Essays in the Economics of Transportation Policy

By

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Abstract

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The following document presents three essays in the economics of transportation policy. The provision of transport infrastructure remains largely a government function and with the increase in population and vehicle ownership, travel demand management is increasing in scope. Policies aimed to reduce the negative externalities associated with travel, namely congestion and air pollution, have been increasing both on the federal and state levels.

In the aftermath of the 1970’s oil crises, government role in shaping vehicle fuel economy was considered essential. This paved the road to the Corporate Average Fuel Economy (CAFE) standards, which mark one major policy approach in transportation. However, in the early 2000’s U.S. fleet fuel economy was decreasing and it became clear that CAFE standards are not sufficient to encourage both the supply and demand for fuel-efficient vehicles. With the growing concerns over the impact of greenhouse gas (GHG) emissions on climate change and, together with the lack of regulatory action on the federal level, states sought to craft their own transportation policies that address these needs. California has been a leader in transportation policy that addresses vehicles’ GHG emissions and has paved the road for other states to adopt stringent environmental standards.

The first essay presents an analysis of California’s Clean Air Vehicle Sticker program, which provided single-occupancy privileges to hybrid vehicles on High Occupancy Vehicles (HOV) lanes. Such privileges have been granted by a few states with the goal of stimulating demand for hybrid vehicles. Using microdata of new vehicle sales, I investigate the effects of the program, giving special attention to the phases of its implementation. I find that the initial period of the program had the most effect on sales volume, and present evidence that vehicle prices increased during the second phase. Contrary to previous investigations I find that the program, on average, increased sales of hybrid vehicles by 20%. Furthermore, I show that the sales of vehicles not eligible for access rights were positively affected by the program.
The second essay surveys congestion pricing theory and policies in California. Congestion costs in California are substantial and increasing, leading the California legislature to explore the use of congestion pricing schemes to manage congestion in the state’s major metropolitan areas. I examine the nature of the CAVS program as a time savings subsidy, and comment on Valuation of Time of California drivers who received such benefits. I find that providing some hybrid vehicles with HOV access privileges capitalized in their value, increasing it by nearly $3000.

The last essay provides a historical overview of U.S. transport emissions, tracing transport CO$_2$ emissions by mode for 1960–2008. Changes in emissions are divided into components related to overall population and economic growth, transport mode shift, changes in the ratio of fuel used to passenger or tonne-km of activity, and changes in the CO$_2$ content of fuels. A decomposition of these changes using Log-Mean Divisia Index and Laspeyres method is provided, illuminating the role of each factor that contributed to the rise in emissions. From this decomposition I speculate to what extent each factor would be important in the future, and what other factors could reduce emissions. This thorough decomposition is imperative for the crafting of transport policy that aims to address climate change.
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The Consumer Response to Government Incentives: A Study of California’s Clean Air Access Program
Calanit Kamala and Kenneth Gillingham

i. Introduction

California has been a pioneer in adopting stringent vehicle emissions standards and a driving force behind the recent update of the national Corporate Average Fuel Economy standards. The passage of Assembly Bill 1493 in 2002, known as the Pavley Bill, specifically targets greenhouse gas (GHG) emission reductions in the transportation sector, the largest emitter of GHG gasses in the state (California Air Resource Board, 2011). Although California’s authority to set GHG automobile emission standards was granted only in 2009, California adopted several policies to encourage the supply and demand of technologically-advanced, fuel efficient vehicles, prior to the policy change. We study a major policy of this type - the California Clean Access Vehicle Sticker Program (CAVS).

CAVS provided single-occupancy access to electric and natural-gas powered vehicles on High Occupancy Vehicle (HOV) lanes in 2000 (California LAO, 2000), and extended these privileges to three hybrid models in 2005. The goal of the policy was both to address congestion, by shifting traffic volume towards underutilized HOV lanes, as well as increase demand for new, fuel efficient technologies (California Department of Motor Vehicles, 2011).

California is not the first to adopt policies with the goal of stimulating demand for hybrid vehicles. Virginia implemented a HOV access program in 2000 and currently five other states have similar programs1. The federal government sought to promote the diffusion of hybrid technology by providing tax credits for newly acquired hybrid vehicles. Several studies investigate the effect of federal and state incentives on the hybrid vehicle market, most notably Diamond (2009) and Gallagher and Muehlegger (2011). Both papers exploit state-level variation in the hybrid vehicle share to estimate whether tax incentives, access rights and several other policies, raised demand for hybrid vehicles.

As California’s legislature continues to utilize the CAVS program to induce demand for clean technology in the vehicle market, a careful investigation of the program’s effect is warranted. This paper adds to growing literature on the impact of the California Clean Access Vehicle Sticker program on the sales of hybrid vehicles by testing three hypotheses: (i) Has the program had a detectable impact on the number of hybrid vehicles sold? (ii) Did the introduction of the program in a time of constrained supply have an effect on prices? (iii) Did the quantity and price impacts in the HOV eligible hybrid market affect the demand for other hybrid models?

The following analysis is the first to employ a monthly, zip-code level dataset created from vehicle sales microdata. The level of detail in our data allows us to examine regional differences in vehicle sales, as oppose to state-level variation which is common in earlier analyses. Contrary to previous findings that show little evidence of a positive impact of HOV access privileges in California, we find that the program had a positive economically and statistically significant effect.

---

1 The states with HOV single-occupancy access programs are: AZ, CA, FL, NJ, NY, UT & VA
on the sales of hybrid models eligible for access rights of up to 20%. Based on these results, we
argue that carefully considering the timing of the CAVS program implementation is necessary to
account for the program’s impact.

The paper is organized as follows: part ii summarizes the relevant literature, part iii
provides an overview of the program, part iv specifies the theoretical framework, part v describes
the data and the empirical approach, part vi discusses the results and part vii concludes with a
summary.

ii. Literature Review

The general increase in gasoline prices, the noticeable adverse impacts of climate change
and the growing concerns over energy independence have all played major role in shaping U.S.
transport policy. The understanding that energy-saving technologies can play a role in addressing
the negative externalities associated with fuel consumption was coupled with evidence suggesting
that such technologies may suffer from inefficiently low adoption rates (Jaffe et al. 2004). A
substantial body of literature studies the so-called Energy-efficiency gap, where cost-effective,
energy-conserving technologies exhibit low adoption rates (Jaffe and Stavins, 1994, DeCanio,
1999). Economists explain this phenomena with two main arguments: the first stresses the role of
market failures such as the existence of information gaps, positive externalities and transaction
costs associated with adoption of new products (Gillingham et al. 2009). The second explanation
focuses on individual preferences and discount rates to explain why some consumers adopt later
or choose not to adopt at all (Hasset and Metcalf 1993, Train 1985).

When hybrid technology was first introduced in 2000, the upfront costs associated with
purchasing a hybrid vehicle in comparison with a gasoline engine alternative did not offset the
savings in gasoline consumption (Lave and Maclean 2001). Since the adoption of hybrid
technology has environmental benefits not captured by individual adopters, the socially optimal
level of hybrid vehicles is higher than actual adoption rates. This led to a common view among
policy makers that policy intervention in this market can be welfare improving (National Energy

As government incentives for the adoption of hybrid vehicles have become more
widespread over the last decade, several studies sought to investigate their effect. Diamond
(2008) studies the effect of Virginia’s single-occupancy HOV program on local hybrid market
shares. He finds a significant local effect on hybrid market shares in areas located near freeways
where the HOV privileges provide significant time savings. In a separate analysis, Diamond
(2009) examines the effect of federal tax incentives and HOV privileges by using state-level,
annual, market-shares of three hybrid models (Prius, Civic and Escape). Diamond finds the effect
of HOV lane privileges to be insignificant in California. Given the data used for the analysis, this
result in not surprising since, as noted by Diamond himself, “… the HOV effect would likely be
on a local, rather than statewide basis…”

Gallagher and Muehlegger (2011) study the relative efficacy of state sales tax waivers,
income tax credits, and non-tax incentives, such as HOV lane access and parking fee exemptions.
They exploit state-level, quarterly variation to estimate the effect on per-capita sales of eleven hybrid models. Out of the seven states with HOV access incentives for hybrid vehicles, only Virginia’s program was found to have a significant effect on sales, though Virginia is the only state that had a HOV program throughout the period of their analysis. Similar to the issue with Diamond’s analysis, a state-level analysis may mask the sub-state level effect that is inherent to the HOV lane policy, as HOV lanes are located only in specific regions of the state.

Shewmake and Jarvis (2011) use independently collected data from the used vehicle market to estimate the market value of the CAVS access sticker, and comment about the implicit subsidy the program provided vehicle owners who obtained stickers. They estimate a sticker’s value at $3200 and claim that auctioning access privileges to all drivers and using revenues to directly subsidize hybrid vehicles would have had a greater impact on hybrid sales. A significant assumption of their analysis is that the CAVS program did not stimulate demand for hybrid vehicles, citing both Gallagher and Muehlegger (2011) and Diamond’s (2009) results.

Bento et al. (2011) analyze the welfare impact of the CAVS program in a primary highway in southern California. Their findings suggest that travel time in HOV lanes increased after the program was implemented, while travel time in regular lanes did not change. They argue that single-occupancy access privileges given to hybrid vehicles posed a negative externality on carpoolers, costing them more than the emissions reduction benefits associated with higher rates of hybrid ownership. In contrast to these findings, in a recent analysis of Bay Area traffic, Jang and Cassidy (2011) find that the expiration of hybrid vehicle access rights had an unfavorable effect on traffic congestion in regular lanes. According to their estimates, adding the stickered hybrid vehicles back to regular lanes during carpooling times will increase people-hours and vehicle-hours traveled by more than 10% in regular lanes.

iii. California’s HOV Lanes System

a. California’s HOV lanes

California has 1,400 miles of paved HOV lanes in the state’s most congested areas: The San Francisco Bay Area, the Sacramento area and Southern California. The purpose of HOV lanes is to encourage carpooling during the most congested traffic times. There is variation across locations in both HOV lanes operation time and minimum capacity requirement. The efficacy of HOV lanes in encouraging car-pooling is a subject of much debate among academics and public opinion alike. In 1999, seven bills were introduced in the California legislature requiring a thorough review of HOV performance as well as directives on how to address underutilization, known as “empty lane syndrome.” California’s legislative analyst office report concluded that although many HOV lanes have substantial unused capacity, HOV lanes carry significantly more passengers than congested mixed use lanes (CA LAO, 2000).

Whether HOV lanes achieve their stated goals is a disputed issue among transportation engineers as well. Chen et al. (2005) conducted an analysis of traffic volume and speed and conclude that HOV lanes lead to increased congestion. Cassidy et al. (2009) provide a detailed critique of Chen et al. methodology. Cassidy et al. (2009) performed a spatiotemporal analysis of

---

2 A map of HOV lanes system is provided in the appendix
similar data, though larger in scope, to find that HOV lanes are in fact effective in reducing aggregate congestion.

Regardless of the ongoing debate over their efficacy, HOV lanes have expanded significantly, with an increase of 50% in paved lanes between 2000 and 2010. Moreover an additional 400 miles of HOV lanes are either under construction or planned (California Department of Transportation, 2010).

The time savings that HOV lanes provide to commuters can be significant. The California Department of Transportation (2011) estimates that traffic on HOV lanes is on average 20 mph faster during carpool times. Several Bay Area HOV lanes provide between 10-20 minutes of commute time savings, which represent 30-70% of the average commute time in the Bay Area (U.S. Census Bureau). Other studies estimate 17 minutes savings in Southern California (Shewmake & Jarvis 2011). Until recently, as additional significant benefit of HOV lanes in the San Francisco Bay Area was toll-free bridge access during times of peak congestion. This benefit changed in July 2010, when the toll-free access was replaced with reduced-toll access.

b. California’s Clean Air Vehicle Sticker Program overview

The CAVS program’s objective is to stimulate demand for fuel-conserving technologies while reducing traffic congestion, by providing fuel-efficient vehicles single-occupancy access to HOV lanes during carpool hours (California DMV, 2011). The rational is that the time savings provided by access privileges raise the value of newly-introduced energy-efficient technology, promoting its diffusion and reducing the negative externalities from the use of gasoline.

