heterogeneity in effect size was to make the study results more directly useful for decision makers, and this study report has a number of companion products that are publicly available.¹ The results summarized in Table 3 are ranges of effect sizes for people living in different types of neighborhoods in California. Note that the effect of each of the built environment variables on VMT was statistically insignificant—and therefore effectively zero—for those living in at least one type of neighborhood, which is why all of the reported ranges of effect sizes include zero.

Table 3: Estimates of Built Environment Variable Elasticities and Marginal Effects from Salon, Boarnet, and Mokhtarian (2014)

	All Household VMT	
	Elasticity (Range across Neighborhood Types)	Marginal Effect (Range across Neighborhood Types)
Transit Use	-0.58 to 0	-0.986 to 0
Local Jobs Access	-0.13 to 0	-2.407 to 0
Regional Jobs Access	-0.19 to 0.13	-0.336 to 1.916
Bike/Ped Use	-0.07 to 0	-0.496 to 0
Road Density	-0.15 to 0	-1.174 to 0
Pct. Single Family Homes	0 to 0.19	0 to 0.139
Gasoline Price	-0.20 to 0	-2.195 to 0
Activity Mix	Not Significant	Not Significant
Control Variables: # Vehicles, Income, # Workers, Household Size, Household Lifecycle Category, Region, Spring or Summer, Day of Week.		
NOTE: Population density was tested and found to be statistically insignificant in models of VMT. Despite statistical insignificance, population density also affected estimates of included variables due to collinearity. Population density was not included in the above models.		

The methodological approach taken was to jointly model the choice of which type of neighborhood to live in and how far to drive on a particular weekday. This procedure partially controls for residential self-selection. Seven neighborhood types were identified, and the relationship between built environment characteristics and VMT was estimated separately for each of these neighborhood types.

¹ The internet link to download all materials related to this study is http://www.arb.ca.gov/research/single-project.php?row_id=64861.

The variables that had the largest effect on VMT across a variety of neighborhood types were gasoline price, local jobs access, and road density. Transit access also had an effect on VMT in many neighborhood types. In addition to the findings regarding the relative effects of variables on VMT, Salon, Boarnet, and Mokhtarian also investigated how the effect size varied between neighborhood types for each variable. For instance, they found that increasing job access did not affect VMT in the most urban neighborhoods but had large effects on VMT in less urban places. This makes sense because urban places already have plenty of jobs – lack of job access is not what is causing people in these neighborhood types to drive.

Like Cervero and Kockelman (1997), Salon, Boarnet, and Mokhtarian (2014) also evaluated some built environment characteristics that were the result of complex calculations. These included “Local Job Access”, “Regional Job Access”, and “Activity Mix”. The criticism that these variables can be difficult to connect to policy actions is again germane.

Bento, Cropper, Mobarak, and Vinha (2003 & 2005)²

Bento *et al.*'s study (published as a working paper in 2003 and as a journal article in 2005) is unusual because it examines variation in the built environment at the scale of the metropolitan area and because it uses annual VMT data rather than daily VMT data to measure driving. The study is regarded to be of high quality due to the care taken by the authors in both data preparation and statistical analysis methods. Table 4 summarizes the results.

Table 4: Estimates of Built Environment Variable Elasticities and Marginal Effects from Salon, Boarnet, and Mokhtarian (2014)

	Household VMT	
	Elasticity, All Cities	Elasticity, Excluding NYC
Population Centrality	-0.18	-0.15
City Shape	-0.04	-0.04
Road Density	0.07	0.07
Supply of Rail Transit	-0.04	-0.02
Jobs-housing Imbalance	0.06	0.06
Distance to Nearest Transit Stop	0.09	0.08
Population Density	+ effect	+ effect
Cost of Vehicle Travel per Mile	Not Significant	Not Significant
Presence of Rail Transit	Not Significant	Not Significant
Supply of Bus Transit	Not Significant	Not Significant
Metropolitan Land Area	Not Significant	Not Significant
Control Variables: Elderly Household, # Working Adult Males, # Working Adult Females, # Nonworking Adults, # Children Aged 0-16, # Children Aged 17-21, Income, Years of Schooling of Most Educated Household Member, White Household, Black Household, Annual Rainfall, Annual Snowfall		

² Both the 2003 working paper and the 2005 journal article are cited here. This is because the elasticity estimates are available only in the working paper, but a peer-reviewed journal article was subsequently published with essentially the same analysis and results.

