Impacts of Residential Density on Passenger Vehicle Use and Greenhouse Gas Emissions

Policy Brief

Marlon G. Boarnet, University of Southern California
Susan Handy, University of California, Davis

September 30, 2014

Policy Brief: http://www.arb.ca.gov/cc/sb375/policies/density/residential_density_brief.pdf

Technical Background Document:
http://www.arb.ca.gov/cc/sb375/policies/density/residential_density_bkgd.pdf

California Environmental Protection Agency

Air Resources Board

Policy Brief on the Impacts of Residential Density on Passenger Vehicle Use and Greenhouse Gas Emissions

Marlon G. Boarnet, University of Southern California
Susan Handy, University of California, Davis

Policy Description

Policies that will result in higher densities have often been mentioned in the suite of land use tools that might reduce vehicle travel, as measured by vehicle miles of travel (VMT), or greenhouse gas (GHG) emissions. Such policies include direct changes to land use, such as relaxing minimum lot size requirements, increasing the density of allowed development, and encouraging urban infill. More broadly, officials can encourage higher density through combinations of infrastructure, zoning, or public finance policies that, for example, focus development around transportation nodes (including transit stations) or raise land prices and hence encourage smaller lot sizes as a result of impact fees.

Residential density is typically measured either as a ratio of population divided by land area (e.g., people per square mile) or housing units divided by land area (e.g., dwelling units per acre). Some studies distinguish between gross and net density. Gross density is the density on all land, and net density is the density on land zoned for residential use only. Employment density also has an important influence on travel behavior, but is addressed in a separate policy brief (see Employment Density at http://arb.ca.gov/cc/sb375/policies/policies.htm).

Density is correlated with a large number of land use traits that are associated with travel, including mixed land uses, transit access, the quality of the pedestrian environment, and proximity to regional employment or shopping centers. While density is easily measured, many planning researchers believe that policy attention should focus not only on density but on a more holistic set of land use characteristics (see, e.g., Chatman, 2008). Yet for purposes of summarizing the evidence on density and VMT, unless otherwise noted, the evidence here shows the effect of residential density alone on VMT.

Impacts of Residential Density

Effect Size

The table below summarizes the results from recent studies that met the following criteria:

- the studies used data for individuals or households,
- the studies were from geographic settings larger than a consolidated metropolitan area, e.g. larger than the Southern California Association of Governments (SCAG) or Metropolitan Transportation Commission (MTC) area,
- the studies controlled for a broad range of individual or household sociodemographic characteristics, and
- the studies, with the exception of Fang (2008), used statistical methods to control for the possibility that people might choose where to live based in part on how they wish to travel.

Table 1 summarizes the available evidence on the effect of residential density on VMT from studies that meet the criteria outlined above.

Table 1: Residential Density and VMT: Results from Studies of Individual or Household Travel

Study	Study Location	Study Year	Results	
			Built Environment Variable	*VMT Reduction for 100% Change in Built Environment Variable*
Bento et al. (2005)	114 U.S. MSA's	1990	City shape, jobs-housing balance, road density, rail supply – each variable alone	Less than or equal to 7%
Fang (2008)	California	2001	Population density	8% to 9%
Brownstone and Golob (2009)	California	2001	Population density	12%
Heres-Del-Valle and Niemeier (2011)	California	2001	Population Density	19%
Kim and Brownstone (2013)	National	2001	Population Density	13.8%
Kim and Brownstone (2013)	California	2001	Population Density	9%

A National Research Council (NRC, 2009) study concluded that, on average, doubling residential density is associated with VMT reductions that range from 5 percent to 12 percent. That NRC (2009) conclusion was based primarily on evidence in Bento et al. (2005) and Brownstone and Golob (2009). Stating the NRC (2009) report's result in terms of elasticities, the estimated elasticity of VMT with respect to residential density was in a range from -0.05 to -0.12. (Elasticity relates the change in density to the associated change in VMT; the elasticity is the percentage change in VMT that is associated with, in this case, a 100 percent change in density.)

