Factors Influencing Vehicle Miles Traveled in California: Measurement and Analysis

Kent M. Hymel
Department of Economics
California State University, Northridge

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EXECUTIVE SUMMARY

Through the last half of the 20th century, real gross domestic product (GDP) and per capita vehicle miles traveled (VMT) shared similar growth rates. But in the last decade the trend has not held: growth in per capita VMT stalled even though the economy has begun to recover from the Great Recession. To address this puzzling phenomenon, this report examines the factors that influence vehicular travel. There are four main goals of this study. First, the report illustrates historical VMT growth patterns. Second, it quantifies the effects of various factors on VMT. Third, it addresses observed differences in VMT growth between California and the nation as a whole. And fourth, it presents a set of policy recommendations regarding future transportation planning. The main findings of this study are:

- California experienced an earlier and sharper decline in VMT growth compared to the rest of the nation. In California, the decline began in 2005 while the national decline began in 2007.

- Economic factors significantly impact VMT. Estimates suggest that in California, a 50% increase in income per adult leads to a 15% increase in VMT per adult in the short run and a 23% increase in the long run. Similarly, a one percentage point increase in the unemployment rate leads to a 0.8% decrease in VMT per adult.

- Drivers are responsive to sustained changes in fuel prices. In California, a 50% increase in fuel prices leads to 5% percent decrease in VMT per adult in the short run and a 7.5% decrease in the long run. In addition, Californians are more responsive to fuel price changes relative to the rest of the nation.

- Californians have begun purchasing more fuel-efficient vehicles. However, fuel-efficient vehicles are cheaper to operate on a per-mile basis, thereby encouraging people to drive more. The estimates suggest that a 50% decrease in fuel-intensity (gallons per mile) increases VMT per adult by 6% short-run and by 9% in the long run.

- Drivers shifting to other modes of transportation cannot explain the decrease in VMT. Car trips as a share of all commutes increased slightly between 2007 and 2012. In addition, young drivers have not abandoned the automobile. For those under the age of 20, car trips still account for 60% of all commutes.

- An increase in the availability of public transit tends to reduce VMT, but only by a minuscule amount. The recent growth of public transit usage cannot account for a much larger decrease in VMT. Between 2000 and 2011 the slight increase in public transit passenger miles per adult was dwarfed by the decrease in VMT per adult.

- Although growth in VMT per capita has leveled off, total vehicle miles traveled is expected to grow as the economy rebounds and California's population increases.

POLICY RECOMMENDATIONS

Findings in this report support four key transportation policy recommendations for California. Together they address public revenues, roadway efficiency, and equity. The first three recommendations emanate from the finding that consumers are quite responsive to changes in the per-mile cost of driving. The fourth recommendation addresses investments in public transportation and issues of equity.

Adjust the gasoline excise tax for inflation

Because California's gasoline excise tax is not directly tied to inflation, tax revenue in real terms will decline as the overall price level increases. To maintain the purchasing power of the tax revenue, the State should adjust rates annually to account for inflation. Note that under the revenue-neutrality requirements of AB x8-6, rising vehicle fuel efficiency will not reduce total gasoline tax revenue even though it will reduce gasoline consumption. Furthermore, under the so-called *user-pays principle*, the gasoline tax is preferable – it targets the larger and less fuel-efficient vehicles that cause a disproportionate amount of road damage and pollution.

Implement congestion pricing

Severe traffic congestion plagues metropolitan areas across the state. Increased use of congestion pricing will lead to more efficient use of scarce roadway capacity during peak travel periods. Economic and political impediments (e.g., costs and rights-of-way) hamper highway expansions. So in the short run, the State should promote further development of dynamically-priced managed lanes, which impose tolls on only part of a multi-lane facility. Examples of such facilities include those on I-10 in Los Angeles and on I-680 in Alameda County. In the long run, the State should seek to connect individual managed lanes into a connected network of lanes. Again, under the user-pays principle, toll revenues should be dedicated to finance the maintenance and expansion of existing managed lanes.

Investigate mileage-based taxes

Existing managed lane facilities in California are limited to major freeways and do not reduce high levels of traffic congestion on California's arterial streets. The state should conduct research into mileage-based taxes that vary with traffic congestion or the time of day. Static mileage-based taxes are easier to implement and collect, but do not discourage driving during peak traffic periods. The technology behind mileage-based taxes exists, but more needs to be done to increase public understanding and support of such a system.

Invest in public transportation

Most research – including this report – finds that investing in public transportation does little to reduce personal vehicle travel. But increasing the gasoline tax and implementing congestion pricing will create winners and losers, and may disproportionally impact low-income drivers. To counter the regressive nature of gasoline taxes and tolls, and to promote fairness, the state should invest more in public transportation. Such investment would lower commuting costs and would increase access to employment centers.

1. INTRODUCTION

Many factors influence vehicle travel and a large body of research provides compelling quantitative evidence. Events of the last decade, however, have ignited an increased interest in this topic. Extraordinary events such as the global financial crisis, turmoil in energy markets, and fiscal constraints in government have greatly impacted personal, commercial, and public transportation. But at the same time, inexorable demographic and social trends have increased pressure on transportation infrastructure. In response, policymakers have considered innovative transportation policies such as congestion pricing, tighter fuel-efficiency standards, low-carbon fuel mandates, and vehicle-mileage based taxes. Together, these events provide an exciting and fertile ground to study the factors underlying vehicular travel.

Recent empirical research indicates that fluctuations in national vehicle miles traveled per adult (VMT) can be largely explained by measurable factors such as the price of fuel, the stock of highway infrastructure, and various macroeconomic variables (Small and Van Dender 2007; Hughes et al. 2008; Hymel et al. 2010; Greene 2012; Hymel and Small 2013). The econometric models underpinning this research, however, also include controls for a wide variety of factors thought to influence VMT. The impacts of these other factors are important to policy makers, and have loomed large in policy debates. For example, research based on nationwide data indicates that per-mile fuel costs, personal income, the time cost of driving (i.e., congestion), urbanization, and highway capacity all significantly influence aggregate VMT per adult in the United States (Hymel et al. 2010; Hymel and Small 2013).

However, less is known at the state level, so obtaining California-specific estimates for the effect of these factors on VMT could improve transportation policy.

This report examines the factors that have shaped historical vehicle usage patterns in California using data from a wide variety of sources. Moreover, the report presents statistical estimates that quantify the relationship between VMT and its determinants. It has been widely noted, however, that vehicle usage patterns in recent years were atypical. From the 1960s to the beginning of this century, VMT and VMT per adult have both steadily increased at approximately the same rate as GDP. But since 2007 vehicle miles traveled per adult nationwide has declined, while California witnessed a similar decline beginning in 2005.

The cause of this puzzling phenomenon has been hotly debated. Commonly cited explanations include the aging of the baby boomer generation, reductions in teen driving, changing preferences (e.g., urban living, public transit), increased smartphone use, a rise in telecommuting, and other factors. While many of these explanations are plausible, there is little research to support them.

Nevertheless, recent research has provided some explanations for the decline in VMT. For example, recent research has found that higher gasoline prices reduce new housing construction in areas with long commutes, thereby reducing vehicle miles traveled. Estimates by Molloy and Shan (2013) suggest that a 10 percent increase in gasoline prices causes a 10 percent decrease in residential construction in locations far from employment centers. Furthermore, they find that rising gasoline prices have little effect on residential *relocation* decisions.

Increases in residential density have also been found to reduce VMT, partially because more dense areas tend to have better access to transit and fewer parking spaces (Bento et al.

2005; Brownstone and Golob 2009; Fang 2008). Other research suggests that the reduction in the growth of highway capacity has stunted suburbanization, thus reducing the growth rate of VMT. Estimates by Baum-Snow (2007) suggest that an additional highway running through a city center reduces city population by approximately 18 percent. Furthermore, all of these factors are not mutually exclusive: patterns in VMT usage cannot be explained by one factor.

One way to explain the effect of multiple factors on VMT per adult is through the use of linear regression analysis, which forms the centerpiece of this report's findings. But before presenting the statistical results, Section 2 presents three sources of historical VMT data for California. Visual depictions of these data sources clearly illustrate the long-run trends in vehicle usage. Section 3 presents graphical and quantitative evidence on the factors thought to influence VMT, many of which will be explored more rigorously using regression analysis. The results of the regression models, presented in Section 4, show that fuel prices, income levels, unemployment, highway capacity, and other socioeconomic variables all help to explain VMT trends.

2. TRENDS IN VEHICLE USAGE

California's long-run trend in VMT per adult mirrors that of the United States as a whole. In recent years, however, the trend lines have diverged: Californians drive fewer miles annually than the average American (refer to Figure 1 below). California's high fuel prices, high automobile insurance rates, and severe traffic congestion are thought to explain most of the divergence. Moreover, the divergence suggests that quantitative estimates derived from aggregate United States studies may be inadequate when applied to policy analysis in California. Some recent research has focused on vehicle travel in California (Burger and

Kaffine 2009; Gillingham 2013; Knittel and Sandler 2013), but fuel price fluctuations have been the sole focus of that research. The effect of other factors on VMT in California is not as well understood and deserves more attention from researchers.

Before investigating the factors that are responsible for vehicle usage trends in California, it is useful to examine the trends themselves. This section presents aggregate trends in VMT per adult for California and for the nation as a whole. The figures presented below provide a "macro" perspective of transportation trends. The rest of this report will examine the factors underlying these trends.

A variety of agencies provide estimates of VMT, and although each source has its own shortcomings, together the data portray how vehicle usage has evolved over time. The charts in this section visually demonstrate both recent and long-run patterns in vehicle usage. The data used in this section are drawn from the Federal Highway Administration (FHWA), Caltrans, and the California Bureau of Automotive Repair (BAR). For the most part, all three sources of data correspond, despite their idiosyncrasies.

FHWA Highway Statistics

The Federal Highway Administration of the US Department of Transportation has collected state-level data annually since 1965. They provide rich data on vehicle usage, infrastructure, and other transportation related measures every year in the Highway Statistics publications. To obtain the state-level data, the FHWA relies upon individual states to provide the necessary information. For example, the vehicle miles traveled series is estimated primarily using traffic counts and gasoline consumption data. Although the FHWA has a set of guidelines for estimating vehicle usage, each state is given some latitude in their methods.

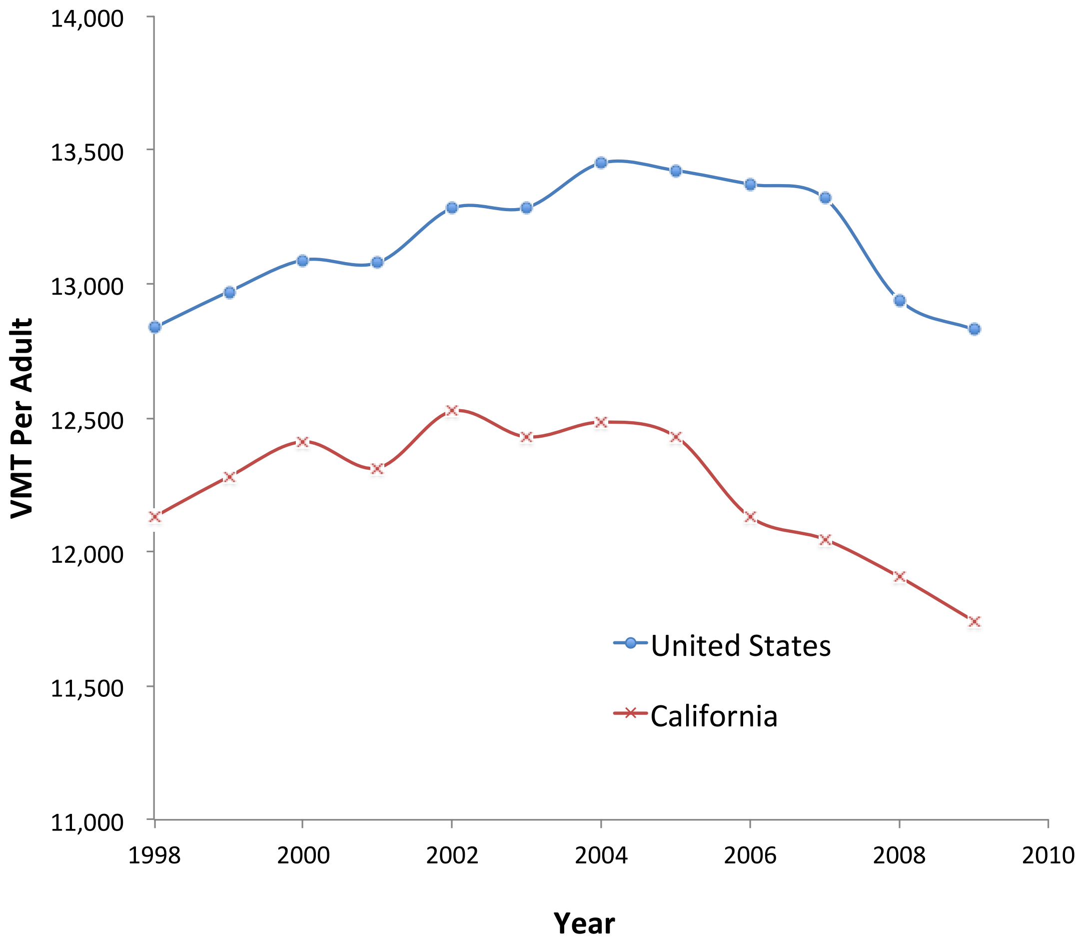
Relative to other states, California ostensibly provides superior data to the FHWA by virtue of its large network of traffic monitoring devices.