The approach taken is similar to that used in Salon, Boarnet, and Mokhtarian (2014); the study jointly models the choice of how many vehicles to own and how far to drive each of them annually. This procedure does not control for residential self-selection. However, this may not be critical because the geographic scale is large; the residential selection in this case is which metropolitan area to live in rather than what sort of neighborhood to choose within a given area.

The measure of VMT used in this study is distinct from the other studies discussed here (and most others in this literature, it turns out) since it is taken over a full year rather than on one particular day. This has the advantage of being a more complete measurement than weekday VMT, including all household personal vehicle travel on both working days and non-working days (except for vacation car rentals). The disadvantage of using the annual VMT measure is that it may include significant long distance “road trip” VMT, which won’t be especially related to the built environment around one’s home location and therefore may dilute the estimated effects of these variables on VMT.

Like the two studies already discussed, Bento *et al.* also created complex composite variables to represent aspects of the built environment – in this case at the scale of the metropolitan area. The main variables in this category are “Population Centrality” (which indicates how centralized the population is compared to a uniform spatial distribution) and “City Shape” (which indicates how much the urbanized area deviates from a circular shape).

Overall, Bento *et al.* find that among the built environment variables that they tested, their measure “Population Centrality” had the largest effect on VMT by a factor of two. An odd result reported in this study that deserves mention is the positive effect of both road density and residential density on VMT, both known to encourage use of modes other than driving. Presumably because these results are counter-intuitive, they are not explicitly discussed in the paper and an elasticity is not provided for the effect of residential density.

In addition to reporting statistical model results and their estimated effects of individual variables, Bento *et al.* used their model to quantify the impact on VMT of composite scenarios. They report that if all of the households in their national sample were to live in Atlanta, household VMT would be 25% higher than if these same households lived in Boston and 43% higher than if these households lived in the New York metropolitan area. These results are driven by differences in public transit supply, city shape, jobs housing balance, and especially population centrality. This simple scenario analysis provides some indication of how VMT might change if many aspects of the built environment change rather than just one – an important insight for policymaking that is missing from most other studies in this literature.

Moving From Evidence to Action: An Example Based on Three Studies

Given the substantial differences between studies in terms of scale, context, and results, and keeping in mind the complexity added by self-selection into neighborhoods, how can decision

makers use the available research-based evidence to inform their policy decisions? Here I provide an example of how evidence could be used from the three studies discussed.

To be clear, this is *not* meant to be a summary of what the literature has found, but rather an *example* of how one might use evidence from the existing and future literature to inform decision making. In the best-case, a practitioner would be able to identify three to five studies done in places that come close to matching the context of the decision being considered. This example can be used as a guide that illustrates how to use those studies to inform the decision.

The starting point can be framed as two questions. Table 1 outlined specific hypotheses about the direction of the effect of various strategies on VMT. The first question, then, is whether or not the evidence in the literature supports these hypotheses. The second question asks what more we can learn from this evidence. Which strategies are estimated to have the largest effects on VMT? Are there any surprising findings that appear robust?

Looking at the example evidence presented in the three studies, four points emerge. First, accessibility is strongly associated with VMT. The better the access offered by a location, the lower the VMT by people living there. All three studies provide evidence on this point. The Accessibility Index in Cervero and Kockelman (1997), the measure of Local Job Access in Salon, Boarnet, and Mokhtarian (2014), and the Population Centrality in Bento *et al.* (2003) all report statistically significant and sizable total VMT elasticities.

A second point of note is that land use mix appears to be important (more mixed use is associated with lower VMT), and that this factor can be shown to be important at multiple geographic scales. Evidence for this comes from the negative effect of Vertical Mixing on non-work VMT (Cervero and Kockelman 1997) and from the positive effect of jobs-housing imbalance across a metropolitan area (Bento *et al.* 2003).

Third, the evidence regarding the effect of transit access on VMT is consistent in the direction of the effect (more transit lowers VMT) and statistically significant in all three studies, but the magnitude of the estimated effect is highly variable. An interpretation of this is that transit availability affects VMT, but that the magnitude of the relationship likely depends critically on local context.

Finally, contrary to the hypothesis presented in Table 1, population density may not have an independent negative association with VMT. The evidence in the three focus studies here is mixed. "Intensity factor," which is closely related to population density, was shown to have the expected negative association with VMT (Cervero and Kockelman 1997). However, Salon, Boarnet, and Mokhtarian (2014) find that population density does not have an independent and statistically significant association with VMT for most of the contexts they examine, and Bento *et al.* (2003) find that population density has an unexpected positive association with VMT at the city scale after controlling for other factors.