A recent meta-analysis (Ewing and Cervero, 2010) concludes that the elasticity of VMT with respect to residential density is -0.04, a magnitude that hardly differs from the NRC's (2009) conclusion. Changing multiple land use variables at the same time can produce larger effects from synergies across the different land use characteristics. Bento et al. (2005) compared predicted VMT, based on estimated models, for people with identical demographic characteristics living in Atlanta, Georgia and Boston, Massachusetts to get insight into the effect of changing multiple land use variables in ways that reflect the different urban form in those two cities. Bento et al. (2005) find that predicted VMT in Boston is 25 percent lower than in Atlanta, suggesting that the combined effect of changing multiple land use variables will be larger than the effect of changing density alone. Similarly, Kim and Brownstone (2013) find that simulating moving a household from a suburban context to an urban context is associated with a VMT reduction of 17.9 percent. That result is based on analyses of national data for 2001. When Kim and Brownstone restrict their attention to data only in California, the impact of moving from suburban to urban settings is smaller, implying an 8.5 percent VMT reduction. Note that these results illuminate differences in VMT that are due to land use differences across two cities or across suburban and urban settings, and so the impacts are not elasticities.

Overall, the impacts in Table 1, combined with the meta-analysis of Ewing and Cervero (2010) and the 2009 NRC report, imply that doubling density is associated with VMT reductions that range from 4 percent to 19 percent. Note, though, that the estimate from Here-Del-Valle and Niemeier (2011) is an outlier at 19 percent. While the data and statistical techniques in that study are as high quality as in the other studies in Table 1, until the 19 percent figure is verified by other research we note that the range of impacts in most studies is from about 5 percent to 14 percent reductions in VMT when density doubles. The impacts from the studies that used California data conform well to the range in the NRC (2009) study, and so we believe that the California evidence agrees with the NRC (2009) conclusion that doubling density is associated with VMT reductions that range from approximately 5 to 12 percent (an elasticity of -0.05 to -0.12).

There is not good evidence on how to choose a value for the impact of residential density on VMT within the -0.05 to -0.12 elasticity range. Similarly, little is known about how the relationship between residential density and VMT might vary across urban or rural areas, as the evidence in this literature is largely from metropolitan areas, which would conform to both urban and suburban locales in California. Evidence suggests that factors other than residential density, including regional access to jobs, are more important for VMT (Ewing and Cervero, 2010). Hence, increases in residential density in places with strong regional access to jobs (e.g., closer to employment centers or sub-centers) may have more of an impact on reducing VMT than similar increases in residential density in places farther from job centers or other travel destinations.

Evidence Quality

The studies in Table 1 use the best available statistical methods to analyze high quality data for individual households. There is some debate about whether the associations in Table 1 show a causal effect of density on VMT, and that is discussed in the sub-section below. Several recent studies have examined the question of whether the impact of land use variables, residential density included, on travel is causal or merely an association. Because all of the studies in Table 1 except Fang (2008) use careful statistical methods to infer causal relationships, and because the bulk of the data in those studies are from metropolitan areas (since the bulk of the population resides in metropolitan areas), policy-makers may infer that the magnitudes shown in Table 1 reflect a likely range of VMT reduction that would result from changes in density over geographies that approximate a consolidated metropolitan area (e.g. at the scale of the 5-county SCAG region or the 9-county Bay Area MTC region).

Many other studies of density and VMT, not cited in Table 1, use aggregate data, meaning the data are not for individuals or households but are aggregated to geographic units. Aggregation has methodological shortcomings. Making inferences about causality is difficult with aggregate data. For that reason, studies that have travel data for households or individuals, such as the studies in Table 1, are preferred.

Caveats

Two methodological issues are most important in the literature on land use and travel, and both have ramifications for the relationship between residential density and VMT. First, people might choose to live in high density settings because they seek to drive less and, if so, the density does not directly reduce VMT but only reduces VMT by providing living places for people who seek to drive less. It would then matter crucially whether higher density neighborhoods are in sufficient supply to meet the demand of people who seek to live in those neighborhoods. If so, building more of these high density neighborhoods would not reduce VMT. If there is a shortage of higher density neighborhoods (relative to demand for such places), building more of these high density neighborhoods would reduce VMT, even if the only effect were from people choosing where to live (called "residential selection"). An extensive review of 38 studies that attempted to control for residential selection found that, in all cases, there was some independent role for the built environment (Cao, Mokhtarian, and Handy, 2009).