Figure 1 below presents vehicle miles traveled per adult data beginning in 1966 and ending in 2011. The first striking observation is that the growth rate of VMT per adult in California began to decline around 1991 and actually became sharply negative in 2005. That decline is puzzling, as it precedes the financial crisis of 2007 and the Great Recession of 2009. Similarly, the US also witnessed a decline in the growth rate of VMT, but it began in 2001. Also, US VMT per adult dropped sharply in 2007, which has widely been noted. The diagram in Figure 2 illustrates VMT per adult between 1998 and 2011 to better highlight recent trends.

Another striking feature of the figures relates to the differences in VMT per adult between California and the United States. Beginning in 1991, California's VMT per adult trend began to diverge from that of the US, and the trends continued to diverge until 2011. Other prominent features of Figure 1 include the pronounced declines in VMT per adult during the oil embargo of 1974 and the Iranian revolution of 1979, both of which drove up gasoline prices. So although it appears that fuel price volatility and macroeconomic factors may explain the trends seen in Figure 1, later sections of this report provide more robust qualitative and quantitative evidence.


United States
California

Figure 2: FHWA VMT trends (1998 - 2009)

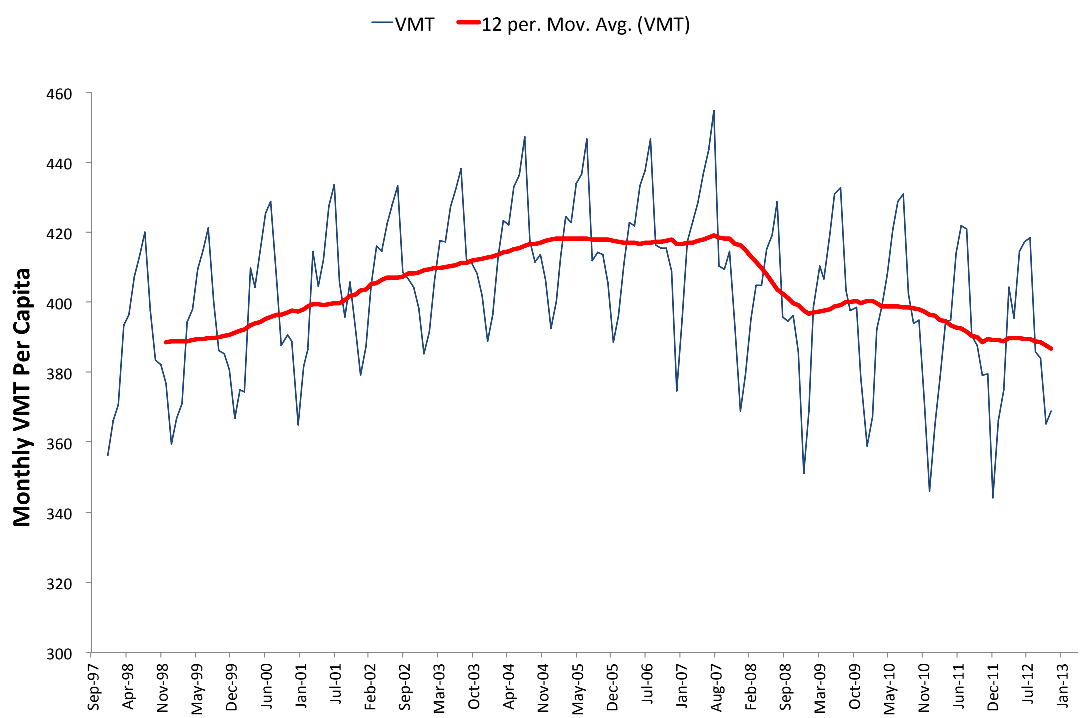


Source: Highway Statistics Annual Publications (FHWA)

Caltrans Data

A complementary source of vehicle usage data is provided by Caltrans, which estimates VMT on California's state highways. This data is derived from magnetic loop detectors, which are sensors embedded in the roadways. Unlike the FHWA data, the Caltrans data is collected monthly. Figure 3 below presents the monthly trends from 1998 to 2013. The more jagged line is actual monthly VMT, which shows patterns of seasonal variation: mileage is substantially higher in the summer months and lower during the winter months. To better comprehend the overall trend, a twelve-month moving average is also included. First, note that VMT per adult on state highways was slowly but steadily increasing up until 2007. We see, however, a precipitous decline in VMT per adult from 2007 to 2009. What is surprising about the timing of the drop is that it coincides with the financial crisis, while Figure 2 showed California's decline beginning earlier in 2005. Because commercial vehicles and trucks utilize the state highway system more heavily relative to passenger vehicles, the financial crisis and Great Recession had a larger negative impact on commercial vehicle travel, thus reducing VMT on state highways. Nevertheless, the FHWA and Caltrans data both show that the financial crisis and Great Recession were associated with a sharp drop in VMT per adult.

Figure 3: Caltrans VMT trends (1998 - 2013)



Source: Caltrans

California Bureau of Automotive Repair Data

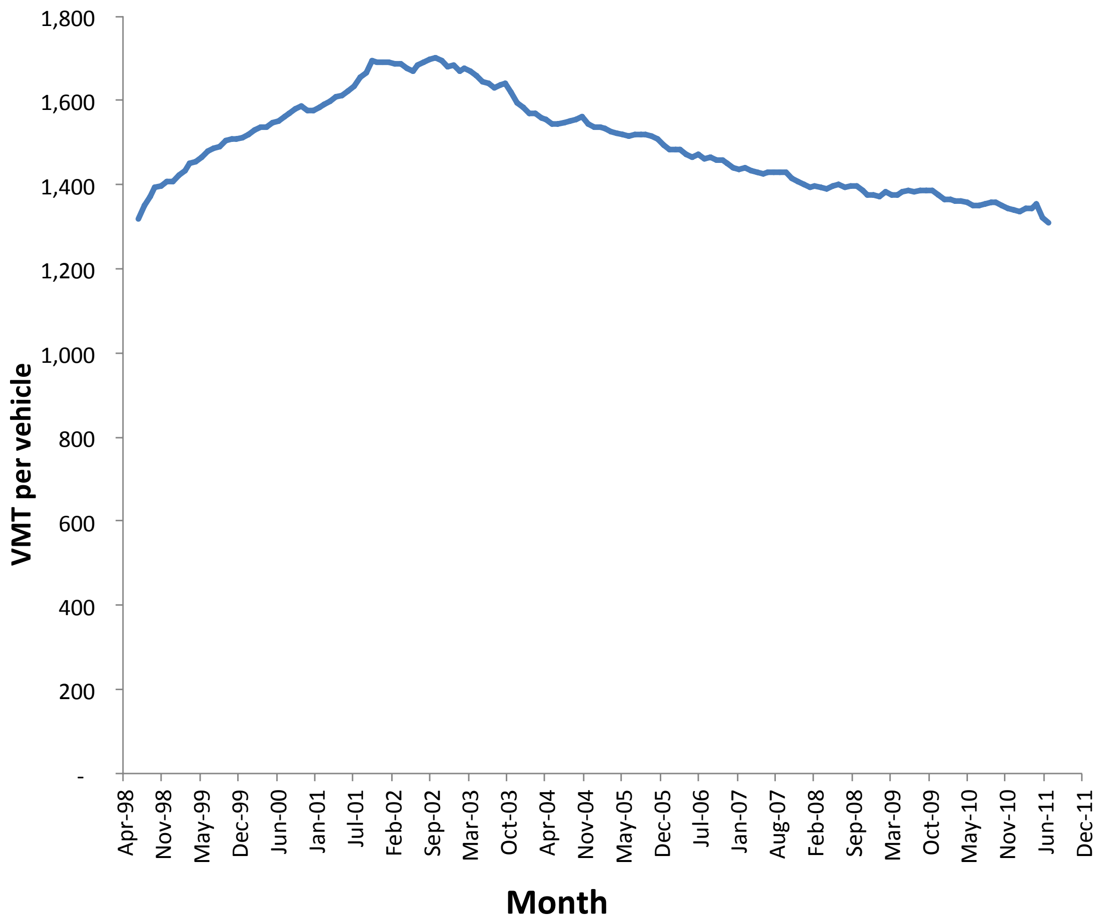
A third set of VMT trends was compiled using data provided by California's Bureau of Automotive repair (BAR). The BAR is responsible for the smog check program in California, and many vehicles are required to undergo biannual checks. The results of each smog check are sent from the test station to BAR, and the results contain dozens of variables, including an odometer reading. The odometer readings provide what is ostensibly the best available source of VMT data. So VMT for any automobile that is observed more than once can be calculated based on two odometer readings. The BAR data set used for this report contains approximately 170 million odometer readings. Although the accuracy of odometer readings is undeniably precise, the BAR data does have its own shortcomings.

First, not all vehicles are subject to biannual tests. Vehicles younger than six years old, hybrids, electric vehicles, motorcycles, and commercial trucks are not subject to tests. Excluding these vehicles is problematic insofar as drivers of new or fuel-efficient vehicles may behave differently than those subject to a test. New vehicles are typically utilized more intensely than the average vehicle, but it is not known whether drivers of hybrid or electric vehicles drive more or less than average. On one hand, some drivers purchase fuel-efficient vehicles for environmental reasons; those drivers would be expected to drive less than average. On the other hand, some fuel-efficient vehicles are driven more than average because those drivers have a monetary incentive to do so: more efficient vehicles are less expensive to drive on a per-mile basis. Thus, someone with a long commute may purchase a clean and efficient vehicle simply to save money.

Figure 4 below shows how much the average vehicle is driven per month across time. First note that in 2011, the average vehicle was driven approximately 1,350 miles per month (about 15,600 miles annually). Whereas results from Figure 2 suggest that the average adult drives a little more than 11,000 miles per year. This finding is surprising, as there were approximately 28 million adult Californians and approximately 35 million cars and trucks in 2011. Thus, we would expect that mileage per vehicle would be less than mileage per adult. But newer vehicles, which are not in the BAR data, are normally utilized more intensely than older vehicles, thereby biasing the average downward. In addition, the FHWA data includes miles traveled by commercial vehicles, whereas commercial vehicles with a gross vehicle weight rating greater than 14,000 pounds are not subject to the smog check program. The latter effect would also be expected to decrease average vehicle miles traveled as measured by the BAR.

Despite the differences just mentioned, the temporal patterns of vehicle usage are most important for this analysis. Note that vehicle miles traveled per vehicle in Figure 4 does not show a sharp decline in vehicle usage between 2007 and 2009, while the national trend and the CA State Highway trend both illustrate the decline.