California first provided single-occupancy HOV access in the year 2000, to Inherently Low Emissions Vehicles (ILEV), namely electric and natural gas powered vehicles. The debate over the effectiveness of HOV lanes along with the introduction of hybrid technology in 2001, led to the proposal to extend these privileges to hybrid vehicles. The proposal, introduced to California’s senate in May 2004 by Senator Pavley, gained wide support among policy makers as a low-cost mechanism to address two major policy concerns. Governor Schwarzenegger signed AB 2628 in September 2004, ordering the distribution of 75,000 “yellow stickers” to hybrid vehicle owners commencing 01/01/2005. Three hybrid models met the bill’s fuel economy standards of 45 mpg or higher: Toyota Prius, Honda Civic and Honda Insight. Owners of these models were eligible to apply with the DMV for an access sticker by filing an application and paying an $8 application fee. Significant to our analysis is the fact that policy makers decided to grant access rights to all hybrid adopters by making them eligible for stickers regardless of the timing of vehicle’s purchase.

Figure 1. CAVS Program Timeline

| 09/2004 | AB 2628 signed |
| 01/2005 | AB 2628 in effect |
| 08/2005 | AB 2628 Federal approval. Sticker Distribution starts |
| 09/2006 | 10,000 additional stickers issued |
| 02/2007 | All stickers distributed |
Since HOV lanes are built with federal funds, the federal government had to approve the California bill. Although the California regulation took effect in January 2005, the DMV was not able to distribute stickers before federal approval was granted. In January, February, March, April and July of 2005, news articles published in California’s major newspapers discussed the stall in Congress that prevented hybrid owners from obtaining their carpool access rights. The federal approval was finally signed in August 2005, nearly a year after the bill was signed in California, after which sticker distribution immediately started.

Given the media coverage of the CAVIS program, the period prior to Congressional approval likely played an important role in raising public awareness to the program. Given the limited number of stickers, consumers who anticipated the policy change and wanted to ensure that they obtained a sticker could still purchase a hybrid vehicle before stickers were issued. Unlike previous papers that estimate the effect of the program based on when stickers were initially distributed (August 2005), we examine the impact of the period prior to sticker distribution, as well as when the stickers were initially distributed.

Table 1 shows the monthly average number of HOV eligible vehicles sold for four different periods: Before the rule took effect (Pre-policy period), after the rule took effect and before the stickers were issued (Announcement period), the first implementation period, when the original 75,000 stickers were issued (Phase I) and the second phase of the program, when an additional 10,000 stickers were issued (Phase II). Figure 2 shows monthly sales of HOV eligible vehicles along with the average sales described in Table 1. It is apparent from the graph that the most noticeable difference in average sales is right after legislation took effect, rather than when implementation started.

<table>
<thead>
<tr>
<th>Date</th>
<th>Period</th>
<th>Average Monthly Sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/2003 – 12/2004</td>
<td>Pre-Policy</td>
<td>1,660</td>
</tr>
<tr>
<td>01/2005 – 07/2005</td>
<td>Announcement</td>
<td>2,970</td>
</tr>
<tr>
<td>08/2005 – 09/2006</td>
<td>Phase I</td>
<td>2,900</td>
</tr>
<tr>
<td>10/2006 – 02/2007</td>
<td>Phase II</td>
<td>3125</td>
</tr>
</tbody>
</table>

3 Selection of news: L.A. Times, 01/01/2005 Hybrids' Shift to a New Lane Stalls; S.F. Chronicle 01/05/2005 Hybrid road rage, L.A. Times 03/11/2005 Transportation Bill Clears House; Oakland Tribune 05/18/2005 Senate Runs Red Light on Roads Bill; L.A. Times 07/30/2005 Solo in a Hybrid? Merge Left

4 We analyze the period after the introduction of the 2nd generation Prius to the market
Theoretical Framework

Fuel efficiency demand is often analyzed by employing a hedonic pricing approach, where a vehicle is seen as a bundle of attributes, each having a marginal effect on price (Atkinson & Halvorsen 1984, Dreyfus and Viscusi 1995, Espey and Nair, 2005). The introduction of hybrid technology adds additional dimensions to the fuel efficiency attribute, as hybrid vehicles provide additional benefits on top of fuel savings. Several papers document the general perception of hybrid vehicles as an environmentally-friendly choice, leading to higher adoption rates in green communities (Kahn 2007, Sexton & Sexton 2011). Government incentives provide additional benefits in the form of commuting and parking privileges. In the following formal representation we focus on fuel savings, environmental services and commuter services as the three major components that contribute to the hybrid attribute value. Equipped with the insights of the model we are able to provide By decomposing the additional value of hybrid vehicles we are able to provide stylized predictions of the CAVS program on the hybrid vehicle market.

Assume the utility derived from a vehicle, $U_v$, has three components:

1. $T$ – utility derived from transport services and is a function of miles driven, $m$, and $X$, a vector of vehicle attributes;
2. $E$ – utility derived from perceived environmental benefits. This may include actual emissions reductions that are a result of better fuel efficiency and a symbolic value of
being perceived as environmentalist. For simplification we assume that the perceived environmental services depend only on whether the vehicle is a hybrid or not.

(3) C – utility derived from commuter time savings benefits, which depend on whether the vehicle is a hybrid, the planned usage of HOV lanes, the commute distance, and the valuation of time.

To relate the effect of increased demand for eligible hybrid vehicles to the demand for other hybrid models, we make a few assumptions about the nature of consumer heterogeneity in the market. Let one group of consumers, referred to as environmentalists, derive utility only from environmental benefits, E. The other group, commuters, derives utility only from time savings, C. Let δ, the consumer’s type indicator, equal 1 for commuter and 0 for environmentalist.

A linear separable vehicle utility function can be written as:

\[ U = u(T(x, \bar{m})) + (1 - \delta) \cdot u(E(\theta)) + \delta \cdot u(C(\theta)) \]

Where \( \theta \) is an indicator for whether the vehicle is an HOV eligible hybrid.

Consider a consumer expenditure minimization problem. Assume the consumer predetermines a specific level of utility, \( \bar{U} \), provided by vehicle choice and based on some expectation of \( \bar{m} \), total miles driven. For simplification we disregard a possible rebound effect.

Following the representation of Griliches and Ohta (1986), let the consumer’s expenditure on a vehicle be represented by two components: the vehicle cost, \( P_v \), which is paid for in the present, and variable gasoline costs, which are paid for throughout the time a vehicle is owned. The vehicle costs are given by \( \frac{p_g \cdot m}{mpg} \), where \( p_g \) is the price of gasoline, \( m \) is miles driven, and \( mpg \) is miles per gallon – the vehicle’s fuel economy.

Then, the expenditure minimization problem faced by a commuter can be written as:

\[
\text{EQ. (2)} \quad \text{Min}_{x,\theta} \ P_v(X, \theta) + (1 - \theta) \cdot \frac{P_g \cdot \bar{m}}{mpg_{Alt}} + \theta \cdot \frac{P_g \cdot \bar{m}}{mpg_{EH}}
\]

s. t. \( u(T(x, \bar{m})) + (1 - \delta) \cdot u(E(\theta)) + \delta \cdot u(C(\theta)) = \bar{U} \)

For eligible hybrid vehicles \( \theta = 1 \), 0 otherwise. \( mpg_{EH} \) is fuel economy of eligible hybrid vehicle and \( mpg_{Alt} \) is the fuel economy of a an alternative vehicle choice.

Solving for the Lagrange we get the following equations:

\[ \mathcal{L}: P_v(X, \theta) + (1 - \theta) \cdot \frac{P_g \cdot \bar{m}}{mpg_{Alt}} + \theta \cdot \frac{P_g \cdot \bar{m}}{mpg_{EH}} + \lambda(\bar{U} - u(T,E,C)) \]
1. \( \frac{\partial L}{\partial x_i} = \frac{\partial P_v}{\partial x_i} - \lambda \left( \frac{\partial u}{\partial T} \cdot \frac{\partial T}{\partial x_i} \right) = 0 \)

2. \( \frac{\partial L}{\partial \theta} = \frac{\partial P_v}{\partial \theta} - \frac{p_g \cdot \bar{m}}{mpg_{Alt}} + \frac{p_g \cdot \bar{m}}{mpg_{EH}} - \lambda \left( (1 - \delta) \cdot \frac{\partial u}{\partial E} \cdot \frac{\partial E}{\partial \theta} + \delta \cdot \frac{\partial u}{\partial C} \cdot \frac{\partial C}{\partial \theta} \right) = 0 \)

Rearranging the second condition:

Eq. (3) \[ \frac{\partial P_v}{\partial \theta} = \left( \frac{p_g \cdot \bar{m}}{mpg_{Alt}} - \frac{p_g \cdot \bar{m}}{mpg_{EH}} \right) + \lambda \left( (1 - \delta) \cdot \frac{\partial u}{\partial E} \cdot \frac{\partial E}{\partial \theta} + \delta \cdot \frac{\partial u}{\partial C} \cdot \frac{\partial C}{\partial \theta} \right) \]

Equation 3 states that the marginal value of an eligible hybrid is a function of: (1) fuel savings, (2) the marginal utility derived from environmental benefits, (3) the marginal utility derived from commuter benefits.

Before the CAVS program, \( \delta = 0 \) since no one has commuter benefits, and market demand for eligible hybrids is driven by environmentalists’ willingness-to-pay. After the program is initiated, \( \delta = 1 \), adding to the market consumers with commuter benefits. Thus, if we assume that fuel savings is the same across consumer types, the difference in value of an eligible hybrid relies on the difference between the marginal value of environmental services for environmentalists and the marginal value of time savings for commuters.

Two market forces came into play to produce our hypotheses for the subsequent analysis. First, the market supply of HOV eligible vehicles was constrained until August 2006, so the policy-induced increase in demand for hybrids by commuters likely translated to price increases and longer waiting periods. Environmentalists, who by assumption derive utility from driving any hybrid model may therefore opt to purchase a non-eligible hybrid, especially if the prices of eligible hybrid models became comparable to non-eligible models. We therefore predict that sales of other hybrid vehicles increased up until August 2006, when the supply of eligible hybrids was no longer constrained.

Our second prediction is derived from the implementation method of the CAVS program. Given the fixed number of stickers and the fact that all vehicles purchased before stickers’ distribution were eligible to receive a sticker, a consumer values time savings highly would have purchased a hybrid vehicle as soon as he finds out about the program, so as to ensure his ability to obtain a sticker. We therefore hypothesize that the magnitude of the program’s impact will be largest even before the distribution of the stickers.

A simple treatment analysis that omits these two market forces would likely fail to capture the full impact of the program. In the following section we test our hypotheses empirically.
v. Empirical Estimation

a. Data

Vehicle Sales

The original dataset used in the analysis is transaction-level new vehicle data acquired from R.L. Polk that primarily originates from the CA Department of Motor Vehicles (DMV). Each vehicle is identified in the data by the 17-digit Vehicle Identification Number (VIN), and contains information on the zip code that the vehicle was registered in. The period analyzed is 10/2003-02/2007. The sales volume and trends in the hybrid vehicle market changed significantly with the introduction of the 2004 model, 2nd generation Prius in October 2003. The Toyota Prius has an innovative, distinct design and demand for the new Prius exceeded Toyota’s forecasts. 2003 was the year the Civic Hybrid was introduced to the market. We therefore limit our analysis to sales data between October 2003 and February 2007, when all the stickers were distributed.