Second, there is reason to believe that the impact of land use on travel is characterized by thresholds. For example, Boarnet et al. (2011) give evidence that within small neighborhoods (a mile or less from end to end) residents can have as much as a fivefold difference in walking trip generation rates and differences as large as thirty percent in car trip generation rates. Those travel differences are associated with differences in land use characteristics within the small neighborhoods and persist even after controlling for differences in individual and household characteristics. For policy-making, variations in the impact of land use on travel over such small geographies are important, but are obscured by regional averages such as those reported in Table 1. Often little is known about such localized (neighborhood) effects, and neighborhood impacts may be different from regional averages. The best estimates of the regional impact of residential density on VMT are those in Table 1, above.

Greenhouse Gas Emissions

There are few studies that give direct evidence of the effect of residential density on GHG emissions. The NRC (2009) report compared GHG emissions reductions from hypothesized residential density increases to a baseline case. The report focused on two scenarios: (1) 25 percent of all future new residential development in the U.S. was assumed to be at twice the average density of new development built in the U.S. in the 1990s, and (2) 75 percent of future new development was assumed to be at twice the 1990s density level. Residential development in the 1990s averaged approximately one or two dwelling units per acre, so doubling that density implies a range from two to four dwelling units per acre. The NRC (2009) scenarios show a reduction in GHG emissions ranging from 1 percent to 11 percent below baseline trends in the year 2050. The larger GHG emissions reduction, approximately 11 percent from baseline in 2050, assumed that 75 percent of new development would be built at twice 1990s density levels and that the impact of land use change would include VMT reduction beyond what could be attributed to residential density alone. These results demonstrate that GHG emissions reductions from increasing residential density will be modest in the near-term (the next one to two decades), but can accumulate over time. If multiple strategies are used together (e.g. mixing residential and commercial land use, improving metropolitan job accessibility), their combined impact could be considerably larger than what would be obtained by only changing residential density. Many scholars, including the authors of the NRC (2009) report, therefore argue that planners should consider and implement a large number of strategies to change land use characteristics and other factors that influence travel.

Co-benefits

Increases in density should be considered as part of coordinated land use plans, rather than in isolation. There are many possible co-benefits from land use policies that encourage higher residential densities, concentrations of employment, shopping, and service destinations, and infrastructure and urban design that make non-motorized travel modes (e.g., walking and bicycling) more attractive options. Increases in non-motorized travel might bring health benefits, and there is evidence that land use characteristics, including higher residential density, are associated with increased walking (e.g. Boarnet, Greenwald, and McMillan, 2008; Boarnet et al., 2011). However, some caution is in order, as increases in walking might partially compensate for reductions in other kinds of physical activity, and so health benefits may not scale one-for-one with increases in walking (see, e.g., Rodriguez, Khattak, and Evenson, 2006). The shifting of trips from motorized to non-motorized modes will also have positive impacts on local and regional air quality. More generally, the land use elements associated with non-motorized travel are often associated with vibrant neighborhoods, and hence might be associated with resident satisfaction. Yet density by itself may not be the most important variable for community livability. In Song and Knaap (2003), factors such as street connectivity, transit access, and pedestrian access to shopping were associated with higher house prices, which is consistent with those neighborhood characteristics being more valued by home buyers, but density, after controlling for those other factors, had a small but negative association with house prices.