Figure 4: BAR VMT Trends (1998 - 2011)



Source: California Bureau of Automobile Repair odometer readings

3. FACTORS AFFECTING VMT

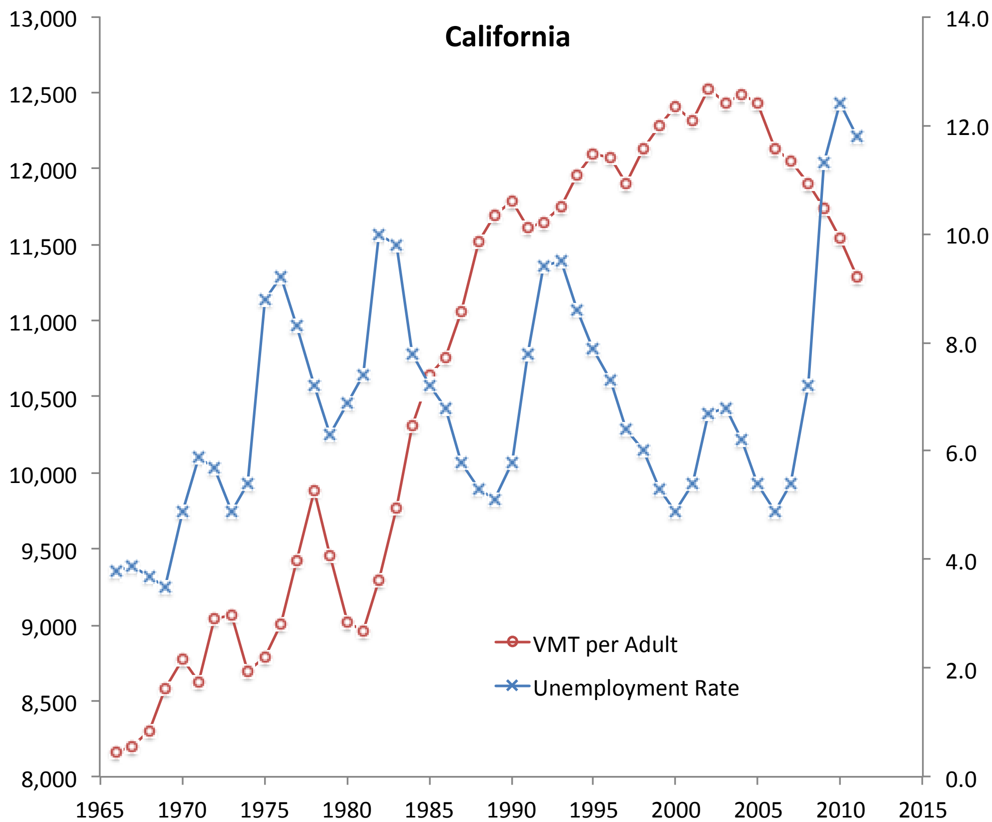
The key findings of the previous section were that Californians currently drive fewer miles than other Americans, and that vehicle miles traveled per adult (and per vehicle) have steadily declined in recent years. These findings naturally invite the question: why? This section considers a wide variety of factors that help explain the trends. The graphical and tabular results presented below highlight how vehicle use in California is correlated with other transportation, demographic, and macroeconomic trends. Later, these correlations will be examined with more rigorous econometric methods.

Economic Factors

Three key economic variables that help determine aggregate vehicle miles traveled per adult are the unemployment rate, the level of per-capita income, and median household income. Although the three factors are closely related, they affect VMT in different and subtle ways. First, increased unemployment tends to decrease vehicle usage at the extensive margin. In other words, those that become unemployed often discontinue commuting and forego many trips they otherwise would have taken. While unemployment has a large affect on the driving behavior of the unemployed, it has a relatively small impact on the employed for the reasons just mentioned. Per capita and median income levels, on the other hand, affect vehicle usage at the intensive *and* extensive margins. If decreases in income were widespread across many drivers (both employed and unemployed) one would expect to see fewer discretionary vehicle trips. Thus, increases in unemployment and decreases in per capita income would tend to reduce driving. Determining whether or not these effects are meaningful will rely on various pieces of empirical evidence.

Consider Figure 5 below, which plots California's unemployment rate (right vertical axis) against vehicle miles traveled per adult (left vertical axis). Prior to 1990, there is no apparent relationship between the unemployment rate and VMT per adult. The figure clearly illustrates the recession periods when unemployment sharply increased in the 1970s, but there is no corresponding movement in VMT. But after 1990, the figure does show a negative relationship between the two variables. Note that the range of the right vertical axis begins at 8,000 miles for illustrative purposes, so direct comparisons of the relative magnitude of the trends are exaggerated. Statistical evidence supports the graphics: the correlation between unemployment and VMT per adult from 1990-2011 is indeed strongly negative; the coefficient is equal to -0.85 and is significant at the 0.99 level.

Figure 5: Unemployment rate and VMT (1966 - 2011)

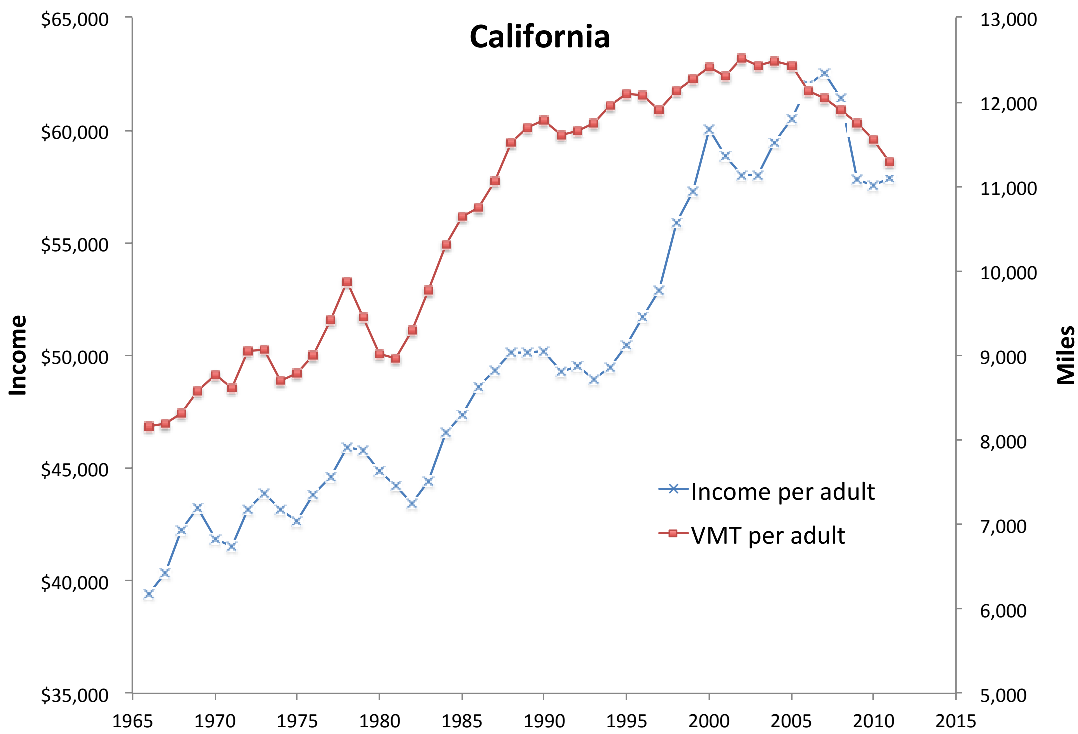


Source: Bureau of Labor Statistics and FHWA

A similar set of evidence suggests that per capita income and VMT are positively correlated. Figure 6 plots per capita income against VMT per adult between 1966 and 2011 in California. Between 1966 and 2000, the two trends track one another closely. But beyond the year 2000, the positive relationship is less clear: per capita income fluctuates considerably while VMT per adult ultimately decreases. Nevertheless, the correlation coefficient computed for years 1966 through 2011 is strongly positive (0.88 and statistically significant at the 0.99 level).

Another economic measure is median income per household. Because of inequality in the income distribution, the median represents a typical Californian's income better than the statewide average. Figure 7 plots the median household income in California between 1984 and 2011 against VMT per adult.[1] This chart shows that the relationship between median incomes and VMT per adult is positive and strong even after the year 2000. The correlation coefficient is equal to 0.61 and is significant at the 0.99 level. More robust statistical evidence in the next section further supports a strong positive relationship between income and vehicle usage in California.

Figure 6: Per capita income and VMT (1966 - 2011)



Source: US Bureau of Economic Analysis, US Census, and FHWA

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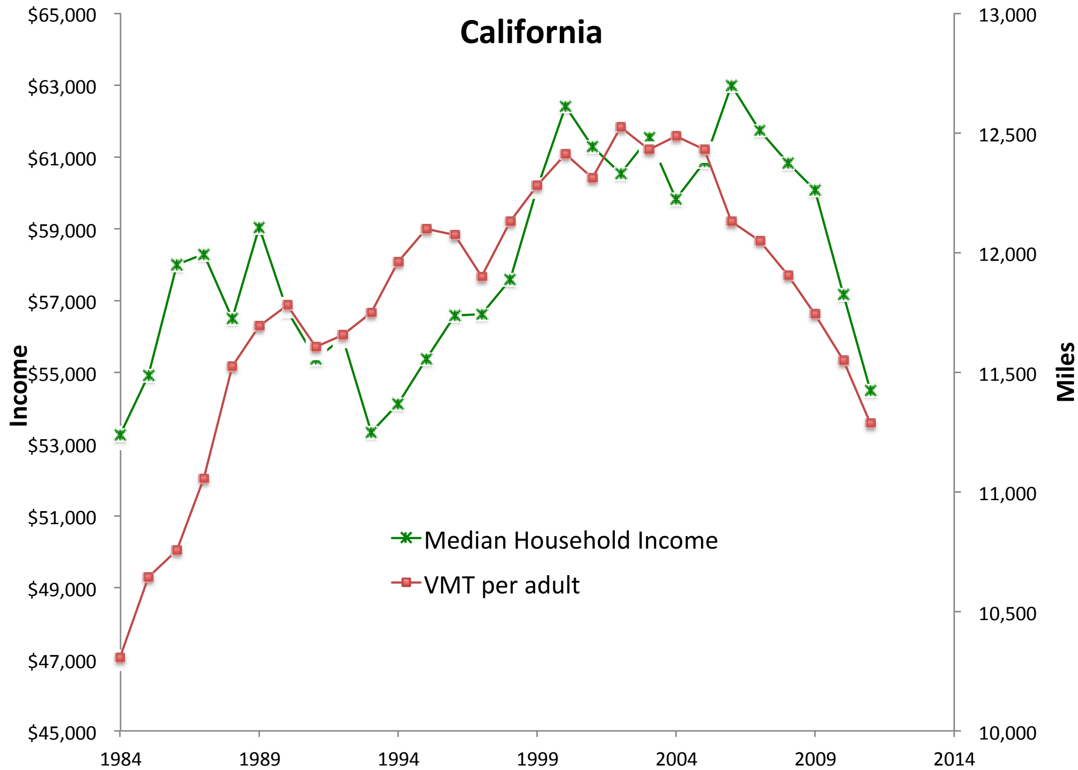
[1] The US Bureau of Economic Analysis only provides state-level median income per household beginning in 1984.

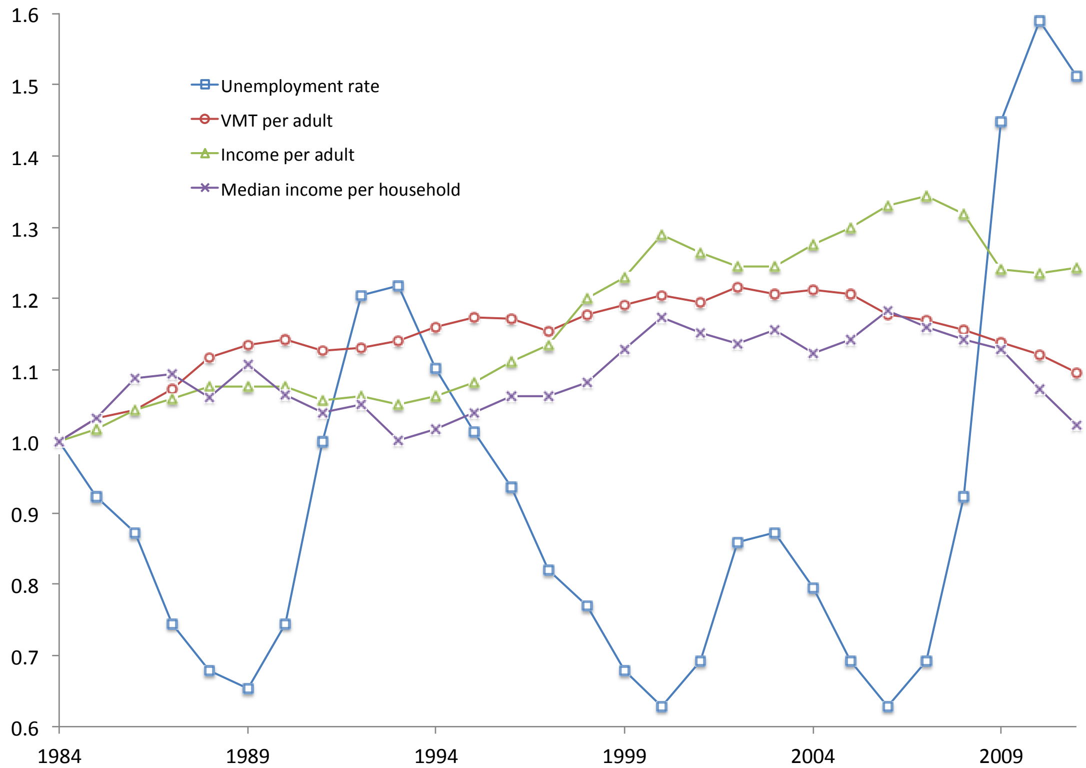
Figure 7: Median income and VMT (1984 - 2011)



Source: US Bureau of Economic Analysis, US Census, and FHWA

The three previous figures somewhat exaggerate the trends in VMT by measuring VMT, unemployment, and income on separate vertical axes. Figure 8 presents the same three time-series on one chart by standardizing the units of measurement. Using a base year of 1984, the figure shows how VMT, income, and unemployment have varied in percentage terms. One can clearly see from Figure 8 that unemployment and income were substantially more volatile than was VMT between 1984 and 2011.