Vehicle Price

Individual records of sales of new hybrid vehicles were obtained from California’s Department of Motor Vehicles (DMV) for the years 2005-2007. The dataset includes zip code, Manufacturer Suggested Retail Price (MSRP) and actual purchase price. Some variation in purchase price exists due to the acquisition of dealer-installed accessories. This should affect the estimation results only if the correlate with the treatment effect, which we argue is not the case. Promotional rebates are deducted from the reported purchase price, but these benefits are the same across California and are given on a seasonal basis, so our Fixed Effects estimation should control for that variation. Our dependent variable in the price analysis is the difference between MSRP and actual purchase price.

Controls

Gasoline prices are thought to be a significant driver of hybrid vehicle market trends (Beresteanu and Li, 2011). The monthly average retail gasoline price (tax-inclusive) at the county level in California is acquired from the Oil Price Information Service (OPIS). Other controls include zip code-level demographics and county-level average commute times from the US Census Bureau. Economic conditions are captured by county-level, monthly unemployment rate from the Bureau of Labor Statistics (BLS) and a national, monthly “consumer confidence index” (CCI), provided by the Conference Board.

Table 2 shows sample means for the zip code-level controls data, calculated for each vehicle type: HOV eligible models, other hybrid models and gasoline-engine models. For each vehicle type, we calculate the mean over all zip codes in the sub-sample of all control variables. The most striking differences are observed for population and income. Not surprisingly, the average population in zip codes with hybrid sales (either eligible or not) is significantly higher. Similarly, income in zip codes with hybrid sales is considerably higher. Other variables, such as age and racial composition are of similar magnitudes.
Table 3 shows summary statistics of total sales as well as market share, by vehicle type. The mean monthly sales in each zip-code is calculated, for each of the vehicle groups: regular gasoline engine vehicles, eligible hybrids and other hybrid models. The means as percentages of total sales are also reported.

Table 2. Control Variables Means, by vehicle engine type

<table>
<thead>
<tr>
<th>Variable</th>
<th>Gasoline engine</th>
<th>HOV eligible hybrids</th>
<th>Other hybrids</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country-Level:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Prices</td>
<td>2.9</td>
<td>2.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Unemployment Rate</td>
<td>5.6</td>
<td>5.1</td>
<td>5.0</td>
</tr>
<tr>
<td>CCI</td>
<td>103.7</td>
<td>103.7</td>
<td>103.8</td>
</tr>
<tr>
<td>Commute time (min)</td>
<td>25.9</td>
<td>26.7</td>
<td>26.7</td>
</tr>
<tr>
<td><strong>Zip-Code Level:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>26,900</td>
<td>33,000</td>
<td>34,200</td>
</tr>
<tr>
<td>Density</td>
<td>3.6</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Businesses</td>
<td>790.4</td>
<td>1302.8</td>
<td>1375.4</td>
</tr>
<tr>
<td>Population growth rate</td>
<td>1.8</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Income</td>
<td>62,100</td>
<td>71,000</td>
<td>73,700</td>
</tr>
<tr>
<td>% Population above 65</td>
<td>12.2</td>
<td>12.1</td>
<td>12.2</td>
</tr>
<tr>
<td>% Population under 18</td>
<td>24.3</td>
<td>24.1</td>
<td>24.0</td>
</tr>
<tr>
<td>% White</td>
<td>64.2</td>
<td>62.8</td>
<td>63.3</td>
</tr>
<tr>
<td>% Black</td>
<td>4.5</td>
<td>5.0</td>
<td>4.8</td>
</tr>
<tr>
<td>% Hispanic</td>
<td>29.7</td>
<td>27.8</td>
<td>27.0</td>
</tr>
</tbody>
</table>

Table 3. Summary statistics of monthly zip-code sales, by vehicle engine type

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gasoline Engine</strong></td>
<td>68.12</td>
<td>79.48</td>
<td>1</td>
<td>703</td>
</tr>
<tr>
<td>as market share</td>
<td>97.5%</td>
<td>5.6%</td>
<td>14.3%</td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>HOV eligible hybrids</strong></td>
<td>3.03</td>
<td>2.68</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>as market share</td>
<td>5.0%</td>
<td>10.4%</td>
<td>0.2%</td>
<td>100.0%</td>
</tr>
<tr>
<td><strong>Other hybrids</strong></td>
<td>2.30</td>
<td>1.85</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>as market share</td>
<td>3.5%</td>
<td>8.6%</td>
<td>0.2%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
b. *Econometric Specification*

To test for the impact of the CAVS program on hybrid sales, we regress sales volume in zip code $z$, at time $t$ on a policy indicator variable, zip-code level controls and month-of-the-year and county fixed-effects. We construct a monthly sum of the three hybrid models sold in each zip code as a dependent variable, as well as the hybrid share of total vehicles sold. Since vehicle sales’ trends vary significantly by month, we use month-of-the-year fixed-effects to control for seasonality of vehicle sales. County fixed effects control for time-invariant differences among California’s counties. We report robust standard errors, clustered at the county level. The model is estimated by Ordinary Least Squares regression, according to the following specification:

$$y_{zt} = \beta_0 + \beta X_{zt} + \delta \cdot \text{Treat}_t + \theta_c + \gamma_m + \text{trend}_t + \epsilon_{zt} \quad (1)$$

Where $y_{zt}$ is the number of HOV eligible vehicles sold in zip code $z$, at time $t$. $X_{zt}$ is a vector of zip-code level controls. \text{Treat}_t is a vector of dummy variables to account for the varying phases of the policy, $\theta_c$ are county fixed effects and $\gamma_m$ is a month-of-year fixed effect. To control for a general sales trend, we add a linear trend variable, \text{trend}, $\epsilon_{zt}$ is the error term. Figure 3 presents the different treatment variables considered in the analysis.

Identification of the coefficient on the treatment variable requires that any unobserved factors affecting sales of hybrid vehicles in a particular zip-code are uncorrelated with the timing of the program. More formally, identification requires that $E \ [ \text{Treat}_t \cdot \epsilon_{zt} | X_{zt}, \theta_c, \gamma_m ] = 0$.

For example, the error term may include the effect of advertising on sales. If dealers responded to the program by directing their advertising efforts at commuters, then the treatment effect may be biased upward. In a direct communication with Toyota sales representatives, we confirmed that the Prius had very few cash incentives during the period of the program. Furthermore, any such incentives were offered on a seasonal basis, thus adding the month-of-year fixed-effects should control for potentially correlated unobservable marketing activity.

Beresteau and Li (2011) find that gasoline prices, household income, travel time and whether households have children, to be significant factors in affecting hybrid vehicle adoption rates in 22 major MSA. We control for county-level gasoline prices and travel time and zip-code level income, age and racial composition.
vi. Results

a. Impact on Sales

Table 4 presents regression results for the treatment period estimated in the previous literature, referred to as implementation period. The policy indicator equals 1 from August 2005 to February 2007, the period of sticker distribution. In the initial specification, without accounting for general time-driven sales trends and demographic controls, the coefficient on the treatment variable is positive and significant. However, when time trend is added, the coefficient changes signs and becomes significant and negative. Adding gas prices and zip-code level demographic controls increases the magnitude of the coefficient. This result is not surprising. If, as we hypothesize in this analysis, the majority of the impact on sales occurred before the program’s implementation, then including the announcement period as part of the control will result in a negative coefficient estimate on the treatment period.

The next specification changes the policy indicator to include the announcement period, i.e. the treatment variable equals one between January 2005 and February 2007, referred to as the CAVS treatment. Without controls, the coefficient on the policy indicator is positive and significant. When a trend is added, the coefficient decreases by nearly 50% but remains positive and significant. When adding gasoline prices and all other control variables, the coefficient increases and remains positive and significant at 99%.
Table 6 provides further insight to the effect of each period, by providing the results of two additional specifications. The first regression tests for the differences in sales of the announcement period, relative to prior months, whereas the second regression includes Phase I of sticker distribution. As the coefficients indicate, the impact on sales was largest during the announcement period. The coefficient decreases in magnitude by 25% when Phase I is added and decreases by an additional 20% when Phase II is included.

Table 4. Dependent Variable: number of HOV eligible models sold

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementation</td>
<td>0.776*** (0.127)</td>
<td>-0.350*** (0.106)</td>
<td>-0.564*** (0.0949)</td>
</tr>
<tr>
<td>trend</td>
<td>0.0550*** (0.00481)</td>
<td>0.0492*** (0.00590)</td>
<td>0.501*** (0.102)</td>
</tr>
<tr>
<td>Gas price</td>
<td>1.952*** (0.0549)</td>
<td>1.566*** (0.0659)</td>
<td>0.645 (1.182)</td>
</tr>
</tbody>
</table>

Demographic Controls

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>N</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Observations</td>
<td>33,705</td>
<td>33,705</td>
<td>33,705</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.128</td>
<td>0.142</td>
<td>0.329</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

Table 5. Dependent Variable: number of HOV eligible vehicles sold

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAVS</td>
<td>1.041*** (0.115)</td>
<td>0.542*** (0.055)</td>
<td>0.609*** (0.06)</td>
</tr>
<tr>
<td>trend</td>
<td>0.024*** (0.005)</td>
<td>0.013*** (0.00)</td>
<td>0.22* (0.134)</td>
</tr>
<tr>
<td>gaspr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.995*** (0.047)</td>
<td>1.78*** (0.08)</td>
<td>.176 (1.106)</td>
</tr>
</tbody>
</table>

Demographic Controls

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>N</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Observations</td>
<td>33,705</td>
<td>33,705</td>
<td>33,705</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.14</td>
<td>0.144</td>
<td>0.330</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1
These results indicate that total sales of HOV eligible hybrids during the program increased, but only when the announcement period is included in the treatment. The coefficient on the CAVS indicator is 0.609 with 95% confidence interval between 0.543-0.675. Average monthly sales per zip-code are 3.02, meaning the coefficient represents an 18-22% increase in sales during the treatment period. The most striking effect is during the announcement period with a coefficient of 1.02, which represents a 27-40% increase over average monthly, zip-code sales.

Table 6. Dependent Variable: number of HOV eligible vehicles sold

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Announcement</td>
<td>1.02***</td>
<td>(0.209)</td>
<td></td>
</tr>
<tr>
<td>Announcement &amp; Phase I</td>
<td></td>
<td>0.76***</td>
<td>(0.077)</td>
</tr>
<tr>
<td>CAVS</td>
<td></td>
<td></td>
<td>0.609***</td>
</tr>
<tr>
<td>trend</td>
<td>-0.000</td>
<td>(0.012)</td>
<td>0.004</td>
</tr>
<tr>
<td>gaspr</td>
<td>0.72*</td>
<td>(0.259)</td>
<td>0.31**</td>
</tr>
<tr>
<td>Demographic Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Constant</td>
<td>-.615</td>
<td>(1.03)</td>
<td>0.151</td>
</tr>
<tr>
<td>Observations</td>
<td>17,060</td>
<td>29,285</td>
<td>33,705</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.303</td>
<td>0.323</td>
<td>0.330</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

We estimate that the 20% increase over the entire period represents nearly 13,000 additional hybrid vehicles sold, of which 7,600 vehicles were purchased during the announcement period alone.