Examples

Infill development is increasingly common in California communities, and can range from developments on one parcel to coordinated plans for larger areas. For example, the city of Irvine has developed a plan to foster residential development in a 2,800 acre area that was previously a business center. Long-term plans envision as many as 15,000 to 17,038 residential units, all of which could be considered infill development.[1] Outside of California, increases in density have been implemented in conjunction with rail transit, including projects such as Atlantic Station in Atlanta, Georgia and transit-oriented developments in Portland, Oregon. From 1993 to 2003, population density within Portland's Urban Growth Boundary (as defined in the early 1990s) increased from 3,136 to 3,721 people per square mile. In Portland, daily VMT per person equaled the national average in 1996, but in 2007 Portland residents drove 17 percent fewer miles per day than the U.S. average (from U.S. and Oregon Department of Transportation Data, cited in National Research Council, 2009, Annex 3-1). The VMT result for Portland is likely related to that metropolitan area's comprehensive system of land use and infrastructure planning, of which increases in residential density are only one part.

[1] http://www.cityofirvine.org/cityhall/cd/planningactivities/advance_planning/ibc_graphics/default.asp

References

Bento, Antonio M., Maureen L. Cropper, Ahmed Mushfiq Mobarak, and Katja Vinha. 2005. The Effects of Urban Spatial Structure on Travel Demand in the United States. *The Review of Economics and Statistics* 87,3: 466-478.

Boarnet, Marlon G., Michael Greenwald, and Tracy McMillan. 2008. Walking, Urban Design, and Health: Toward a Cost-Benefit Analysis Framework, *Journal of Planning Education and Research* 27: 341-358.

Boarnet, Marlon G., Kenneth Joh, Wally Siembab, William Fulton, and Mai Thi Nguyen. 2011. Retrofitting the Suburbs to Increase Walking: Evidence from a Land Use – Travel Study**.** *Urban Studies* 48: 129-159.

Brownstone, David. 2008. *Key Relationships Between the Built Environment and VMT*. Draft paper prepared for Transportation Research Board panel on "Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy." October. http://onlinepubs.trb.org/Onlinepubs/sr/sr298brownstone.pdf.

Brownstone, David and Thomas Golob. 2009. The Impact of Residential Density on Vehicle Usage and Energy Consumption. *Journal of Urban Economics* 65: 91-98.

Cao, Xinyu, Patricia Mokhtarian, and Susan L. Handy. 2009. Examining the impacts of residential self-selection on travel behavior: A focus on empirical findings. *Transport Reviews* 29 (3), 359–395.

Chatman, Daniel G. 2008. Deconstructing development density: Quality, quantity and price effects on household non-work travel. Transportation Research A 42: 1008–1030.

Ewing, Reid and Robert Cervero. 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record* number 1780: 87-114.

Ewing, Reid and Robert Cervero. 2010. Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association,*76: 265 – 294.

Fang, Hao Audrey. 2008. A discrete–continuous model of households' vehicle choice and usage, with an application to the effects of residential density. *Transportation Research Part B* 42: 736–758.

Handy, Susan L. Xinyu (Jason) Cao, and Patricia Mokhtarian. 2009. Active Travel: The Role of Self-Selection in Explaining the Effect of Built Environment on Active Travel. San Diego: Robert Wood Johnson Active Living Research Program, available at http://www.activelivingresearch.org/files/ALR_Brief_SelfSelection.pdf, accessed Feb. 24, 2010.

Heres-Del-Valle, David and Deb Niemeier. 2011. CO2 emissions: Are land-use changes enough for California to reduce VMT? Specification of a two-part model with instrumental variables. *Transportation Research B* 45: 150-161.

Kim, Jinwon and David Brownstone. 2013. The impact of residential density on vehicle usage and fuel consumption: Evidence from national samples. *Energy Economics* 40: 196-206.

National Research Council, Committee on Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption. 2009. *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO2 Emissions*. Washington, D.C.: National Academies Press.

Rodriguez, Daniel A., Asad Khattak, and Kelly Evenson. 2006. Can new urbanism encourage physical activity? Physical activity in a new urbanist and conventional suburban neighborhoods. *Journal of the American Planning Association* 72 (1): 43-54.

Song, Yan and Gerrit Knaap. 2003. New urbanism and housing values: a disaggregate assessment. *Journal of Urban Economics* 54: 218-238.

Acknowledgments
This document was produced through an interagency agreement with the California Air Resources Board with additional funding provided by the University of California Institute of Transportation Studies MultiCampus Research Program on Sustainable Transportation and the William and Flora Hewlett Foundation.