Figure 8: Macroeconomic variables and VMT (1984 - 2011)



Source: BEA, BLS, Census and FHWA

While the unemployment rate and income fluctuate with the business cycle, VMT per adult is less volatile in the short run. Commuters (who are responsible for a large fraction of VMT) cannot easily change the locations of their workplace or residence. Hence, short-run changes in VMT are usually small. Furthermore, there is often latent demand for vehicular travel. As fewer people drive during peak periods, congestion declines. And when congestion declines, so does the time cost of driving. The lower cost induces drivers to undertake more trips than they otherwise would have. Put simply, following a reduction in congestion the flow of traffic and VMT usually bounce back.

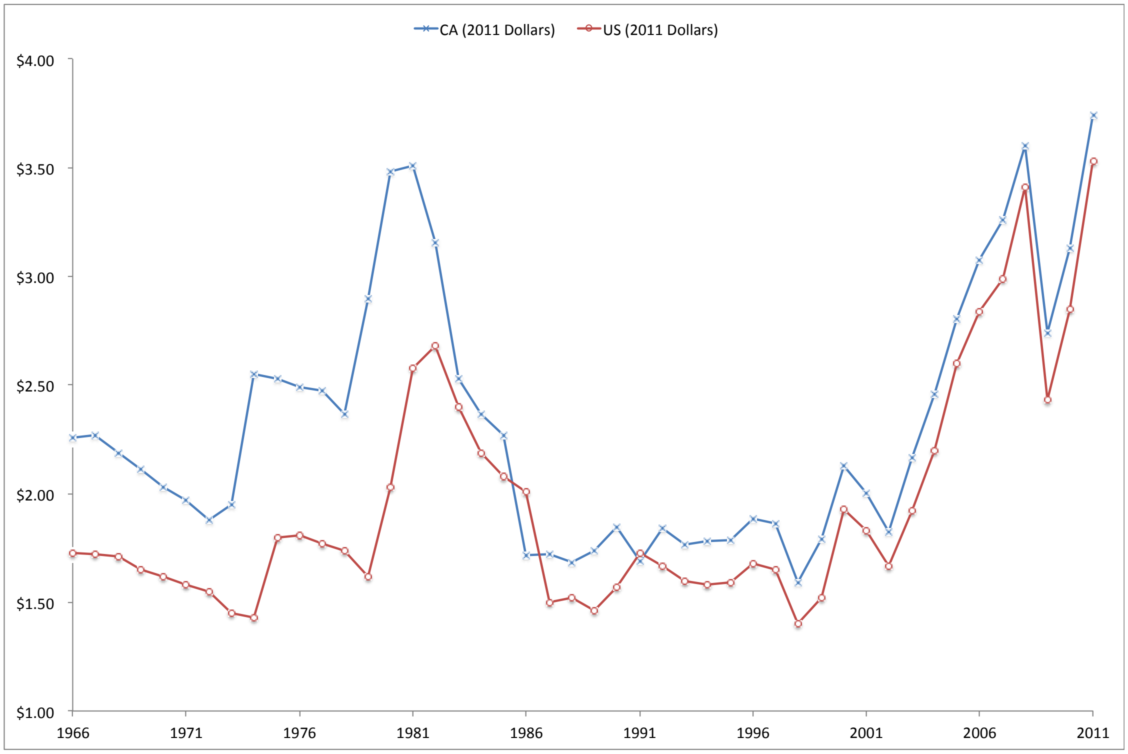
Fuel Prices

A large amount of research has focused on the relationship between vehicle use and the price of fuel. Most research suggests that the short-run impact of a price change is relatively small, but that over the long run drivers are quite responsive to sustained price changes. Again, as previously mentioned, drivers have limited flexibility in altering their workplace, residence, and mode of transport in the short run. Over longer periods of time, however, these constraints are more flexible. Hence it may take several years to notice a meaningful decrease in driving following a sustained increase in fuel prices.

One of the striking findings evident in Figure 1 above was the divergence in VMT trends in California relative to the US as a whole. This divergence began in the early 1990s and has persisted until the present. Could differences in fuel prices between California and the US possibly explain this fact? It is well known that California has higher gasoline prices than all states except for Hawaii. As fuel costs represent a large fraction of the total cost of driving, it is worth examining whether or not the price difference may be responsible for the divergence in driving.

Figure 9 compares the historic differences in regular grade gasoline prices (in 2011 dollars) for the United States and California. Except for 1986 and 1991, California has always had higher gasoline prices. Furthermore, in the 1970s, the price differential was quite pronounced, as California gas prices were roughly 75 cents higher than the national average. But in more recent years, the price differential has diminished. In recent years the price difference has been only 25 cents.

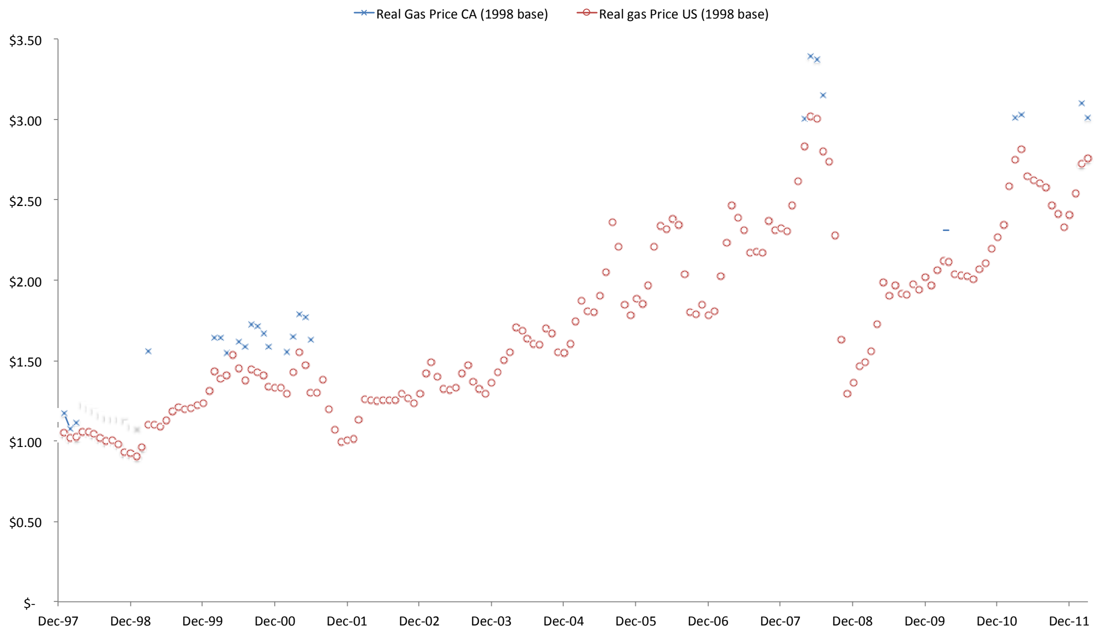
Figure 9: Annual real gasoline prices US and CA (1966 - 2011)



Source: Energy Information Administration and California Energy Almanac

By itself, the price difference does not account for the wider VMT discrepancy between the US and California, which was more pronounced in Figure 1. Also, the divergence in fuel prices preceded 1991, the year in which the US and California VMT trends diverged. However, one interesting fact is that fuel prices are more volatile in California: the peaks and troughs in prices are more prominent, as can be seen in Figure 10. Research by Hymel and Small (2013) finds that drivers are more responsive to fuel price increases when price volatility is high. Based only on visual depictions of fuel price trends, it is not evident that differences in fuel prices alone can explain the divergence in VMT per adult.

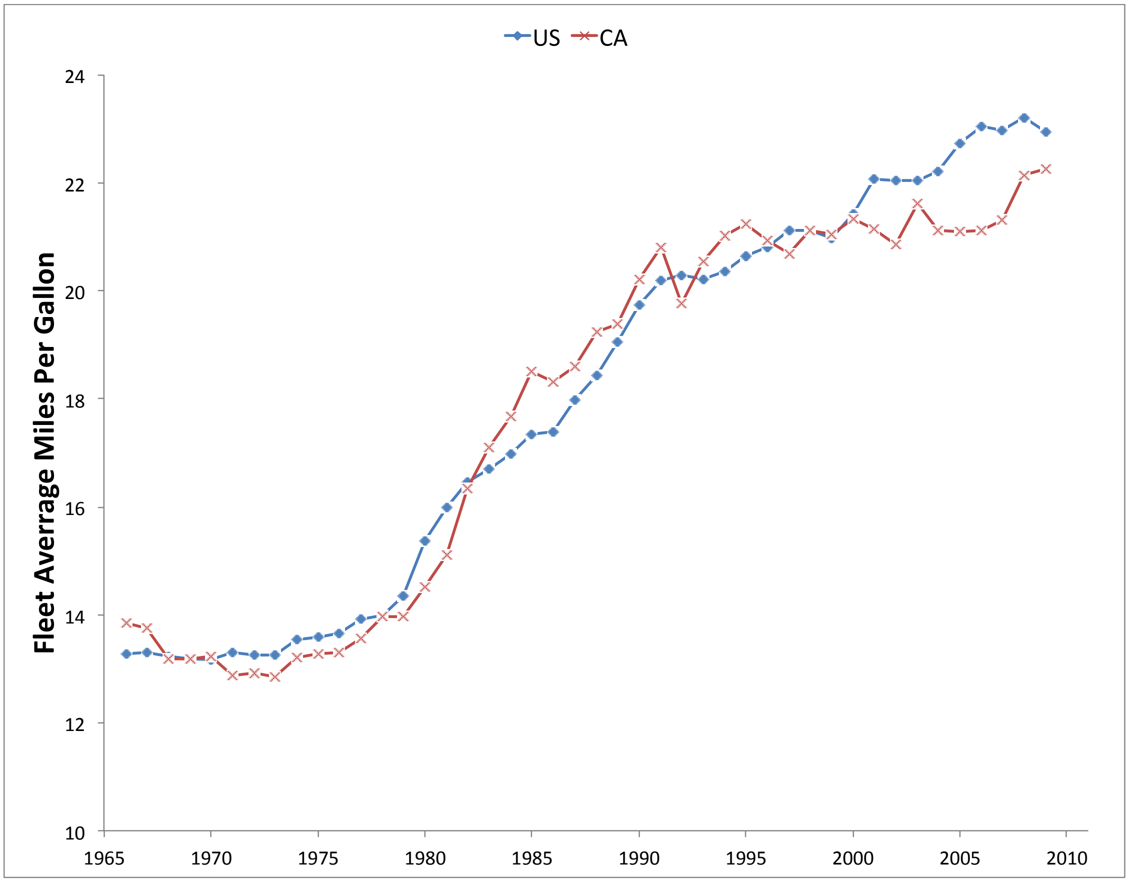
Figure 10: Monthly real gasoline prices (1998 - 2011)



Source: Energy Information Administration and California Energy Almanac

Although fuel prices do play a large role in driving behavior, other closely related variables are also important. First, average fleet fuel economy (measured in miles per gallon) in California in recent years has actually been lower than the nationwide average as shown in Figure 11. Hence, even if gasoline prices were the same in California and the rest of the United States, it would cost Californians more to drive on a per-mile basis.