The regressions presented in Tables 5 & 6 study total sales as the dependent variable. The volume of cars sold may not be indicative of the true effect if the vehicle market as a whole exhibits similar patterns. For example, if there was an overall increase in vehicles purchased during the announcement period, then the preceding regressions may capture total rather than the hybrid market effect. Figure 4 shows the monthly sales of eligible and non-eligible hybrid models, as total quantity and share of market. The graph has time markers for January 2005, when AB 2628 took effect, for August 2005 when stickers were initially distributed and for September 2006, when phase I of sticker distribution ended. A noteworthy observation is the spike in sales of eligible hybrids on July 2005, right before sticker distribution started. As people found out about the Congressional meetings taking place on the first week of August, they may have responded quickly by making their purchase.
Figure 4. Monthly Hybrid Vehicle Sales, aggregate and as market share

Table 7 presents the results of several of the preceding specifications, with hybrid market share as the dependent variable. To account for aggregate sales volume in each zip code, we run weighted regressions.

All results follow the pattern of the regressions presented in tables 4, 5 and 6. When only the implementation period is considered (Table 7, regression 1) as the treatment period, the coefficient on treatment is negative and significant. When the announcement period is included as part of treatment, the coefficient is positive and significant. Similarly to the results in Table 6, the magnitude of the effect is largest when estimating the impact of the announcement period alone.

Interpreting the coefficients on market share in a similar fashion, hybrid market shares still increase, but the magnitude of the effect is more modest. Looking at the entire treatment period there is an increase of 5.5%-8% in hybrid market share. The greatest impact is for the announcement period, where hybrid market shares increased by 9-12%.

These results provide compelling evidence of the program’s positive effect on the volume of hybrid vehicles sold and are congruent with our hypothesis that the majority of the impact on sales occurred during the announcement period.
Table 7. Dependent Variable: Market share of HOV eligible vehicles sold

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementation</td>
<td>-0.00487***</td>
<td>0.00341***</td>
<td>0.00541***</td>
<td>0.00460***</td>
</tr>
<tr>
<td>CAVS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Announcement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Announcement &amp; Phase I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>trend</td>
<td>0.00762***</td>
<td>0.00485***</td>
<td>0.00898***</td>
<td>0.00478***</td>
</tr>
<tr>
<td>gaspr</td>
<td>0.000331***</td>
<td>9.91e-05**</td>
<td>-0.000115</td>
<td>4.21e-05</td>
</tr>
<tr>
<td>Demographic Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Constant</td>
<td>0.0163***</td>
<td>0.0163***</td>
<td>-0.0206**</td>
<td>0.0173***</td>
</tr>
<tr>
<td>Observations</td>
<td>33,705</td>
<td>33,705</td>
<td>17,060</td>
<td>29,285</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.336</td>
<td>0.336</td>
<td>0.334</td>
<td>0.327</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

b. Impact on Prices

We continue by analyzing the effect of the policy on prices. The Toyota Prius, which accounts for nearly 80% of all HOV eligible hybrid sales during the study period, was in excess demand until the end of Phase I (August 2006)\(^5\). The Prius’ success exceeded Toyota’s expectations and they adjusted their production to meet demand only with the introduction of the 2007 model. With a capacity-constrained market, it is reasonable to expect an impact on prices. We test this hypothesis using DMV records of individual new vehicle sales, detailing MSRP and actual sale price for 2005-2007.

Figures 5 and 6 present histograms of the difference between MSRP and actual sales price. The Prius’ price difference is generally higher and exhibits greater variability than the Honda hybrid price difference. Whereas there are almost no observations with low markup for Prius, 25% of the Honda hybrids fall in the range between -$1,500 to $1,500. Since Prius constitute the majority of the sample and exhibits greater variation in prices, we focus the price analysis on Prius sales.

\(^5\) This information was given in private communication with Toyota’s Northern CA Sales Manager, Mr. Joseph Carbis
**Figure 5.** Price Difference Distribution for Prius sold 2005-2007

**Figure 6.** Price Difference Distribution for Honda Insight and Honda Civic sold 2005-2007
We follow the same specification as equation (1), with the price difference as the dependent variable. Since the data available is for 2005-2007, we cannot properly control for the separate effect of the announcement period. We therefore run a single regression, weighted for zip-code level sales, that includes a treatment indicator for each phase of the program’s implementation. Table 8 shows the results of the regression. In the first specification, with no controls, the markup in Phase I is higher by 25% than the markup in the announcement period and by 240% than the markup in phase II. Adding a trend changes the results significantly. The treatment coefficients are much higher and exhibit a decreasing trend – the coefficient is highest during the announcement period and decreases with each phase of implementation. These results remain robust when all control variables are added. These results demonstrate that during the announcement period the price difference was nearly $4,000. During phase I the markup falls by 10% and during phase II, when the Prius was no longer in excess demand the markup falls by additional 60%. These results corroborate our previous findings, exhibiting largest quantity and price effects during the announcement period.

Table 8. Dependent Variable: Price difference = purchase price – MSRP

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Announcement</td>
<td>1772***</td>
<td>(100.5)</td>
<td>3,941***</td>
</tr>
<tr>
<td>Phase I</td>
<td>2219***</td>
<td>(82.1)</td>
<td>3,540***</td>
</tr>
<tr>
<td>Phase II</td>
<td>647.59***</td>
<td>(113.1)</td>
<td>1,176***</td>
</tr>
<tr>
<td>trend</td>
<td></td>
<td>(10.3)</td>
<td>82.17***</td>
</tr>
<tr>
<td>Gas prices</td>
<td>183.1**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>2316***</td>
<td>(208.8)</td>
<td>-57</td>
</tr>
<tr>
<td>Demographic Controls</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>County F.E.</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>31,585</td>
<td>31,585</td>
<td>31,227</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.2844</td>
<td>0.297</td>
<td>0.334</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

c. Impact on Sales of Non-Eligible Hybrids

The last question we address in our investigation is whether there were any effects on the sales of hybrid vehicles not eligible for the CAVS sticker. As described in Part iv, a possible impact of the CAVS program was to increase commuters’ demand for eligible hybrids, crowding-out consumers who value hybrid vehicles for their environmental rather than commuting benefits.

Since other hybrid models were not available before September 2004, the validity of an effect during the announcement period would be hard to test. We therefore test for the effects of Phase I and Phase II. Table 9 summarizes the results.
The coefficient on Phase I is positive and significant at 99% indicating that during that period sales of other hybrid models were higher by 9-15%. During Phase II, when the Prius was no longer in excess demand, there was a negative impact on sales of other hybrid models. The coefficient indicates that sales during that period decreased by 12-16%. This may serve as confirmation that the market of non-eligible hybrids was positively affected by the demand patterns created by the CAVS program of eligible hybrids.

**Table 9. Dependent Variable: Total monthly, zip-code sales of Non-HOV hybrid vehicles**

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>0.273***</td>
<td>(0.0649)</td>
<td></td>
</tr>
<tr>
<td>Phase II</td>
<td>-0.349***</td>
<td>(0.0575)</td>
<td>0.378***</td>
</tr>
<tr>
<td>Implementation</td>
<td></td>
<td></td>
<td>(0.0692)</td>
</tr>
<tr>
<td>Trend</td>
<td>0.0648***</td>
<td>(0.00784)</td>
<td>0.0690***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.00881)</td>
<td>0.0457***</td>
</tr>
<tr>
<td>Gas Prices</td>
<td>-0.192</td>
<td>(0.129)</td>
<td>0.175*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.105)</td>
<td>0.0645</td>
</tr>
<tr>
<td>Demographic</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Controls</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Month F.E.</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>County F.E.</td>
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<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.796</td>
<td>(0.865)</td>
<td>-2.140**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.919)</td>
<td>-1.040</td>
</tr>
<tr>
<td>Observations</td>
<td>14,347</td>
<td>18,182</td>
<td>18,182</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.319</td>
<td>0.319</td>
<td>0.319</td>
</tr>
</tbody>
</table>

**vii. Robustness Checks**

We confirm the validity of our results by testing several specifications. We first examine whether including the period right after the bill was signed by the governor changes the estimates on the announcement coefficient. This adds sales during October 2004-December to the announcement period. The results of these regressions are of similar magnitude. Since it is likely that awareness to the program increased around the time it went into effect, we define the beginning of announcement period on January 2005.

To further control for regional variation we also run regressions with county-specific sales trends, which do not seem to impact the results. Since 90% of the sample is in counties that either have HOV lanes or in counties adjacent to HOV lanes counties, running the regression separately for these counties does not alter the analysis significantly. A further control of regional variation can be tested by creating a zip-code level distance measure to HOV lane. An initial examination indicates that the average distance to HOV lane does not vary much within a county. Furthermore, it is plausible that the distance to HOV lanes within a county, may have either a positive or
negative effect on hybrid sales. On one hand those who live closer to HOV lanes are able to use these privileges more frequently. On the other hand those who live relatively further away from HOV lanes may value of commute time savings more.

viii. Conclusion

The California Clean Access Vehicle Sticker program has been used as a policy instrument to induce demand for vehicles with new fuel-conserving technology. This paper utilizes microdata from California new vehicle market to examine whether the policy has had the intended effect on sales in the hybrid vehicle market.

By addressing the economic and policy circumstances specific to California, the preceding analysis provides strong evidence that the program generated a sales response, but that the response was concentrated before the policy was actually implemented, a period disregarded in previous literature. This finding is robust across specifications. We also present suggestive evidence that the policy affected prices of eligible vehicles, pointing to the possibility that car dealers profited from higher margins on such vehicles. An additional interesting possible consequence is the spill-over effect on sales of other hybrid models. Though unintended by the program, our findings suggest that the program induced sales of non-eligible hybrid vehicles as well, in response to increased demand and constrained supply of eligible hybrids.

We estimate that the program induced the purchase of 13,000 additional eligible hybrid vehicles, which is a 20% increase in sales volume. More challenging to quantify are the positive impacts of the program on the supply of hybrid vehicles as well as the demand for other hybrid models.

We conclude that the CAVS program did have a significant effect on the hybrid vehicle market, but that this effect may be in part due to the unusual circumstances of the policy’s delayed implementation, as well as the prevailing market conditions.
References


California Legislative Analyst's Office. 2000. HOV lanes in California: Are they achieving their goals?


Appendix

Figure A.1. Northern California HOV lane map. Source: California Department of Transportation, 2009
Figure A.2. Southern California HOV lane map. Source: California Department of Transportation, 2009
Congestion Pricing and HOV Privileges in California
Calanit Kamala

i. Introduction

Standard economic literature has identified travel congestion as a classic example of a negative externality as early as Pigou (1920). With steady population growth and increased levels of automobile ownership, congestion costs are significant and growing. According to Texas Transportation Institute (2011), in 2010 congestion caused urban Americans to travel 4.8 billion additional hours, with estimated aggregate costs of $101 billion, or $713 per commuter. A significant body of economic literature examines the potential welfare gains associated with congestion pricing, a tax levied on driving, that can potentially affect congestion by internalizing the social costs of individual travel.

Although identified as efficient by economists and transportation planners alike, up until recently, congestion pricing has been grossly unfeasible due to both technological and political barriers. Technologically, the equipment needed to adjust prices as road conditions change as well as charge drivers without creating bottlenecks, became available only in recent years. Politically, policy makers have been resistant to price currently-free road access. Nonetheless, with the steady increase of traffic congestion costs (Texas Transportation Institute 2011), the growing concerns over air quality externalities associated with driving and the mounting budgetary needs of transport agencies, congestion pricing is gaining more credence as a policy option (Department of Transportation 2006).

California provides a major case-study of congestion pricing. First, California has a long record of transport policy leadership and has been the first in the nation to use High Occupancy Toll (HOT) lanes since 1995. Second, California is home to 3 of the top ten most congested areas in the U.S.: Los Angeles, San Jose and San Francisco (Texas Transportation Institute 2011). Third, California has been crafting a major GHG transport emissions reduction plan to reach its climate change goals and has been examining the effects of congestion pricing as a policy option to reduce travel volume (CARB 2010).