Concluding Remarks

This white paper has provided a theoretical framework for thinking about the relationships between the built environment and travel, discussed the challenges that researchers face when attempting to quantify the magnitudes of these relationships, and presented an example of using the results of three prominent studies to inform policy decisions. Some readers were likely hoping to find more direct recommendations for specific policies and planning actions in this paper.

However, what is contained herein is a valuable resource to inform policymaking because it provides specific guidance regarding how to evaluate both existing and future research and use it to inform decisions. In the terms of the old adage, this white paper *teaches* how to “fish” for good information. To conclude, a summary of the most important insights from this white paper are as follows:

Use studies with contexts similar to decision context

For the results in academic studies to be used to inform specific policy and planning decisions, it is important that the study context and geographic scale are similar to the context and geographic scale of the policy and planning decision being made. Ideally, a policy being considered in a particular neighborhood will be informed by research results based on data that come from a similar type of neighborhood, even if the data are not from the exact location where the policy is being considered. Salon, Boarnet, and Mokhtarian (2014) report a range of results for different neighborhood types, designed to be used in this way.

For some policy choices, evaluation studies can provide the best evidence

Much of the lack of clarity in this literature stems from the fact that the data that are the basis of most studies are cross-sectional, collected from many people but only at one point in time. Although we can and do try to use these data to shed light on the likely effect of changes in Table 1 strategies on driving, there simply is no way for even the fanciest statistical methods to fully overcome the challenges of correlation between variables and self-selection. To understand the effects of a change in policy, we need to collect data on travel choices before and after real changes in policy happen, and compare them to estimate the policy’s effect.

Research following this evaluation model is unusual in the transportation literature. As described earlier in this white paper, one reason for this is that many of the effects of land use policy change occur over relatively long periods of time, making this approach infeasible. There are cases, however, where the policy changes and infrastructure investments can be evaluated using a short time horizon. Researchers associated with the National Center for Sustainable Transportation have recently led two such studies (described briefly in text boxes in this white paper), and additional evaluation work is currently underway and being funded by the National Center for Sustainable Transportation. One important note of caution is that—as in the case of cross-sectional study results—evaluation results should be used to guide policy only if the context for the evaluation is similar to the context of the policy under consideration.

Focus on studies that control for many aspects of the built environment

In considering which existing studies might provide good evidence for a particular policy decision, it is important to focus on those studies that control for many aspects of the built environment. If key variables are left out, reported effect size results are likely to be biased and these studies should certainly not be used to inform real-world decisions. Controlling for many aspects of the built environment is most commonly done by including many variables in a statistical model (as all of the studies discussed in detail in this white paper did). Another approach that accomplishes this goal is analyzing data collected at multiple points in time in the same places, where most of the built environment characteristics stay the same but one changes.

Studies that inform the likely effect of policy packages are rare

Policymakers and planners often consider policy packages rather than actions in isolation. There are likely important interaction effects between some policies, making the total effect unlikely to be the sum of its parts. However, researchers in this area have focused almost exclusively on the effects of each variable studied on its own. Bento *et al.* (2003 and 2005) do report results of multi-variable scenarios, but even these are essentially sums of the individually estimated effects of each variable. Researchers are now working to fill this gap.

Research-based evidence supports action

Despite all of the difficulties of the precise estimation of effect sizes, research-based evidence does support policy action. The relationships between built environment characteristics and the amount that people drive have mostly been shown to be consistent with expectations. As alternatives to solo driving become available, people drive less. As driving becomes more expensive and less convenient, people drive less. As trip destinations and origins move closer together, people drive less. When people drive less, society reaps all the benefits of less driving: lower greenhouse gas emissions, less air pollution, reduced dependence on oil, improved public health through increased exercise, and enhanced community interaction. Where politically feasible, then, decision makers at all levels of government should not hesitate to enact policies and make politically feasible investments that encourage less driving.

Even in cases where relevant studies are not available to provide comparative estimates of the likely effect sizes for different possible policies, prudent decisions can still be made. These decisions will be based on a combination of estimated cost and informed reasoning about how the policy and investment options under consideration are likely to affect driving, taking into account the mechanisms through which a policy might affect driving in both the short and long term (i.e. alternatives to the car, price and convenience of driving, the distances between trip origins and destinations).

When these policies are enacted and investments made, there should also be serious consideration of using evaluation methods to estimate more precisely how much these actions actually reduced how much people drive. Over time, this will improve the evidence basis for future decision making.

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