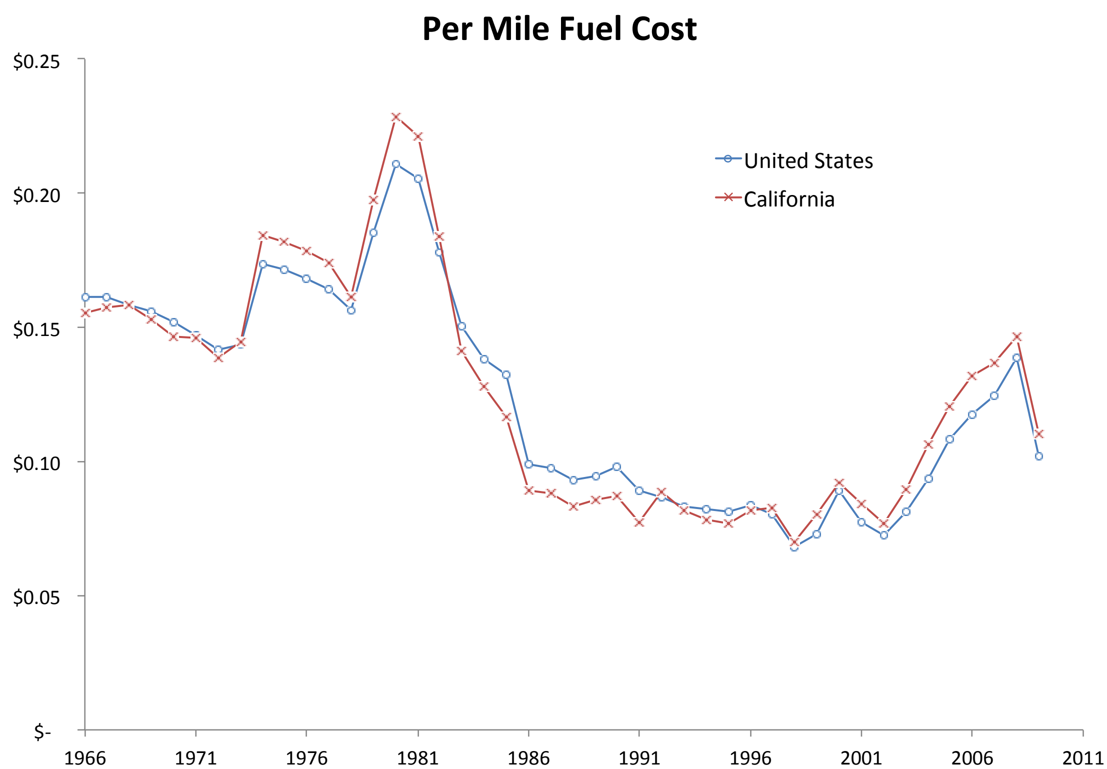
Figure 11: Fleet fuel economy (1966 - 2011)



Source: Energy Information Administration

Using both fuel price trends and fleet fuel economy trends, Figure 12 depicts the trends in per-mile fuel cost, which is equal to the fuel price per gallon divided by fuel economy (measured in miles per gallon). In most years, Californians have had a higher per-mile fuel cost. Although the short run effect of the higher costs on VMT may be small, behavioral changes tend to take longer to manifest. So it may not be easy to observe the effects of higher fuel costs simply by comparing graphical trends. The next section explores these relationships more rigorously using regression analysis.

Figure 12: Per-mile fuel costs (1966 - 2011)



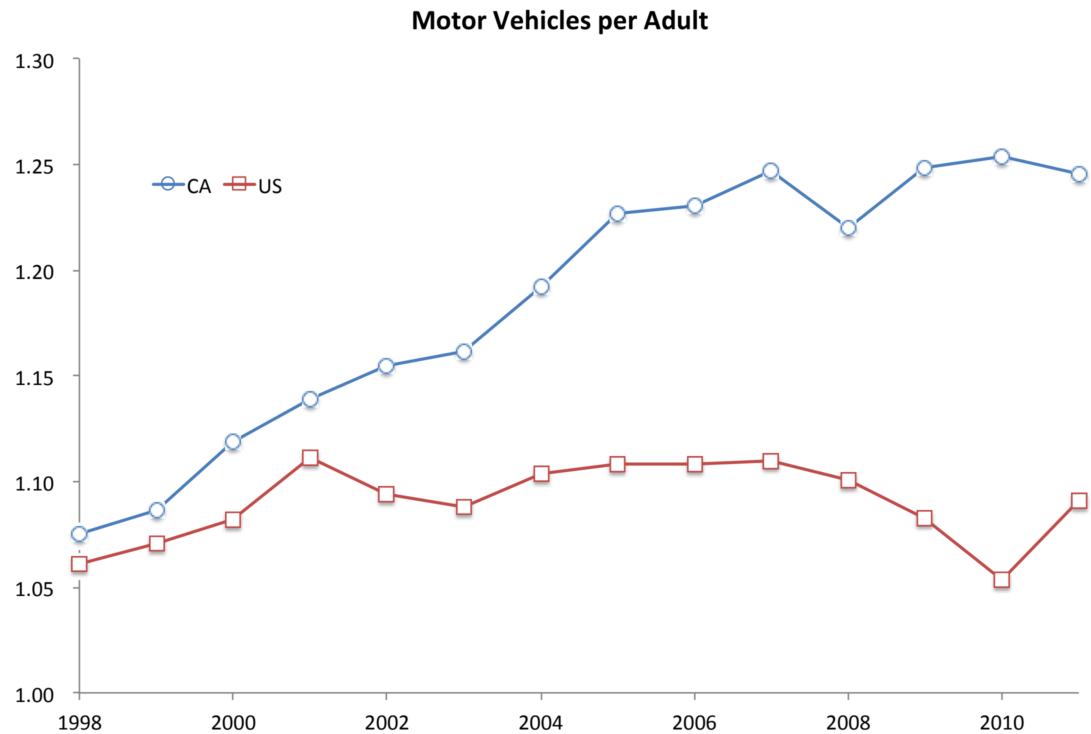
Source: Annual Highway Statistics Publications (FHWA) and Energy Information Administration

Motor Vehicle Registrations and Licensing

Besides macroeconomic variables and fuel prices, other transportation related variables might have caused vehicle usage to decline in recent years. One popular explanation is that Americans (especially the young) are beginning to rely less on vehicles, especially because smartphones and social media have made it easier to connect with peers. Although that may be partially true, it still does not explain how people are still able to commute, shop, or undertake leisure activities. This subsection analyzes the extent to which people have abandoned the automobile by looking at vehicle registration and licensing data.

Figure 13 below plots the number of motor vehicle registrations per adult for California and the United States. It is clear the level and growth rate of motor vehicle registrations per adult in California has outpaced the US as a whole. Furthermore, for both groups the number of automobiles exceeds the number of adults. It is not surprising that California's adults own more vehicles than average: this state's level of wealth is higher than many other states. Also, the fact that there are more automobiles in the United States than adults suggests that increases in the vehicle stock may not necessarily lead to increases in vehicle miles traveled. Instead, it suggests that a larger number of vehicles per adult allow households to alternate vehicles by purpose (e.g., commuting versus hauling a boat). Similarly, a larger vehicle stock per adult also allows households to switch to a more fuel-efficient vehicle when fuel prices are high. Hence it is not immediately clear that motor vehicle registrations should be correlated with vehicle miles traveled.

Figure 13: Vehicle stock (1998 - 2011)



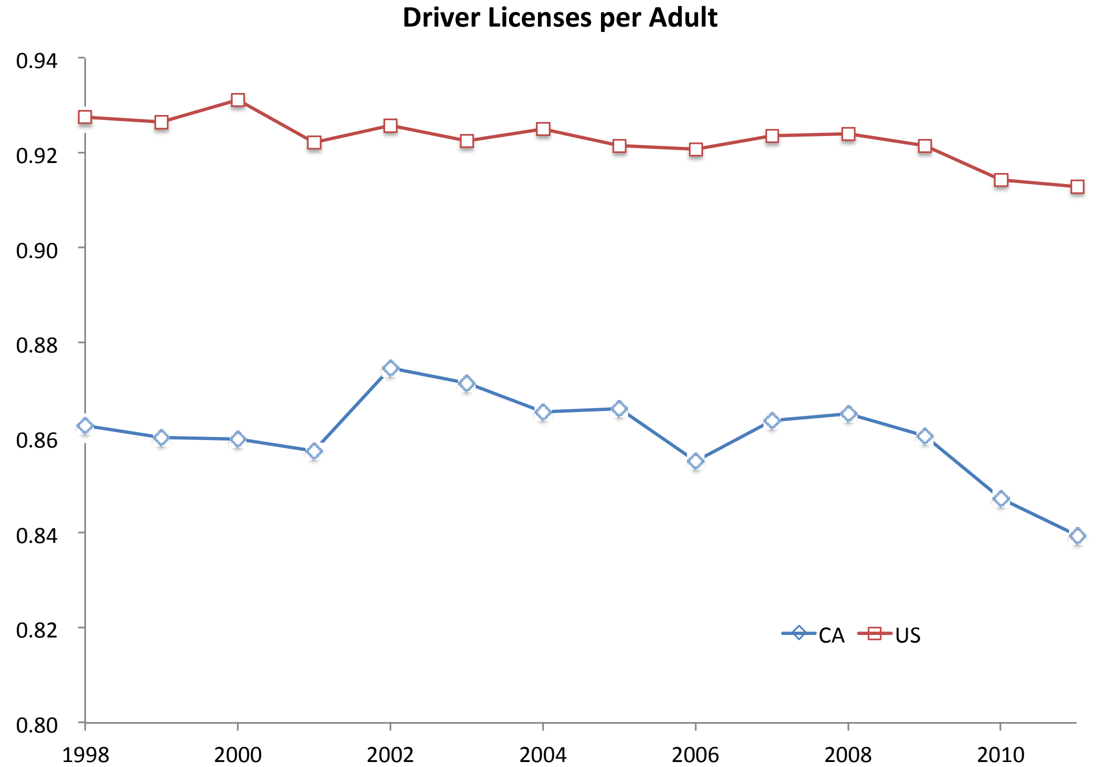
Source: Annual Highway Statistics Publications (FHWA)

The number of driver licenses per adult in California may also help explain the divergence of vehicle usage trends. One would expect that states with more licensed drivers per capita would drive more than the national average. Figure 14 below displays the number of licensed drivers per adult in California and the United States. It is immediately clear from the plot that Californians are less likely to be licensed than their nationwide counterparts. In the United States approximately 92% of adults were licensed in 2011, while only 84% of Californians were licensed in 2011.

The data, however, does not describe which groups of individuals are less likely to be licensed. Census data indicates that California has a relatively low percentage of elderly individuals (those aged 65 or older) compared to the United States: the figures are 11.4% and

13.0% respectively. Hence, it is less likely that the aging population in California (who presumably are less likely to be licensed) accounts for the difference in licensing rates.

Figure 14: Driver licenses (1998 - 2011)

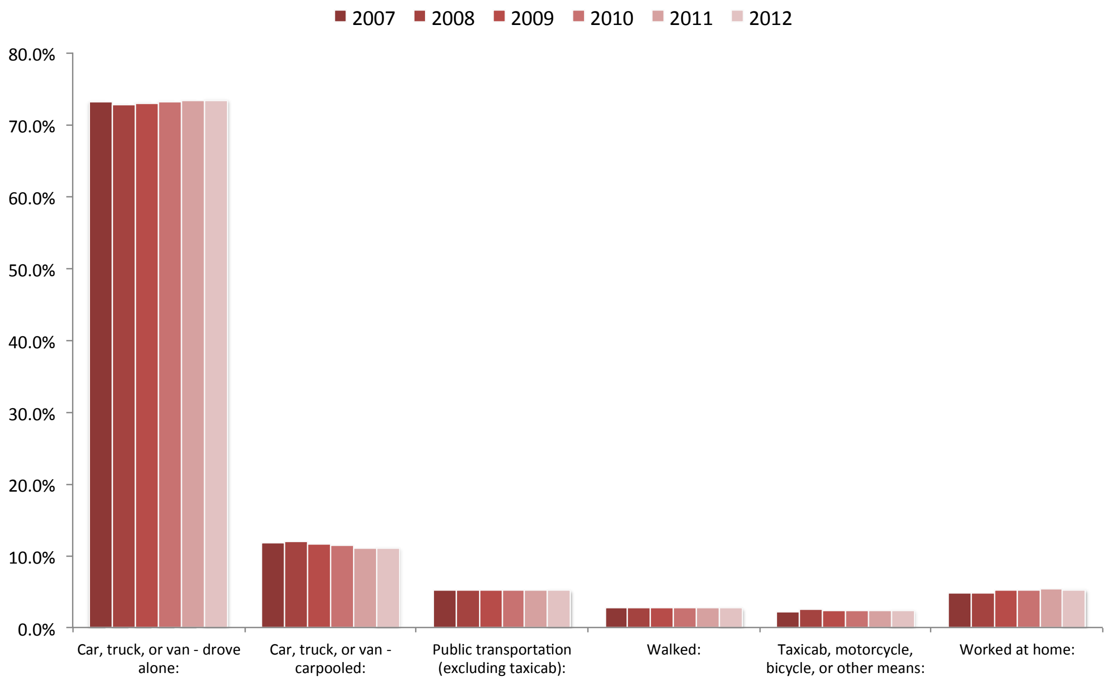


Source: Annual Highway Statistics Publications (FHWA)

Mode Share

The evidence presented thus far has demonstrated that VMT per adult has declined in recent years and several factors seem to be correlated with the decline. This subsection presents travel mode share data, which helps determine the extent to which transit, carpooling, biking, and telecommuting have substituted for vehicle trips. The first set of mode share data was drawn from the American Community Survey (ACS), which was developed by the US Census Bureau. The survey samples a random set of households nationwide and asks respondents a large variety of socioeconomic questions. The figures below show how the mode share split in California has evolved in recent years. Figure 15 presents the shares for all drivers in the sample, while Figure 16 restricts the attention to young drivers (less than 20 years of age). The column chart in Figure 15 shows that the automobile is the dominant form of transportation to work (roughly 70% of the total). Moreover, the share has slightly increased from 2007-2011. During the same time span carpooling has slightly declined, working from home has slightly increased, and the other mode shares have not significantly changed.