The following paper is organized as follows: part ii provides a review of congestion pricing economic literature, part iii details the California experience with road pricing schemes and relates California’s HOV privileges program to Valuation-of-time literature. Part iv uses data from the used vehicle market to assess the value of time-savings benefits on HOV lanes, part v summarizes the paper.

ii. Congestion Pricing in Economic Literature

Early congestion theory (Beckmann et al. 1956, Walters 1961) develops a static model of travel demand and costs. The generalized model defines average and marginal travel cost, as a
function of vehicle flow, $F^6$. Vehicle flow, measured in the number of vehicles per hour is the product of density (vehicles/mile), $D$, and speed (miles/hour), $S$.

Equation 1  

$$F = D \cdot S$$

As traffic density increases, traffic speed decreases, reducing flow. Individuals considering the optimal level of travel do not take into account their own impact on traffic flow and thereby the aggregate level of travel is higher than the socially, congestion-free, optimum. The marginal external cost of congestion$^7$ is defined as the distance between Average costs and Marginal costs and equals the increase in travel time attributable to extra congestion from one more trip $T'(F)$, times the number of trips/hour $(F)$, times value of time (VOT), defined as the Willingness-to-Pay to save one hour of travel time.

Equation 2  

$$MEC = F \cdot T'(F) \cdot VOT$$

The standard model solves for an optimal Pigouvian tax that internalizes externality costs, which is the marginal external cost at the socially optimal level of trips. A general key finding of the static model is that, prior to toll revenue recycling, all drivers are made worse off with the first best Pigouvian toll, assuming they all have the same VOT. Drivers who continue to use the priced-road are worse off since the toll is higher than VOT savings. Others may be worse off since they are diverted to less desired travel routes.

The basic Pigouvian framework omits discussion of several determining factors in transport congestion such as the dynamic nature of travel decisions, the heterogeneity of users, and travel system network effects. Vickrey (1969) developed the first dynamic model of vehicle congestion with endogenous driver decision over timing of travel. He described six types of congestion and discussed the deterring effect of bottlenecks in travel decisions. Contrary to the static model, Vickrey finds that under a bottleneck congestion scenario, it is possible to design a dynamic toll that eliminates a bottleneck and does not reduce drivers’ welfare. Henderson (1974) extends on Vickrey’s model and argues that congestion pricing leads to efficient organization of travel. Rather than shifting travel to alternate transport modes as assumed in the Pigouvian literature, congestion pricing is likely to alter the choice of travel time, potentially increasing overall travel volume as traffic flow becomes smoother overall. This finding is significant, especially in the context of other externalities associated with travel such as accidents, emissions and systems’ wear-and-tear.

Arnott et al (1994) developed a theoretical framework to address travelers’ heterogeneity and show that welfare effects of congestion pricing can vary significantly with travelers’ preferences over cost of travel time, arrival time at work, and the costs travelers incur from early and late arrival. They find that variable tolls have significant distributional effects, claiming that drivers with high VOT benefit significantly more from congestion pricing. Their overall conclusion makes a strong statement of the distributional effects of congestion pricing: “Since unit travel time costs are typically strongly positively correlated with income, a toll without rebate tends to benefit the rich on average, and hurt the poor.”

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$^6$ For a detailed description of the model see Parry 2009

$^7$ This refers only to travel time costs of congestion and not other externality costs such as pollution
Some authors concluded that these distributional effects are at the root of the lack of public support for congestion pricing policies, suggesting that toll revenues should be distributed in a manner that benefits a larger segment of the traveler population (Goodwin 1989, Small 1992a). As a result, the debate in congestion pricing literature has extended to devising efficient mechanisms to distribute toll revenues. King et al. (2007) provide a summary of the literature and argue that the lack of political support for congestion pricing is a result of the absence of a cohesive interest group that would benefit from toll revenues. They therefore suggest making cities the beneficiaries of toll revenues, thereby creating an interest group that would advance congestion pricing schemes.

Calfee and Winston (1998) furthered the debate over distributional impacts of congestion pricing by contesting the conventional methodology to estimate WTP for time savings. They assert that estimating WTP for time savings from urban commuters’ choice of transportation mode, does not reflect VOT of highway commuters. Employing a Stated Preference (SP) methodology, they find commuters have a low WTP for travel time savings and claim that congestion pricing simply does not benefit travelers sufficiently to gain political support. Calfee and Winston suggest that individuals adjust to congestion through their choices over housing and employment locations, therefore those who face congestion are willing to do so because they have lower VOT.

Quantifying the welfare effects of congestion pricing or general transportation improvements requires a reliable estimate of travelers’ VOT. Early empirical analysis derived VOT estimates by modeling the choice of transportation mode (i.e. vehicle, vs. bus, walking, train) in a utility maximization framework that is constrained by time and income (Hensher 1978). Theoretically, these models assume individuals equally value the disutility from an hour of work and an hour of travel time, defining VOT in relation to one’s wage. These early estimates exhibit great variation, especially by income and geography and range anywhere from 20%-180% of gross hourly wage (Small 1992b).

Improvements in the econometric methodology of WTP estimation, greatly contributed to expanding VOT empirical literature. Revealed Preferences (RP) data describe actual choices made by travelers while Stated Preferences (SP) data usually involve surveying travelers about their choices under a set of hypothetical travel scenarios. RP data frequently suffer from collinearity issues among cost and travel-time variables that can significantly bias VOT estimates (Small et al 2005). In addition, it captures only the choice made, without information about the set of alternatives affecting the choice. Another issue with RP data is that explanatory variables, such as existing tolls, may not exhibit the sufficient variation required for the identification of their effect. SP data overcomes the issue of identification as the researcher defines the variation of parameters in the provided scenarios. SP surveys usually ask respondents to rank options, so the researcher gains insight to an individual’s choice relative to alternatives. However, the hypothetical nature of SP data raises questions to the applicability of the results under actual market conditions. Furthermore SP analysis is much more sensitive to econometric specification (Calfee et al 2001).

Since actual congestion pricing schemes were not implemented in the U.S. until the late 1990’s, Calfee and Winston (1997) chose to study their potential effect in a SP setting. They
examined a random sample of automobile commuters in major U.S. metropolitan areas who regularly drove to work and faced some congestion. Survey respondents had to rank 11 travel scenarios that specified differing levels of congestion and time savings. They found that the average WTP per hour of time savings was 19% of the gross hourly wage, a much lower estimate than those based on transport mode choice, which estimated VOT at 50-60% of gross hourly wage (Small 1992b). Furthermore, their findings are insensitive to respondents’ income-level and how toll revenues are spent, contradicting the arguments that redistribution issues are relevant to congestion pricing policies.

Calfee and Winston’s paper was followed by a substantial amount of work contesting their findings on both methodological and theoretical grounds. Lam and Small (2001) show that econometrically accounting for heterogeneity in motorists’ preferences can result in substantially higher VTTS estimates and that these estimates often increase with the degree of heterogeneity. Small et al (2005) use both RP and SP data and compare VOT magnitudes of each method. Similarly to Calfee and Winston, they investigate travel choices of long-distance commuters, but are able to analyze commuters who face an actual choice of using a priced, uncongested lane or a free, congested lane in Orange County. Their RP estimates provide VOT estimates that are 80% higher than their SP results, reflecting the wide discrepancy in estimates based on methodology.

Several stated preferences studies found that motorists are willing to pay for increased travel time reliability on top of WTP for time savings (Small et al 1999, Hensher 2001). The concept of travel time reliability accounts for the random variation in travel time, addressing the element of uncertainty in the decision making of individuals. The majority of Value of Reliability (VOR) studies focus on day-to-day travel time variation that is a result of unanticipated circumstances, although some address the variability that arises due to different departure times or different driving behaviors.

The theoretical underpinnings of VOR literature is an expected utility problem in which mean travel time and variance travel time affect the expected utility function directly. Empirically Small et al (1999) estimate the following equation:

\[ E(U) = \beta_T E(T) + \beta_{SD} SD(T) + \beta_C C \]

Where \( \beta_T \), \( \beta_{SD} \), and \( \beta_C \) are the estimated parameters for the expected travel time (E(T)), the standard deviation of travel time (SD(T)) and travel cost (C) respectively. VOR measures travelers’ WTP for a unit reduction in variability in travel time and is defined as the ratio of \( \beta_{SD} / \beta_C \).

Commuter’s preference for reliability is highly confounded with the value of time savings, making RP studies insufficient to obtain reliable estimates. The majority of VOR empirical research is established on SP data, by asking respondents to make choices under hypothetical scenarios to reveal their behavioral responses to this attribute. The methodological developments in the VOR literature also shed light on the sensitivity of VOT estimates. In a detailed review of the literature Li et al (2010) show that the representation method of trip time variability is a major contributing influence on respondents’ perceptions of travel time reliability as well as valuation of time savings.
To summarize, the valuation of travel time savings and reliability continues to be a major source of inquiry in transportation economics. The advancement of econometric methodology coupled with emergent congestion pricing schemes contribute to increasingly robust estimates of travelers Willingness-to-Pay for time, supporting better analysis of their welfare effects.

iii. California’s Road Pricing Policies

California has a long history of pricing transportation infrastructure. In 1968, the Golden Gate Bridge became the first major bridge in the world to collect one-way toll. In 1995 the first toll-based express lane in the country was opened in Orange County.

Road pricing schemes can be characterized as flat, time-of-day, or dynamic (De Palma and Lindsey 2011). A flat toll is a constant charge and is the most common toll, in part due to technological limitations. Most of Bay area bridges are flat toll facilities. A time-of-day toll changes within specific hours, but is constant within a specific time interval. The recent Bay Bridge toll in San Francisco was modified to a time-of-day toll scheme, with higher tolls charged during peak-hours. A dynamic toll is the most direct form of congestion pricing since it varies with real-time traffic conditions, such as the tolls utilized in California’s express/High Occupancy Toll (HOT) lanes.

An express lane operates parallel to, but separated from free lanes. Express lanes in California provide preferential access to either High Occupancy Vehicles for free, or to solo drivers subjected to toll payments that vary with time and congestion levels. Table 1 summarizes California’s current express lanes, all operating with dynamic tolls.

Table 1. Operating Express Lanes in California

<table>
<thead>
<tr>
<th>Road</th>
<th>Year implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orange County SR-91</td>
<td>1995</td>
</tr>
<tr>
<td>San Diego I-15</td>
<td>1996</td>
</tr>
<tr>
<td>Contra Costa County I-680</td>
<td>2010</td>
</tr>
</tbody>
</table>

The introduction of express lanes in California in the 1990’s contributed to both VOT and VOR literature by providing the first RP experiment in the U.S. for congestion pricing. Lam and Small (2001) provide initial estimates for VOT and VOR by surveying users of the I-91 express lane. They find a VOT of $22, which represents 60% of gross hourly wage. Another interesting finding of their analysis, that demonstrates the relevance of commuters’ heterogeneity, is that women’s VOR is twice as high as the VOR for men. Brownstone et al. (2002) analyze RP data collected from commuters on California’s I-15 express lane. They find a median VOT estimate of $30 per hour. They also show that heterogeneity of commuters plays a significant role in estimating VOT with results ranging from $7 for part-time workers on non-work trips to $65 for high-income individuals on work-trip commutes.
Small et al (2005) further extended the analysis of congestion pricing on the I-91 by combining RP and SP data. By doing so, they were able to confirm the significant differences in VOT estimates of the two methodologies. Their estimates for VOT using the RP data are nearly identical to their previous findings (Lam and Small 2001), while the SP estimate was merely $12.