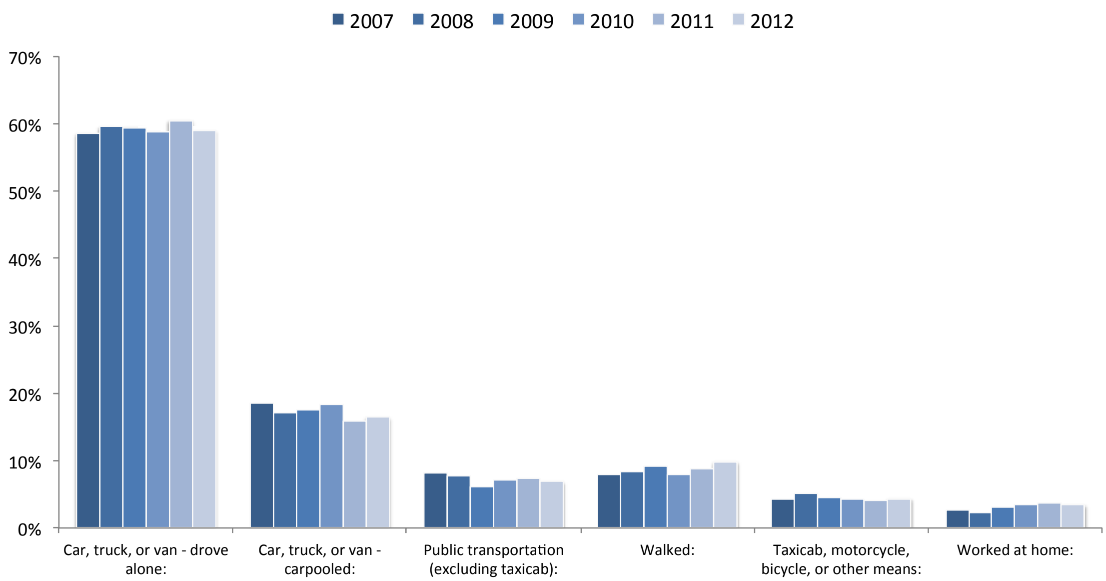
Figure 15: Mode shares (2007 - 2012)



Source: American Community Survey (US Census Bureau)

To examine whether or not young Californians have altered their mode of transport to work, Figure 16 presents mode share trends for drivers less than 20 years of age. The lack of meaningful changes in mode shares is consistent with that for all age groups: the evidence does not suggest that young commuters have abandoned the automobile.

Figure 16: Modes shares for drivers under 20 (2007 - 2012)



Source: American Community Survey (US Census Bureau)

One caveat, however, is that the American Community Survey only includes mode share data for commute trips to work. It may be the case that the mode shares for non-work related travel are different. Unfortunately the ACS does not provide this information.

An alternate source of data that includes all trips (both work and non-work related) is the decennial California Household Travel Survey (CHTS). This survey is directed by Caltrans and administered by NuStats, a private company. Over 40,000 individuals across California participated in the survey, and they provided detailed information about their daily travel behavior either through wearable GPS units or with a travel diary.

The CHTS mode shares from 2000-2001 and 2010-2012 are presented in Table 1 below. The survey results show that the fraction of automobile trips relative to the total declined by about 10 percentage points in the ten years between the two surveys, dropping from 86% to 75%. An increase in walking trips accounts for much of the difference as that mode share grew from 8.4% to 16.6%. Public transportation and bicycle trips also increased over the ten-year time period.

Table 1: CHTS mode shares (2000 - 2012)

	Mode Share	
Mode	2000-2001	2010-2012
Automobile Trips	86.0%	75.2%
Walk Trips	8.4%	16.6%
Public Transportation Trips	2.2%	4.4%
Bicycle Trips	0.8%	1.5%
All Other Trips	2.6%	2.3%
Total	100%	100%

Source: 2010-2012 California Household Travel Survey (Table 1.2.3)

By itself, this information is not sufficient to conclude that individuals are undertaking fewer automobile trips than they did in the past. Instead, the total number of trips may have increased, which would also increase the denominator in the mode share fraction. The results in Table 2 support that assertion: the number of trips per person and per household increased between the 2000-2001 and 2010-2012 surveys. Nevertheless, the number of weekday driver trips per household (i.e., by automobile) did decrease over that same time period by about one trip per day. Together, this evidence suggests that two changes were taking place over this time period. First, there was a substantial increase in the total number of non-automobile trips (especially walking trips). Second, the number of driver trips per household decreased, but not by a margin large enough to account for the overall decrease in automobile trip mode share.

Table 2: CHTS total trips (2000 - 2012)

	All trips		Weekday driver trips
	per person	per household	per household
2000-2001 CHTS	3.0	7.9	5.9
2010-2012 CHTS	3.6	9.2	5.0

Source: 2000–2001 California Household Travel Survey (Table 11) and 2010-2012 California Household Travel Survey (Table 1.2.2)

4. ECONOMETRIC RESULTS

Section 2 documented vehicle usage trends for California and compared them to the national trends. Across time, the vehicle miles traveled per adult trend in California largely mirrored the overall US trend. But the trendlines diverged beginning in the early 1990s and Californians now drive fewer miles on average than other Americans. Furthermore, Section 3 presented evidence that vehicle miles traveled per adult in California are correlated with other factors. In particular, the charts suggested that trends in unemployment and income were correlated with VMT per adult. The charts and tables are suggestive and persuasive, but are not sufficient to capture the complex relationships between VMT and its determinants. This section presents the results from a more rigorous approach using linear regression analysis.

To explain trends in aggregate vehicle miles traveled per adult, two regression models were employed. The first model explains how various factors influence vehicle miles traveled per adult at the national level over time. The second model, estimated only with California data, examines California-specific vehicle usage trends. Results from various specifications of these two models quantify the separate effects of different variables on VMT per adult. For more complete descriptions of the models and the underlying econometric methods, refer to Small and Van Dender (2007), Hymel et al. (2010), and Hymel and Small (2013).

For the nationwide model, the unit of observation in the data is a given state in a given year, which is observed across time from 1966-2011. The macroeconomic, spatial, and demographic data used to estimate the model come from a variety of sources and are described in Appendix A. For the California-specific model, vehicle miles traveled and its determinants are observed annually from 1966-2011. The regression results help explain the decline in vehicle miles traveled per adult observed in the last decade. Furthermore, the nationwide and California-specific results will be compared to determine why VMT per adult in California is lower than in other states.

One item to note about the empirical results presented below is the manner in which the variables are entered into the regression equations. Most variables are entered into the equations as natural logarithms. For such variables, the interpretation of the regression coefficients takes on a special meaning, and in economic terminology they are referred to as “elasticities”. Not only does the log transformation improve the precision of the estimated coefficients, it also greatly simplifies the *interpretation* of the coefficients.

An elasticity is simply a unit-free measure of the strength of the relationship between two variables. Specifically, an elasticity measures the percentage change in the value of variable Y that would follow a given percentage change in the value of variable X. For example, if variables X and Y are both measured in natural logarithms, the coefficient from a linear regression of Y on X (and perhaps other covariates) is a measure of the elasticity of variable Y with respect to variable X.

$$\text{Elasticity}_{Y,X} = \frac{\%\text{ change in } Y}{\%\text{ change in } X} = X's \text{ regression coefficient}$$

One of the most important elasticities examined below is the *per-mile* fuel cost elasticity of vehicle usage. The estimated value of this elasticity measures the percentage change in vehicle miles traveled per adult that would follow a given percentage increase in the per-mile fuel cost.

In addition, many of the variables thought to influence vehicle usage patterns have effects that persist for periods of time longer than one year. Thus the regression models also include terms that capture slow-changing behavioral effects, allowing one to measure both short-run (one year) and long-run elasticities. For example, vehicle use tends to respond relatively slowly to changes in fuel prices in the short run: drivers are relatively inflexible in altering their behavior. But in the long run, drivers have more freedom to change their vehicle, residence, workplace, or mode of transport in response to a sustained increase in fuel prices. In the discussion below, both short-run and long-run elasticities will be discussed.

Nationwide Results

Overall, the nationwide regression results indicate that most of the variation in VMT per adult can be explained by the independent variables: the estimated R-squared values are above 0.98 across all specifications. This statistic indicates that the regression model explains more than 98% of the variation in vehicle miles traveled per adult. Moreover, the regressions employ instrumental variables, an econometric technique which allows one to view the regression coefficients as having *causal* effects. Whereas the correlations presented in Section 3 above do not provide causal evidence. The regression tables from which the results are derived are presented in Appendix B.

Fuel Prices

The nationwide regression results show that increases in fuel prices tend to decrease VMT per adult. The short-run elasticity of VMT per adult with respect to fuel price is equal to -0.057 and is statistically significant. This estimate indicates that in the short-run (i.e., in one year) drivers are not very sensitive to changes in fuel prices. For example, if fuel prices were to double (a 100% increase), we would only expect vehicle miles per adult to fall by 5.7% percent. Nevertheless, even small reductions in vehicle miles traveled can substantially reduce traffic congestion.

Moreover, although the short-run fuel price elasticity is relatively small, the long-run elasticity is approximately six times larger and is estimated to be -0.343. The explanation for this result follows logically from the earlier discussion and is in accord with microeconomic principles (i.e. elasticities are typically larger in the long run than in short run). With regard to vehicle usage, drivers have much more flexibility in choosing their mode of transport, their decision to join the labor force, and their residential and workplace locations in the long run.

So although the short-run elasticities may seem small, their long run counterparts are not trivial, and indicate that fuel price changes can have substantial impacts on driving behavior.

Another closely related measure is the per-mile fuel cost of driving, which takes into account the fact that the marginal cost of driving is based on both fuel prices and vehicle fuel economy. Thus, the per-mile fuel cost of driving is:

$$\frac{dollars}{mile} = \frac{dollars}{gallon} \times \frac{gallons}{mile}$$

Note that gallons per-mile is commonly referred to as fuel intensity, which is the reciprocal of fuel efficiency.

The elasticity of VMT per adult with respect to the per-mile fuel cost also has a special interpretation; it measures the responsiveness of drivers to changes in vehicle fuel economy. Although technological improvements and regulations can make automobiles more fuel-efficient, they also reduce the per-mile cost of driving. And when the cost of driving decreases, the incentive to drive increases. So the indirect effect of fuel economy improvements actually tends to increase vehicle miles traveled. The elasticity of VMT per adult with respect to the per-mile fuel cost of driving is estimated to be -0.047. Thus, a 100% decrease in fleet fuel-intensity (gallons per mile) would lead to a 4.7% increase in vehicle miles traveled per adult in the short run and a 28.2% increase in the long run. This so-called “rebound effect” has important consequences for predicting future levels of VMT, as the Corporate Average Fuel Economy standards will rise significantly in the coming decade. The implications of this finding are further discussed in Section 5 below.

This result, however, comes with several caveats. First, the elasticity tells us the expected *average* change in driving that would follow an increase in per-mile fuel costs. This average pertains to all of the states and all of the years in the sample. But the effect of per-mile fuel costs on driving may vary substantially across individuals and across time. To address this issue, the regression model also includes so-called "interaction terms". The regression coefficients of these interaction terms have a special interpretation: they tell us the degree to which the per-mile fuel cost elasticity of VMT *itself* varies with other factors.

Based on the interaction term coefficients, the results show that drivers are *more* responsive to rising per-mile fuel costs when fuel costs are already high, and are *less* responsive to rising per-mile fuel costs when incomes are high. The interpretation of these findings is as follows. A driver's reaction to fuel cost changes depends on the fraction of the total cost of driving currently accounted for by fuel costs.[2] Thus, we would expect that the fuel-cost elasticity of VMT would increase with fuel costs and would decrease with income. To explain, as one's income rises, the opportunity cost of a driver's time also rises, making the total cost of driving a mile greater. Thus the fuel-cost fraction of the total cost of driving decreases making individuals less responsive to fuel prices. For a theoretical explanation of this phenomenon, see Greene (1992).

There are also psychological factors at play: when fuel prices eclipse historical peaks, newspapers and other media tend to draw drivers' attention to the high prices. Research by Hymel and Small (2013), find evidence for this type of behavior; they find that, holding fuel prices constant, intense media coverage of price hikes tends to decrease vehicle miles traveled.

[2] The total cost of driving a mile includes time costs, wear and tear, tolls, etc.

Macroeconomy

In addition to the effect of fuel prices, other factors included in the regression model help explain nationwide driving behavior. In terms of macroeconomic variables, per capita income is seen to have a positive and strong effect on driving behavior. The estimated income elasticity is equal to 0.08, meaning that doubling per capita incomes would increase VMT per adult by 8% in the short run and by 48% in the long run. This finding is not surprising as higher incomes allow drivers to make more discretionary trips. Similarly, higher income states tend to have more economic activity and would thus also be expected to have more industrial, retail, and service related trips.

The regression results also suggest that rising state unemployment levels decrease vehicle miles traveled per adult. A one percentage point increase in the unemployment rate, leads to a modest 0.1% decrease in VMT per adult. The explanation for this result is straightforward: commuting accounts for a large fraction of the total number of miles people drive. So when unemployment rates increase, commuting naturally declines. Note that the effect of unemployment on VMT is smaller than the effect of income. The rationale for the difference stems from the fact that rising income per capita tends to affect a large segment of the population. But decreases in unemployment tend to affect a relatively small fraction of the population: in recent years the unemployment rate in California has ranged from roughly 7 to 12 percent.

Transportation

The effects of other transportation-related factors were also examined. The regression model includes variables that measure the degree of traffic congestion, the availability of transit, and the size of the vehicle stock. First, congestion is measured as the number of adults in a given state divided by the number of highway lane miles, which is the best available measure of congestion for the full sample (1966-2011). The estimated elasticity of vehicle miles traveled with respect to the level of congestion is 0.015, meaning that doubling (100% increase) the number of adults per highway lane mile (measured across an *entire* state) would reduce VMT per adult on all roads by 1.5% in the short run and by 9.1% in the long run. The effect of an increase in adults per road-mile would be substantially higher in urban areas. Although this model accounts for traffic congestion and highway capacity in a simple way, similar results using superior congestion measures have been documented in the literature. (Noland 2001; Hymel et al. 2010).

The availability of transit in a given state is measured as the fraction of a state's population that resides in a metropolitan area with access to light or heavy rail. The estimated elasticity of VMT per adult with respect to the transit variable is negative (-0.007) as expected, but is so small as to be statistically and economically insignificant. Unfortunately, more reliable state-by-state transit measures are not available for all years in the sample (1966-2011).

Demographics

To address demographics, the nationwide regression model includes a measure of family size within each state. That variable is measured as the total state population divided by the number of adults (18 and over) in the state. The results suggest that VMT per adult is higher in states where adults are responsible for a greater number of minors. The estimated elasticity is equal to 0.07, meaning that doubling the ratio of the total population relative to the adult population would increase vehicle miles traveled by 7% in the short run and by 42.2% in the long run. The consequences of predicted demographic changes will be discussed further in Section 5.

In sum, the nationwide regression model does a good job of explaining variability in vehicle miles traveled per adult. The estimated coefficients have the expected signs and are generally statistically significant. Later, these nationwide estimates will be compared to estimates from California to examine the factors that may be responsible for the divergence in vehicle miles traveled per adult since the year 2000.

California-Specific Results

To examine the factors underlying vehicle usage in in California, a regression model similar to the one described above was estimated using only California data. Because the sample size for the California-specific model is much smaller, a more parsimonious set of explanatory variables was included. Nevertheless, most of the coefficients are still precisely estimated and the value of R-squared is above 0.99 across all model specifications.

Rising fuel prices decrease vehicle miles traveled per adult in California. The estimated short-run elasticity is equal to -0.11, the long-run elasticity is equal to -0.16 and both are statistically significant. Similarly, the per-mile fuel cost variable in the California model is also negative, statistically significant, and is approximately equal to -0.12. Again, this figure indicates that decreasing fleet fuel-intensity by 100% would lead to a 12% increase in vehicle miles traveled per adult in the short run. This model also included a set of interaction variables, which are described in the previous subsection. The California results are similar to the nationwide results. The regression estimates suggest that the effect of rising fuel costs is greater when fuel costs are already high, and that the effect of rising fuel costs on VMT per adult diminishes when incomes are higher.

In addition to fuel cost related variables, macroeconomic variables were also found to be important determinants of VMT per adult. Increases in per capita income and decreases in the unemployment rate are positively related to VMT per adult. The estimated income coefficient can be interpreted as an elasticity, and the results suggest that a 100% increase in income leads to a 30% increase in VMT per adult in California in the short run. The unemployment coefficient, which is not entered in log form, has a slightly different interpretation. The unemployment coefficient suggests that a one-unit (i.e., one percentage point) increase in the unemployment rate decreases VMT by 0.8% in the short run. The magnitude of income's effect on driving is substantially larger than the effect of unemployment as expected. Again, the explanation for this finding is that the unemployed make up a relatively small portion of the population. So an increase in unemployment would impact mostly those who lose their jobs. Aggregate income increases on the other hand impact a larger portion of the population and more strongly impact vehicular travel.

Comparing California and US Estimates

This subsection compares results derived from the nationwide model and the California-specific model. The goal is to find evidence for the observed differences in vehicle travel trends. Table 3 below shows select elasticities from the nationwide and California-specific models presented in the previous two subsections.

Table 3: Elasticity comparison US and CA

	US Model	CA Model	US Model	CA Model
Time Period	1966-2011	1966-2011	2000-2011	2000-2011
Short run elasticity				
Per-mile fuel cost	-0.047	-0.122	-0.028	-0.099
Per capita income	0.078	0.314	0.078	0.314
Unemployment	-0.001	-0.008	-0.001	-0.008
Lagged VMA	0.835	0.350	0.835	0.350
Long run elasticity				
Per-mile fuel cost	-0.295	-0.188	-0.178	-0.152
Per capita income	0.472	0.483	0.472	0.483
Unemployment	-0.009	-0.009	-0.009	-0.009

Beginning with the fuel cost elasticities, the results suggest that Californians and other Americans differ in their responsiveness to rising fuel costs. The estimates indicate that Californians are almost three times more responsive to short-run changes in fuel cost than other Americans: the corresponding US and CA elasticities are -0.047 and -0.122 respectively. In the bottom panel of Table 3, however, the long-run fuel cost elasticity is somewhat smaller in California, which implies that Californians are less responsive to sustained increases in fuel costs over a period of many years.

The regression results also indicate that nationwide, drivers have become less responsive to rising per-mile fuel costs over time. Between years 2000 and 2011 the estimated short-run per-mile fuel cost elasticities are indeed smaller; they equal -0.022 for the US and -0.099 for California.[3] The increased responsiveness of Californian's to higher fuel costs helps explain the observed divergence in vehicle miles traveled between California and the rest of the

[3] The regression model was specified so that the estimated effects of income and unemployment were constant across time.

nation. Fuel prices sharply increased in real terms beginning in 1998, continuing to rise until the great recession. And because Californian's are more responsive to such increases, they curtailed vehicular travel more relative to the rest of the nation.

Also, note that relative to the rest of the nation, Californian's are much more responsive to changes in unemployment and income. The effects of unemployment and per capita income on VMT per adult are 8 and 4 times higher in California respectively. Moreover, California's unemployment rate has been higher than the national rate since 1990, which also helps explain the divergence in VMT per adult trends.

5. SUMMARY OF FINDINGS AND DISCUSSION

This report presented robust statistical evidence that personal income, family size, and fuel-costs are strong determinants of vehicle miles traveled per adult nationwide and in California. Other factors also influence vehicle miles traveled, but more weakly. Those factors are the unemployment rate and the availability of transit. Because it is difficult for drivers to quickly change their residence, workplace, or type of vehicle, the effects of these factors on VMT are relatively small in the short run (i.e., one year). Over the long run, however, the effects of these factors are much larger. Together, these findings help explain the decline in vehicle miles traveled per adult over the last decade.

Per gallon fuel prices and per gallon fuel costs play a large role in determining vehicle miles traveled per adult. Moreover, the responsiveness of Californians to rising per-mile fuel costs has important policy implications. California's Advanced Clean Cars program and the tightening of federal fuel efficiency standards (CAFE) will substantially increase the average fuel economy of California's vehicle stock in the coming decade, thereby making it less expensive to drive on a per mile basis. The CAFE standards for new passenger cars and light trucks call for approximately a 41% decrease in fuel intensity (measured in gallons per mile) by 2025. The results presented here predict that a 100% decrease in fleet fuel intensity will lead to a 15.2% increase in annual vehicle miles traveled per adult in the long run. The current condition of California's highway infrastructure will not be able to handle the increase in travel and will lead to increasing congestion and deterioration of roads. Moreover, if gasoline taxes are not tied to inflation, revenues will decline, thereby diminishing the State of California's ability to fund infrastructure improvements.

Slow income growth in recent years also helps explain the decline VMT per adult. Although income per capita has steadily grown, median incomes have not. Only a small portion of the population has realized much of the income gains and inequality has risen. Thus, rising per capita incomes have not benefitted lower or middle-income households, which represent the vast majority of drivers. In real terms, median household incomes have decreased from $62,241 to $54,482 (measured in 2011 dollars). That decrease combined with the strong degree of correlation between median household income and VMT per adult in California, helps explain much of the observed decline in vehicle usage.

Increases in the availability of public transit were also found to reduce vehicle miles traveled per adult. The magnitude of the effect, however, was very small and cannot explain the decline in vehicle miles traveled. Use of public transit in California did increase in the last decade: between 2000 and 2011 passenger miles per adult rose from 246.1 to 255.0. That increase, however, was dwarfed by the magnitude of the decrease in vehicle miles traveled per adult, which dropped from 12,410 to 11,742 over the same time period. Furthermore, the

American Community Survey and the California Household Travel survey also showed that automobile mode shares have barely changed in the last decade.

Together, the statistical evidence also helps explain the divergence of vehicle miles traveled per adult in California from the nationwide trend in recent years. Californians are more likely to be unemployed, experience more income inequality, are less likely to be licensed, are more responsive to fuel price increases, drive less fuel-efficient vehicles, and are less flexible altering their driving behavior in the long run.

Although vehicular travel declined between 2005 and 2011, the most recent evidence indicates that vehicle miles traveled is bouncing back. According to the FHWA's Highway Statistics publications, VMT per adult in California increased by 0.4% between 2011 and 2012. Similarly, the FHWA's Traffic Volume Trends indicate that total vehicle miles traveled increased by 1.5% between 2012 and 2013 in California. These recent observations are not sufficient to determine whether or not the declining VMT per adult trend has reversed. But an increasing population will likely increase total vehicle miles traveled in the State. Indeed, the Energy Information Administration forecasts annual VMT growth of 0.9% for light-duty vehicles and annual growth of 1.8% for heavy trucks between 2014 and 2040. Currently, the US population growth rate is 0.7% and is projected to decline. Together, these trends suggest that vehicle miles traveled per capita is likely to rise in the future.

6. POLICY RECOMMENDATIONS

Increasing VMT presents challenges for California. The structure of the gasoline excise tax will erode the real monetary value of tax revenues over time as inflation increases. Also, increasing VMT will exacerbate already severe levels of traffic congestion. In light of these predicaments, the research in this report supports four key policy recommendations. The recommendations below pertain to three broad transportation policy objectives: revenue generation, system efficiency, and economic equity. Each of the recommendations addresses one or more of the objectives.