A recent policy development in California is the plan to convert existing HOV lanes to HOT lanes. HOT lanes have been more widely accepted politically since they provide solo drivers a previously unavailable option, rather than impose new costs on all drivers (King et al, 2007). Among policy makers HOT lanes are believed to be an effective tool to increase efficiency of HOV lanes, by providing dynamic congestion management, especially in areas where HOV lanes are over-crowded and no longer provide time savings benefits (California Department of Transportation 2010).

HOV lanes can be regarded as a type of subsidy provided to motorists who meet the capacity requirements, given value of time savings exceeds transaction costs associated with carpooling. Preferential access on some lanes exploits people’s valuation of time savings to induce desired behavior, namely carpooling. In 2000 the California legislature decided to use these travel time savings benefits to induce the adoption of fuel-efficient vehicles using emerging technologies, by providing owners of such vehicles, single-occupancy access to HOV lanes. Since, at the time, many HOV lanes suffered from an “Empty Lane Syndrome”, the policy was regarded as a no-cost option to increase HOV lane capacity as well as reduce overall fleet fuel economy.

The California legislature mandated the distribution of 85,000 yellow stickers that would provide their owners solo-driving HOV privileges until January 2011. Stickers were initially available in August 2005 to owners of hybrid vehicles who paid $8 and filed an application with DMV. The sticker was attached to a specific vehicle, and therefore was transferable between owners. Providing time savings benefits to a limited number of vehicles offers an additional opportunity to study VTTS, as economic inference suggests that the value of time savings would capitalize in the value of these cars. The previous paper details some suggestive evidence that prices of new vehicles varied with the timing of the HOV access program. The following section analyzes the possible effects in the used vehicle market.

iv. Value of Travel Time Savings as revealed by HOV Access

Commuter’s value of HOV access depends on driver’s valuation of time, commute distance, proximity to HOV lane, expected time savings and expected increase in travel time reliability. Estimating the additional value drivers are willing to pay for vehicles with stickers can provide a measure of WTP for travel time savings. The sticker itself provides access benefits as long as the vehicle is owned or as long as the program is in place, whichever comes first.

Efficient estimation of HOV sticker value requires data that would reveal true transaction price of vehicle sold and would allow the researcher to control for both vehicle and buyer characteristics. However accurate, detailed sales data for used vehicles are generally unavailable. All vehicle sales transactions are reported with DMV, but these data are generally unavailable due

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8 The original end date of the program was July 2010 but was extended to January 2011.
to confidentiality concerns. Moreover, even DMV data may be inaccurate as sales price is often misreported, since buyers have an incentive to underreport transaction prices so as to lower registration taxes.

In order to obtain accurate used vehicles sales prices, I independently collected data of Prius vehicles sold on eBay Motors between September 2006 and December 2007. eBay Motors, the largest on-line auction web-site for vehicles, provides a reliable source of vehicle sales data of a particular used vehicle market. A major strength of the eBay data is accuracy of vehicle characteristics\(^9\) and final sale price. A major weakness of the eBay data is that sample selection biases are likely. For example, a seller of a stickered vehicle may want to sell their vehicle on eBay, hoping that a bidding-style sale would result in higher prices than a regular transaction. Due to the specificity of this market, any results can only be extended to the sample population, and not the general population.

a. Data

A total of 356 Prius vehicles were sold over the period, 97 of which were sold in California, and 25 had a HOV sticker. Table 2 provides summary statistics for vehicles sold in California and figure 1 shows distribution of vehicles by model year.

Figure 1. Vehicle Distribution, by model year

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\(^9\) eBay sellers have strong incentives to provide accurate vehicle descriptions. In addition, eBay offers costless insurance against fraud and vehicle misrepresentation.
Table 2. Vehicle Summary Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starting bid</td>
<td>12653</td>
<td>8615</td>
<td>0.01</td>
<td>27500</td>
</tr>
<tr>
<td>Winning bid</td>
<td>17935</td>
<td>4962</td>
<td>4700</td>
<td>32418</td>
</tr>
<tr>
<td>miles</td>
<td>22954</td>
<td>29725</td>
<td>225</td>
<td>153208</td>
</tr>
<tr>
<td>% of sample with warranty</td>
<td>23%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of sample with salvage title</td>
<td>66%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of sample with HOV sticker</td>
<td>25%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. Estimation Results

A vehicle’s price reflects the value of a bundle of attributes, as commonly assumed in hedonic price models. I assume that the effect of HOV sticker enters price linearly and is not correlated with other vehicle characteristics. I estimate the following equation using OLS procedure with White’s correction for heteroskedastic standard errors.

\[ P_i = \alpha + \delta_1 \text{HOV}_i + \beta Z_i + \epsilon_i \]

Where \( P_i \) is the final bid price of vehicle i as published on the eBay website, HOV is a dummy variable that indicates whether the vehicle has a HOV sticker and \( Z_i \) is a vector of vehicle specific characteristics. Vehicle characteristics include mileage, whether the vehicle is under warranty, whether vehicle has a salvage title and the model year. I also include the vehicle’s starting bid, which is the initial asking price with which the car was listed.

Table 2 summarizes regression results. The first regression presents the results without accounting for seasonal effects. All coefficients are significant and have expected signs. The results indicate that the value of Prius with HOV sticker is $2,800 more than a Prius without a sticker, with a 95% between $1,270 and $4,330. Since vehicle sales exhibit significant monthly seasonality, the second regression controls for unobserved time variation with monthly fixed-effects. The coefficient slightly increases and the standard error slightly decreases. The value of sticker is $2823 with 95% confidence interval of $1,310-$4,335.

The effect of other car characteristics is as expected and is robust to specification. An additional mile reduces vehicle price by 5.5-6.5 cents. A vehicle under warranty is sold for $3,600-4,100 more and a salvage title decreases the value of a car significantly by $2,500-$2,600. Lastly, a newer model adds $1,500-1,800 to vehicle price.

Although the sample size is small, the coefficient on HOV is significant at 99% for both specifications, providing some evidence that HOV stickers did have an impact on used vehicles sales price. The variation in sticker value may point out to the significance of heterogeneity in travel time savings, as some WTP is more than $4,000 and others WTP is as low as $1,300.

There is only one additional paper that attempts to estimate sticker value in a similar fashion. Shewmake and Jarvis (2011) collect used hybrid vehicle market data mainly from
Autotrader. Autotrader is a listing web-site, meaning that their analysis does not reflect actual sales price.

They find that the value of the sticker in February of 2007 was $2,200 and was decreasing at a rate of $12 per week. Using these figures, Jarvis and Shewmake conclude that the sticker was valued at $625 a year ($12 a week times 52), claiming that drivers who obtained stickers in August 2005 were willing to pay $3,200 for HOV access privileges for the entire period. Jarvis and Shewmake use these figures to derive a VOT of $4.5 per hour, a considerably low estimate than observed in VOT literature.

An individual’s WTP for a sticker depends on their expectation over how long they are keeping the vehicle. It is possible that people who purchased hybrid vehicles before sticker distribution ended were those with highest VOT. Thus, generalizing the findings to account for sticker’s value over the entire period is likely to underestimate the differences in sticker value over time and differences in VOT over different buyers.

Table 2. Dependent Variable: Final Sales Price

<table>
<thead>
<tr>
<th>Variable</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOV dummy</td>
<td>2,801***</td>
<td>2,823***</td>
</tr>
<tr>
<td></td>
<td>(771.7)</td>
<td>(759.00)</td>
</tr>
<tr>
<td>Starting Bid</td>
<td>0.00793</td>
<td>0.0548</td>
</tr>
<tr>
<td></td>
<td>(0.0381)</td>
<td>(.0468)</td>
</tr>
<tr>
<td>miles</td>
<td>-0.0664***</td>
<td>-0.05458***</td>
</tr>
<tr>
<td></td>
<td>(0.0160)</td>
<td>(.0172)</td>
</tr>
<tr>
<td>Warranty dummy</td>
<td>3,604***</td>
<td>4,138***</td>
</tr>
<tr>
<td></td>
<td>(890.0)</td>
<td>(966.3)</td>
</tr>
<tr>
<td>Salvage dummy</td>
<td>-2,645***</td>
<td>-2,554***</td>
</tr>
<tr>
<td></td>
<td>(828.9)</td>
<td>(899.7)</td>
</tr>
<tr>
<td>Model year</td>
<td>1,572***</td>
<td>1,874***</td>
</tr>
<tr>
<td></td>
<td>(335.0)</td>
<td>(370.0)</td>
</tr>
<tr>
<td>Monthly F.E.</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Constant</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Observations</td>
<td>97</td>
<td>97</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.791</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

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10 2.6% of their sample is collected from eBay, over the course of 4 months. They do not specify the number of eBay observations for which they observe HOV stickers.
My estimate of the sticker’s value is 27% higher than Shewmake and Jarvis estimate and is observed for the period right after sticker distribution ended, when their value was probably highest. At that time sticker was valid for 3.5 years, thus average WTP for expected time savings over 3.5 years was $2,800. Following a similar calculation to that of Jarvis and Shewmake, with average commute savings of 100 minutes a week, 50 weeks a year, the VOT is $9.6, twice as much as their estimate, though still low in comparison to RP data. One explanation for that finding is that due to loss aversion associated with congestion pricing, the value that travelers put on time savings when they have to pay for it is higher than the value they place on it when it is a given as a subsidy. Sample size and unobserved buyer’s heterogeneity can also significantly affect the low VOT estimates.

v. Conclusion

Policy makers in California employ both carrots and sticks addressing the growing congestion costs in the state, by either pricing on-peak driving or rewarding carpooling. The choice of efficient policies that will produce the desired behavioral outcomes highly depends on commuters’ valuation of time savings. This paper surveys congestion pricing literature and provides an estimate of VTTS through analyzing the effects of time-savings benefits given to owners of hybrid vehicles. Assessing VTTS through taxes versus subsidies is likely to result in significantly different results, as the findings presented in this paper suggest.
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i. Evolution of Carbon Emissions from Domestic Transport Activities

The transportation sector has become the leading and most-rapidly growing contributor to GHG emissions in the U.S. as well as globally. In 2007, the transportation sector was responsible for a third of U.S. GHG emissions from CO₂ and 28% of global GHG emissions [1]. CO₂ emissions from the U.S. transportation sector exceed total CO₂ emissions of any other economy in the world besides China [1].

The sector’s almost total reliance on petroleum fuels [2] is a major determinant of this trend. Other major contributors are urban development patterns, higher incomes and generally low fuel prices, that lead to an increase of vehicle ownership as well as increase of Vehicle miles traveled (VMT) [3]. Between 1960 and 2008, highway travel has grown threefold due to higher population, greater number of vehicles per capita, and higher vehicle use per vehicle [4].

Driven largely by rising economic activity, transport emissions have more than tripled since 1960, augmenting the need to include transportation in climate regulation. While attention has been largely directed to reducing vehicles’ emissions per kilometer and reducing the CO₂ content of fuels, other important factors were overlooked. Understanding the underlying forces responsible for the increased demand for passenger transport (henceforth —travel) and freight over the long-run yields important insights into additional ways transport policies may moderate carbon emissions. With recent high-level commissions pointing to the need for significant reform in transport financing and policy [5], understanding the links between vehicle activity and CO₂ will assist crafting policies that effectively address transport emissions. This paper contributes to the global discussion over the urgency to reduce CO₂ emissions by 2050 to 1990 levels, by analyzing transport emissions pathways between 1960 and 2008.

The following analysis begins with a review of past major trends in transport activity and emissions in the U.S. We continue with presenting a useful decomposition framework and comment on the prospects of future regulation to address the issues brought up by our findings.

ii. Results and Discussion

a. Data

Energy use by mode is created using data from the Oak Ridge Transportation Energy Data Book [2] and the online National Transportation Statistics from the Bureau of Transport Statistics [4]. The share of light trucks used as household vehicles follows key surveys [6,7] and estimates published by [4] and [5]. Travel data are from [7] and [8]. Freight hauled by medium trucks and
light trucks is estimated at 3 tonnes and 200 kg per vehicle km, respectively in order to include this vehicle activity. Using standard CO$_2$ coefficients, these fuel consumption data are converted into CO$_2$ emissions from fuel combustion in vehicles [5]. The small amount of electricity used for rail systems is converted to primary energy and CO$_2$ emissions at U.S. averages for the year in question.

This work is carried out in S.I. units. The reader should recall that a Quad (quadrillion British thermal units, a common U.S. unit, $10^{15}$ BTU) is approximately 1.055 exajoules ($10^{18}$ Joules) and a BTU/passenger-mile is approximately 1.7 megajoules (mJ)/passenger-kilometer. 10 liters/100 km of consumption of gasoline is equal to 23.65 miles per gallon.

**b. Historical Trends**

Between 1960 and 2008, travel volume (in passenger-km) grew by a factor of nearly 3.5, while freight grew almost 3 times, as reflected in Figures 1 and 2, respectively. While travel has been dominated by cars and personal light trucks or SUVs, providing 90% of travel in 1960, air travel actually grew faster and went from under 3% to over 12% of total travel by 2008. Rail and bus shares for passenger travel tumbled from just over 7% in 1960 to around 4% in 2008. Similarly for freight, the share of trucks rose to almost 32% of tonne-km by 2008, while rail fell from 36% of freight in 1960 to 33% in 2008. The share of water-borne freight decreased significantly while air freight, although under 1% in 2008 of total freight travel, grew ten-fold over the entire 48 year period. Notably, the modes of travel and freight that consume the most energy per unit of service grew faster than those that use the least energy.

**Figure 1. Total Passenger Travel by mode**
Figures 3 and 4 show the respective total CO$_2$ emissions by each mode in the same four benchmark years. Not surprisingly, cars and air travel, and truck freight dominate carbon increases, both because these modes dominate transport activity and because they generally have the highest emission per passenger- or tonne-kilometer.
To understand whether an economy is becoming more or less CO$_2$ intensive it is useful to compare the trends in transport to trends in GDP. While GDP is not necessarily a perfect measure, the amount of passenger travel certainly depends on people’s wealth, just as the amount of freight moved is related to overall economic activity. Significantly, neither travel nor freight rose as rapidly as GDP throughout the entire period, although travel led by cars did outpace GDP from 1960 to 1973 but diverged from GDP growth by almost 1% a year, in the years after. The ratio of tonne-km of freight to GDP fell by almost 1% a year from 1960 to 2008 [9]. Relative to GDP, emission grew less rapidly, suggesting a loosening of the coupling of energy use and emissions from economic growth.

Figures 5 (for travel) and 6 (for freight) summarize the aggregate changes, where 1973 serves as the base year. Per capita travel and freight increased in all periods (travel/capita) but GDP grew faster, so the GDP intensity of domestic travel or freight fell (travel/GDP). Aggregate emissions per unit of travel fell after 1973, but that of freight rose to a plateau in the 1990s (emissions/unit of travel). When emissions intensities are normalized to GDP, they demonstrate a steady decline from 1970 (travel emissions/GDP).

Consequently, as compared with GDP, the U.S. economy became less travel and freight intensive over time. Some of the drop in travel and certainly the drop in freight were enabled by foreign mobility substituting for domestic, as imports have been increasing. While per capita emissions from travel or freight were higher in the late 2000s than in the earlier years shown, decreasing carbon intensities contributed to the dramatic shrinking of emissions to GDP. Since travel emissions/GDP fell more than freight emissions/GDP, the share of freight in total transport emissions increased, a fact often overlooked by many observers.
Figure 5. Summary of Emissions Changes from Passenger Travel

Figure 6. Summary of Emissions Changes from Freight
iii. Carbon Intensities Pathways

Carbon intensity is defined in this analysis as the ratio of carbon emissions (Figures 3 and 4) to passenger for travel or tonne-kilometers for freight (Figures 1 and 2). This section follows the changes in intensities over the discussed period and describes the structural changes that explain them.

a. Passenger Travel

For cars and light trucks, a meaningful vehicle carbon intensity (in grams of carbon dioxide per vehicle-km), can be calculated, which is related to the inverse of fuel economy of each kind of vehicle. Figure 7 compares the resulting CO₂ intensities of each mode of passenger travel. From 1973 to 2008 major reductions in carbon intensity occurred in air travel (55% fewer emissions per passenger kilometer), and car travel (33% less emissions per vehicle kilometer and 15% fewer emissions per passenger kilometer).

![Figure 7. Carbon Intensities of Travel by Mode](image)

Automobile fuel economy improvements associated with lower carbon intensity of vehicle use were largely in response to national fuel economy standards and higher fuel prices. Apportioning the size of these two forces has been a subject of much debate [10–12]. New cars sold after 1973 initially became much lighter and less powerful, but gradually their engines were more efficient [13]. Indeed, a new car or light truck sold in 2007 used half as much energy per unit of weight in tests as one sold in the 1970s. Since new car weight had crept back up to 80% of the 1975 values for cars, and above 1975 values for light trucks, the decline in test fuel used per kilometer of new cars and light trucks sold compared to those sold in 1973 was closer to 33% at its maximum in the late 1990s. Consequently, by 2007, this change had worked its way through the entire stock of cars and light trucks (excluding commercial vans and pickups). The average
The drop in light duty vehicle occupancy is an important factor that offsets some of the reduction in fuel use per vehicle-kilometer. Defined as the average number of people per vehicle over all kilometers driven, vehicle occupancy fell from over 2 in 1969 [8] to slightly over 1.5 by 2001 [15]. The decline meant that roughly 1/3 more vehicle kilometers were driven to provide a given number of passenger-kilometers than in 1969. Thus emissions/passenger-km fell significantly less than emissions/veh-km. The long-term trend of a drop in vehicle occupancy occurred as auto ownership increased, and more households sent two commuters with their own cars to work. Some of this decline occurred as fewer Americans made trips by other modes and instead drove alone. Additionally, American household size fell from close to 3.4 in 1960 to about 2.6 after 2000. With fewer children and many more single person households, there were fewer people sharing rides.

Changes in fuel prices have to be given some credit for changes in transportation fuel use. Figure 8 shows the real price of gasoline in the U.S. since 1960, the real price of 1 km worth of gasoline, and the share of household expenditures on gasoline as given in the annual consumer expenditure survey. Not surprising is that improved fuel economy helped keep the cost of fuel/km down. Surprisingly, fuel costs for passenger cars (in cents/km) in the summer of 2008 did not surpass their peak of 1980–1982. Yet in the same year, transit ridership was back at its 1957 absolute level [16], and according to preliminary information from the Federal Highway Administration, in 2008 the total of all vkt fell 3.6% from its 2007 value [17]. Unfortunately full data on utilization of cars and other modes in 2008 were not collected in the National Household Travel Survey, but the emerging picture shows less car use and a continued slight shift to transit.

Calculating the same kind of changes for air travel, available data [4] show that the real price of jet fuel went from $1/gallon to $2.44/gallon (real 2,000 $) between 1980 and 2008, while the fuel used per passenger km fell almost 46%, leaving the fuel cost per passenger-km 25% higher in 2008 than in 1980. For trucking, the increase in diesel fuel costs has been significantly greater than the decline in fuel use/tonne-km, leaving trucking paying about 20% more per tonne-km in 2007 than in 1980 for diesel fuel. Ironically, it is households who saw the least pressure from fuel prices, relatively, except for a few months in 2008 when gasoline rose well above $4/gallon in nominal terms.

While automobile fuel use was reshaped by efficiency standards, there were no similar policies aimed at air travel. Instead, technological progress permits aircraft today to carry more passengers on two engines than they carried on four in 1973 [4]. In terms of air travel, many non-stop flights between smaller cities were eliminated because of unprofitability, particularly after deregulation, in favor of hub-and-spoke patterns developed by the major airlines [18], which contributed to higher load factors. In addition, air travel intensity fell because the capacity utilization of airplanes increased substantially, with planes at about 80% full in 2006 compared with around 50% in the early 1970s [4]. While this meant aircraft became more crowded, the impact on reducing fuel consumption was large. The resulting decline in the energy or carbon intensity of air travel of 60% between 1973 and 2006 was the largest among any major transportation mode.
Rail passenger traffic, which includes commuter rail and intercity rail as well as metros in large cities, was affected by various restructuring activities. Some intercity passenger rail lines had very low energy intensities, such as those well utilized lines in the North East corridor or major commuter lines.

In all Amtrak’s energy intensity (including the primary energy for electricity) was well below that of auto or air travel. With commuter rail, light rail, and metros, the overall intensity of this mode was also well under that of the automobile, even counting the primary equivalent of electricity used to power many passenger lines.

Bus travel, which includes intercity buses, school buses, and urban buses, had a mixed record. For parts of the 1990s, the average city bus released more CO₂ per passenger-km than the average car/light truck because buses had so few passengers. But by 2000 a new generation of buses used progressively less fuel/km, so that with an average of 9 passengers/bus, intensity fell below that of automobiles again. Intercity buses and school buses had lower energy intensities so that the overall energy or carbon intensity of bus travel was lower than that of car travel throughout the entire period [19].

b. **Freight Transport**

For freight, as Figure 9 shows, there was an increase in the intensity of trucking (in carbon dioxide emissions/tonne-km) in the 1970s and 1980s of 5.5% and then a decline of 14% between...
1990 and 2008. In rail freight there was a steady decrease of intensity from the 1970s, while a small increase in water-borne freight intensity can be observed. Air freight, not shown here because it is well off the scale, demonstrated a steady decline consistent with that for travel, hitting a value of around 200 gm/tonne-km in 2008.

Although carbon intensity of trucking in 1990 was slightly above its 1973 level, intensities in 2008 were below those of 1973. Improved engines, tires, lower friction and streamlining of truck cabs and tractors permitted reductions in fuel use per vehicle kilometer for a given size truck [20,21]. Major policy shifts in trucking also changed past practices. With deregulation of interstate trucking in the late 1970s, haulers were permitted to return home loaded, not empty, permitting more freight hauled per kilometer driven and thus driving down carbon intensity of truck freight for a given truck.

Rail freight went through a number of reorganizations and emerged strong in the 1990s with both large bulk shipments (grains, ores, fuels, cars, etc.) as well as trailer on flat car deliveries across the country. As with trucking, the increase in average payload with some modest improvements in diesel engine reduced the energy required and carbon emitted to haul a tonne a kilometer by 2006 to slightly under half of its value in the early 1970s. This last point is important, because vehicle size/capacity and degree of capacity utilization explain more of the variations in carbon intensity over time (as well as cross-sectional differences among countries) than engine efficiencies [20,22].

Technological improvements to vehicles, improved transport industry management practices in response to competition, changing fuel prices, and influential national policy all contributed to the general trend of decreasing carbon intensities in all transportation modes. That emissions rose less rapidly than transport activities after 1973 is not surprising. For most of the period since 1973, U.S. energy policy focused on oil use in the transport sector, particularly the reduction of oil use per kilometer of car, truck, or aircraft movements. These forces reduced fuel intensities, which slowed the rise in emissions.

In spite of these reductions in carbon intensities, total emissions in 2008 were higher than they were in 1973 and are still growing, as can be seen in Figures 3 and 4. Per capita emissions for travel in 2008 were only marginally above their level of 1973, indicating that the changes in emission intensities for car and air travel almost offset the increases in per capita travel for these modes. For freight, however, per capita emissions have increased steadily despite lower intensities. Indeed, overall emissions from freight have risen faster than those from travel, similar to the trends observed in most developed countries [2].