1. Adjust the gasoline excise tax rate for inflation

Because California's gasoline excise tax is not directly tied to inflation, tax revenue in real terms will decline as the overall price level increases. Under the revenue-neutrality requirements of AB x8-6, the Board of Equalization can vote to raise gasoline excise taxes to maintain stable revenues. So to maintain the purchasing power of the tax revenue, the Board of Equalization should also adjust rates annually to account for inflation. Also note that due to the revenue-neutrality requirement, rising fuel efficiency of California's vehicle stock will *not* reduce total gasoline tax revenue even though it will reduce gasoline consumption. Furthermore, under the so-called *user-pays principle*, the gasoline tax is preferable – it targets the larger and less fuel-efficient vehicles that cause a disproportionate amount of road damage and pollution.

2. Implement congestion pricing

Severe traffic congestion plagues metropolitan areas across the state. Increased use of congestion pricing will lead to more efficient use of scarce roadway capacity during peak travel periods. Economic and political impediments (e.g., costs and rights-of-way) hamper highway expansions. So in the short run, the State should promote further development of dynamically-priced managed lanes, which impose tolls on only part of a multi-lane facility.

Examples of such facilities include those on I-10 in Los Angeles and on I-680 in Alameda County. In the long run, the State should seek to connect individual managed lanes into a connected network of lanes. Again, under the user-pays principle, toll revenues should be dedicated to finance the maintenance and expansion of existing managed lanes.

3. Investigate mileage-based taxes

Existing managed lane facilities in California are limited to major freeways and do not reduce high levels of traffic congestion on California's arterial streets. The state should conduct research into mileage-based taxes that vary with traffic congestion or the time of day. Static mileage-based taxes are easier to implement and collect, but encourage drivers to avoid peak traffic periods. The technology behind mileage-based taxes exists, but more needs to be done to increase understanding of such a system. Public support of mileage-based taxes is currently low, so research would help allay privacy concerns and educate Californian's about the virtues of such a system.

4. Invest in public transportation

Most research – including this report – finds that investing in public transportation does little to reduce personal vehicle travel. Although new buses and trains will take some drivers off of the road, increased public transportation does not reduce the marginal cost of driving. Hence, latent demand for vehicular travel will increase, even as drivers switch modes of transportation.

But increasing the gasoline tax and implementing congestion pricing will create winners and losers, and may disproportionally impact low-income drivers. To counter the possible regressivity of gasoline taxes and tolls and to promote fairness, the state should invest more in public transportation. Such investment would lower commuting costs and would increase access to employment centers.

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APPENDIX A – DATA SOURCES

Adult population
Definition: midyear population estimate, 18 years and over US Census Bureau

Corporate Average Fuel Economy Standard (Miles Per Gallon)
National Highway Traffic Safety Administration (NHTSA), CAFE Automotive Fuel Economy Program, Annual update 2009, Table I-1

Consumer price index – all urban consumers
Bureau of Labor Statistics (BLS), CPI (1982–1984 = 100) Note: all monetary variables (gas tax, new passenger vehicle price index, price of gasoline, personal income) are put in real 1987 dollars by first deflating by this CPI and then multiplying by the CPI in year 1987.

Highway Use of Gasoline (millions of gallons per year)
1966–1995: FHWA, Highway Statistics Summary to 1995, Table MF-226 1996–2009: FHWA, Highway Statistics, annual editions, Table MF-21

Income per capita ($/year, 1987 dollars)
Primary measure: Personal income divided by midyear population Personal income is from Bureau of Economic Analysis (BEA)

Interest rate:
National average interest rate for auto loans (%) Definition: average of rates for new-car loans at auto finance companies and at commercial banks Source: Federal Reserve System, Economic Research and Data, Federal Reserve Statistical Release G.19 ‘‘Consumer Credit”. Available starting 1971 for auto finance companies, 1972 for commercial banks. For earlier years in each series, we use the predicted values from a regression explaining that rate using a constant and Moody’s AAA corporate bond interest rate, based on years 1971–2004 (finance companies) or 1972–2004 (commercial banks)

New Car Price Index:
Price index for US passenger vehicles, city average, not seasonally adjusted (1987 = 100) Source: Bureau of Labor Statistics web site Note: Original index has 1982–84 = 100

Number of vehicles:
Number of automobiles and light trucks registered 1966–1995: FHWA, Highway Statistics Summary to 1995, Table MV-201 1996–2004: FHWA, Highway Statistics, annual editions, Table MV-1 Note: ‘‘Light trucks” include personal passenger vans, passenger minivans, utility-type vehicles, pickups, panel trucks, and delivery vans

Price of gasoline (cents per gallon, 1987 dollars)
Data Set A: US Department of Energy (US DOE 1977), Table B-1, pp. 93–94 (contains 1960–1977)

Data Set B: Energy Information Administration, State Energy Data 2000: Price and Expenditure Data, Table 5 (contains 1970–2000)□2001–2004: Energy Information Administration, Petroleum Marketing Annual, Table A1□
Note: We use Data Set B for 1970–2000, and for the earlier years we use predicted values from a regression explaining Set B values for overlapping years (1970–1977) based on a linear function of Set A values

Public lane mileage:
Total number of lane miles in state□1980–1995: FHWA, Highway Statistics Summary to 1995, Table HM-220 1996–2004: FHWA, Highway Statistics, annual editions, Table HM-20

Number of Licensed Drivers□
1966–1995: FHWA, Highway Statistics Summary to 1995, Table DL-201□1996–2004: FHWA, Highway Statistics, annual editions, Table DL-1C□Notes: Some outliers in this series were replaced by values given by a fitted polynomial of degree 3

Urbanization:
Share of total state population living in Metropolitan Statistical Areas (MSAs), with MSA boundaries based on December 2003 definitions. Available starting 1969; for earlier years, extrapolated from 1969 to 1979 values assuming constant annual percentage growth rate. Source: Bureau of Economic Analysis, Regional Economic Accounts

VMT (vehicle miles traveled), in millions□1966–1979:
FHWA, Highway Statistics, annual editions, Table VM-2 1980–1995: FHWA, Highway Statistics Summary to 1995, Table VM-202 1996–2004: FHWA, Highway Statistics, annual editions, Table VM-2.

Rail Transit Availability Index
Definition: Fraction of the state's population living in metropolitan statistical areas with a subway or heavy rail transit system.
Source for existence of rail by metro area: American Public Transportation Association (APTA). http://www.apta.com
Source for population by Metropolitan Statistical Areas: *Statistical Abstract of the United States*, section on "Metropolitan Statistics", various years.
Note: Data are missing for years 1969, 1971, 1974, 1979, 1981, 1982, 1989; for those years I interpolate between the nearest available years.

APPENDIX B – REGRESSION RESULTS

Table 4: Descriptive statistics, nationwide sample

Variable	Mean	Std. Dev.	Min	Max
VMT per adult (000)	11.16	2.67	4.75	24.11
Vehicles per adult	1.01	0.19	0.45	1.74
Fuel intensity (gal/mile)	0.06	0.01	0.03	0.09
Price of fuel (dollars/gal)	1.08	0.23	0.60	1.95
Fuel price per mile (cents/mile)	6.62	2.29	2.78	14.20
Income per capita (000)	14.94	3.50	6.45	30.76
Lane miles per adult	0.08	0.09	0.00	0.77
Road miles per sq. mile of land area	2.09	2.71	0.01	25.01
State population per adult	1.41	0.09	1.23	1.74
Fraction of population living in MSA	0.71	0.19	0.29	1.00
Licensed drivers per adult	0.91	0.08	0.60	1.17

Table 5: Nationwide model estimates

	Model US.1	Model US.2	Model US.3	Model US.4
	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)
Intercept	1.5797 (15.331)	1.6261 (15.916)	1.6293 (15.514)	1.6266 (15.723)
Income per adult*	0.0738 (6.316)	0.0781 (6.666)	0.0702 (5.912)	0.0737 (6.205)
Adults per road mile*	-0.0133 (-3.482)	-0.0149 (-3.941)	-0.0135 (-3.486)	-0.0143 (-3.763)
Population per adult*	0.0316 (1.008)	0.0726 (2.255)	-0.0217 (-0.6)	0.0287 (0.776)
Degree of urbanization	0.0387 (1.023)	-0.0205 (-0.526)	0.0390 (1.019)	-0.0223 (-0.566)
Availability of railroad	-0.0120 (-2.786)	-0.0067 (-1.556)	-0.0124 (-2.848)	-0.0064 (-1.474)
Dummy for 1974/1979	-0.0461 (-13.45)	-0.0439 (-12.829)	-0.0472 (-13.542)	-0.0448 (-12.837)
Trend	-0.0006 (-2.628)	-0.0004 (-1.614)	-0.0007 (-3.036)	-0.0005 (-2.15)
Lagged vehicle miles per adult*	0.8430 (82.862)	0.8346 (81.428)	0.8412 (81.456)	0.8372 (80.988)
Vehicle stock per adult*	0.0214 (3.113)	0.0209 (3.116)	0.0234 (3.355)	0.0230 (3.397)
Per-mile fuel cost*	-0.0449 (-15.331)	-0.0466 (-16.086)	-0.0417 (-13.246)	-0.0438 (-14.095)
Per-mile fuel cost squared*		-0.0124 (-2.088)		-0.0164 (-2.764)
Per-mile fuel cost* x income*		0.0528 (4.884)		0.0538 (4.948)
Per-mile fuel cost* x degree of urbanization		0.0119 (1.266)		0.0120 (1.263)
Unemployment rate			-0.0017 (-3.268)	-0.0014 (-2.804)
Rho	-0.0934 (-4.59)	-0.1018 (-4.989)	-0.0826 (-4.04)	-0.0959 (0.02)
Sample years	1966-2011	1966-2011	1966-2011	1966-2011
Sample size	2346	2346	2346	2346
R-squared	0.983	0.983	0.983	0.983
Adjusted R-squared	0.982	0.983	0.983	0.983
S.E. of regression	0.031	0.031	0.031	0.031
Durbin-Watson stat	1.949	1.949	1.944	1.944

Notes: Variables marked with an asterisk(*) are entered in log form, and their coefficients can be interpreted as elasticities. Variable rho is the autocorrelation parameter. The Trend variable is equal to 1 in 1966 and increases by one unit every year.

Table 6: California model estimates

	Model CA.1	Model CA.2	Model CA.3	Model CA.4	Model CA.5	Model CA.6
	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)	Coefficient (t-Statistic)
Intercept	4.4952 (6.474)	4.5763 (6.713)	4.1597 (6.005)	4.6159 (5.201)	6.6365 (7.574)	4.3067 (4.785)
Lagged vehicle miles per adult*	0.3593 (3.569)	0.3498 (3.526)	0.3243 (2.951)	0.3350 (2.589)	0.0484 (0.397)	0.3043 (2.145)
Per-mile fuel cost*	-0.1226 (-7.024)	-0.1224 (-6.739)		-0.1168 (-5.798)	-0.1250 (-6.05)	
Price of fuel*			-0.1097 (-5.266)			-0.1066 (-4.345)
Fuel intensity*			-0.2118 (-2.964)			-0.1878 (-2.478)
Per-mile fuel cost x income*		0.0893 (0.723)			0.1250 (0.874)	
Per-mile fuel cost squared		-0.0683 (-1.898)			-0.1288 (-3.485)	
Trend	0.0017 (1.378)	0.0015 (1.18)	0.0001 (0.059)	0.0060 (4.416)	0.0057 (1.776)	0.0051 (3.105)
Licenses per adult*	0.5589 (2.497)	0.5718 (2.596)	0.4959 (2.172)	0.7059 (2.867)	0.3312 (1.658)	0.6425 (2.566)
Per capita income*	0.3049 (3.565)	0.3138 (3.377)	0.3446 (3.748)			
Unemployment rate				-0.0042 (-2.036)	-0.0081 (-3.205)	-0.0048 (-2.166)
Rho	0.3439 (2.071)	0.5120 (3.281)	0.4205 (2.347)	0.3319 (1.827)	0.9023 (9.603)	0.3813 (1.952)
Sample years	1966-2011	1966-2011	1966-2011	1966-2011	1966-2011	1966-2011
Sample size	44	44	44	44	44	44
R-squared	0.990	0.991	0.990	0.988	0.991	0.988
Adjusted R-squared	0.988	0.989	0.989	0.986	0.989	0.986
Durbin-Watson stat	1.778	1.852	1.802	1.736	2.149	1.767

Notes: Variables marked with an asterisk(*) are entered in log form, and their coefficients can be interpreted as elasticities.
Variable rho is the autocorrelation parameter. The Trend variable is equal to 1 in 1966 and increases by one unit every year.