To summarize, within each transport category, overall shifts towards the most energy and carbon intensive modes raised emissions, particularly for freight. At the same time, the most important modes became less carbon intensive. For travel, the decline in these emissions intensities was far more significant than the shift towards car and air travel. In freight, by contrast, the rise of trucking’s share was significant enough to offset the drop in trucking and rail emissions intensities. Still, aggregate freight carbon intensity was slightly higher in 2008 than in 1990 and 4% above its 1973 level, while that for travel was nearly 25% below its 1973 value. We explore a more detailed decomposition of these effects and differences below.
iv. Decomposition of Overall Changes

An important consideration for policymakers is the aggregate impact of changes over time. Policies that focus solely on carbon intensities of vehicles and not on systematic changes in travel volume and mode may overlook important shifts that offset or even overcome the savings from lower vehicle carbon intensities. For example, even though the intensity of trucking, the dominant component of both freight and transport emissions, declined from 1960 to 1973, the aggregate carbon intensity of freight actually increased. Because car travel, air travel and truck freight are the most carbon intensive modes, shifts in their relative importance can reinforce or offset changes in individual intensities. On the other hand, transport policies that take advantage of improvements in the travel or freight system that either raise vehicle utilization or promote shifts to less carbon intensive modes can give fuel and CO₂ savings at no change in technology. To understand the overall effect on emissions that is reflected in mode shift, intensity shifts, change in fuel mix, and the overall level of travel or freight, we provide additional decomposition techniques. While the foregoing descriptive analysis reveals what lies behind aggregate changes, more powerful decomposition techniques yield greater insights about the past and the future [21].

The starting point of this decomposition is the ASIF equation, developed to understand and decompose components that multiply to yield a given output or input [23].

\[ G \text{ (Emissions)} = A \times S_k \times I_{k,j} \times F_{k,j} \] (1)

\( A \) represents total transport activity in passenger-km (or tonne-km for freight), \( S \) is the modal shares (in % of total passenger or tonne-km carried by each mode \( k \)), \( I \) is the fuel intensity of each mode, in energy use per passenger (or tonne-) km \( k \) using fuel or energy source \( j \), and \( F \) is
the carbon content of each fuel $k$ used in mode $j$.

$I$ depends both on the vehicle energy intensity, $V$ (in energy per vehicle-km), and vehicle utilization, $L$ in passengers or tonnes. $I$ has two subscripts, one for mode $j$ (travel or freight) and one for fuel type $k$. This reflects the fact that the fuel intensities of vehicles, travel, or freight may be a function of the fuel itself.

$F$ expresses the carbon content of a given fuel $k$ used for a given mode $j$. For simplicity it is assumed that fuels are fully combusted, so their carbon contents are given by the Intergovernmental Panel on Climate Change (IPCC). In more sophisticated formulations life-cycle analysis accounts for the CO$_2$ released not only in combustion but in preparation of the fuel and for large transit systems construction of infrastructure [24]. This analysis does count the primary energy and emissions associated with electricity use for traction. For the U.S. this is small and essentially limited to some Amtrak and intercity and urban rail services and trolley buses, overall tiny compared to the diesel fuel used by buses and railroads.

With this formulation the decomposition asks how much changes in $A$, $S$, $I$ and $F$ combine to yield a change in $G$ over time. Note that the —ASIF identity summarizes at the most aggregate level how different components of carbon emissions have changed.

The simplest approach asks the question —how much did total emissions change over any period because of a change in a single factor from a given base year? This —all else equal technique is called a Laspeyres decomposition [25]. This approach is computationally simple but can leave large residuals—the product of each change does not yield the total change because of cross terms. A more sophisticated technique uses the Log Mean Divisia Index or LMDI [26]. This approach has the advantage of using a rolling baseline and allocating the cross terms that appear when all of the components of the ASIF identity have changed over time. Ang [26] argues that LMDI decomposition indices have significant advantages over other decomposition techniques [27]. However, LMDI is computationally challenging and in many cases simpler techniques such as the Laspeyres decomposition produce similar results.

In this paper we produce a set of indices using both techniques partly for comparative purposes. We use 1990 as a base year for the Laspeyres decomposition, as present CO$_2$ negotiations use that same year for a base. Since LMDI does not have fixed weights, a base year is not necessary. Figures 10 and 11 present the LMDI results for different years normalizing 1990 to 100 so that comparisons from that date may be easily made. Table 1 provides the same information in a little more detail. Each index in table one measures the overall change in emissions, owing to changes in an ASIF factor, with the 1990 levels fixed as 100%. Where these indices are falling, changes in the corresponding factor can be understood as contributing to a decline in emissions.

Table 1 also compares the overall change from 1960 to 2008 for both Laspeyres and LMDI methods. As is evident they are quite similar. Note that for the passenger sector a simpler Laspeyres decomposition was used, merging the Vehicle Use ($V$km/$P$km) and Fuel Intensity (Energy/$V$km) indices. The relevant comparison here is of the product of the two LMDI indices (which yields an overall change of 79.70%) with the Laspeyres estimate of 84.9%. In general the
comparison suggests that the much simpler Laspeyres decomposition can yield most of the qualitative conclusions we reach from the more involved LMDI technique. That said, for the remainder of this discussion we refer to LMDI decomposition outputs.

**Table 1. Decomposition of Changes in Carbon Emissions from Travel and Freight, 1960–2008**

<table>
<thead>
<tr>
<th></th>
<th>LMDI Index</th>
<th>Laspeyres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>43.17%</td>
<td>76.58%</td>
</tr>
<tr>
<td>Activity</td>
<td>45.51%</td>
<td>68.70%</td>
</tr>
<tr>
<td>Mode Shift</td>
<td>93.6%</td>
<td>97.25%</td>
</tr>
<tr>
<td>Vehicle Use</td>
<td>83.78%</td>
<td>81.83%</td>
</tr>
<tr>
<td>Fuel Intensity</td>
<td>128.61%</td>
<td>144.02%</td>
</tr>
<tr>
<td>Fuel Mix</td>
<td>98.17%</td>
<td>97.10%</td>
</tr>
<tr>
<td>Carb. Content</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Summary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pkm/GDP</td>
<td>117.1%</td>
<td>128.9%</td>
</tr>
<tr>
<td>Emissions/GDP</td>
<td>115.7%</td>
<td>144.6%</td>
</tr>
<tr>
<td>FREIGHT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual</td>
<td>43.56%</td>
<td>57.40%</td>
</tr>
<tr>
<td>Activity</td>
<td>51.21%</td>
<td>67.04%</td>
</tr>
<tr>
<td>Mode Shares</td>
<td>78.63%</td>
<td>84.38%</td>
</tr>
<tr>
<td>Fuel Intensity</td>
<td>113.43%</td>
<td>107.27%</td>
</tr>
<tr>
<td>Fuel Mix</td>
<td>95.29%</td>
<td>94.72%</td>
</tr>
<tr>
<td>Carbon Content</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
<tr>
<td>Summary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tonne-km/GDP</td>
<td>134.9%</td>
<td>121.4%</td>
</tr>
<tr>
<td>Emissions/GDP</td>
<td>117.1%</td>
<td>108.23%</td>
</tr>
</tbody>
</table>

This decomposition technique can be used to project future trends [28], and reveal how much each of the multiplicative factors in ASIF formula can be altered away from their current trends to lead to lower CO₂ emissions. Similarly, the approach supports a —back-casting‖ exercise whereby rough targets for emission in a future year can be compared to emissions levels today to scope out ranges of change in each of the formula’s components that together might bring the U.S. from the present levels to proposed future levels.

Most obviously, the results in Table 1 show that overall emission levels increased due to higher travel volume. This is reflected in the —activity term, which increased steadily from 1960, and continued rising through all four benchmark years, albeit significantly more slowly after 1990. This increase was strongly led by the increase in the absolute levels of car and then air
travel. The same occurred in freight, with trucking leading much of the growth in overall freight. Travel and freight activity on each mode grew at different rates, giving rise to mode-shift within the sector as a whole, rather than simply shifts between the types of transport. However, the absolute levels of urban transit and intercity rail dropped for most of the period, indicating real shifts in modes from these to car or, for intercity rail, to air. These shifts raised emissions.

Overall the effect of the structural mode shifts within the passenger sector has been small (as observed in line 3). Transit and rail lost a small share to cars, but their share of travel in 1960 was so small that the impact of the shift on emissions was minor. Cars lost significant share to air travel, which now accounts for some 11% of all passenger km Americans travel at home. But by 1990, the base year in the calculation above, the intensity of flying was close to that of car travel, so that shift had only a small impact.

For freight the impact of mode shifts has been much larger. Trucking is much more fuel and CO₂ intensive than rail or ship (Figure 6) and its share rose significantly, from around 25% of all tonne-kilometers hauled in 1960 to almost 45% by 2008. This accounts for the 1960 —mode share index lying at less than 79% of its 1990 value in 1960. The implied increase to 1990 continued almost unabated through 2008, when the mode share index reached 110% of its 1990 value. One reason for the big mode shift 1990–2008 was a near collapse of water-borne freight, whose overall level fell by nearly 33% from its 1990 level. This was largely due to the fall in oil shipments from Alaska to mainland USA with the decline in oil production there. The volume of freight decreased relative to GDP, but not quite as rapidly as that of travel, and the overall emission relative to GDP for freight fell less than did freight volume.

To some degree the increase in emissions attributed to activity and mode shifts has been offset by improvements in both fuel intensity and the intensity of vehicle utilization. In the passenger sector, fuel intensity indices went from over 128% of 1990 values in 1960 to less than 89% by 2008. This index measures the energy used per vehicle km traveled and is therefore closely linked to the technological energy efficiency of passenger transport. At the same time vehicle utilization rose from about 84% of its 1990 value in 1960 through the early 1990s until beginning to fall to about 95% of the 1990 value in 2008. Vehicle utilization is indicated by the inverse of the ratio of passenger kilometers to vehicle kilometers. The decline in index values in recent years was caused by an increase in the number of passengers sharing vehicles (principally air, urban rail and bus), as well as an end to the longer-term decline in vehicle occupancy of cars. Overall, this meant lower emissions for the same number of passenger kilometers. That is, if more people use the same number of vehicles, emissions fall compared to constant utilization, hence the value of the index falls.

For freight as well, efficiencies have improved as indicated by the intensity index going from over 113% of the 1990 value in 1960 to about 85% in 2008. The intensity indicator here captures the effects on emissions of changes in energy used per tonne km in the freight sector.

Shifts in fuels had little impact on carbon intensities in the passenger sector. This is seen by the fact that the fuel mix index varies from 98.17% of 1990 values in 1960 to 101.54% in 2008. The small impact arises because oil products—gasoline, diesel, jet fuel and marine or rail diesel—dominate. All release similar amounts of CO₂ when burned relative to the energy they contain.
Perhaps in the future were fuel shifts to electricity increase (and be accompanied by an increase in renewable generation), we might see this factor playing a greater role.

For freight there is a slightly larger influence of fuel mix changes, with this index alone contributing to a slow increase in emissions over the last five decades (from about 95% of the 1990 levels in 1960 to about 107% in 2008).

Figure 10. LMDI decomposition results for the passenger sector
To summarize, although significant gains have been achieved in fuel intensity for both passenger travel and freight, it is not sufficient to offset the leading factor in that contributed to an overall increase in emissions, namely travel activity. In order to gain the bold reductions in emissions required, policies must address not only the fuel intensity of travel modes, but travel volume as well. Thus policies such as smart growth plans, pay-as-you drive insurance and congestion fees are increasingly more significant in addressing emissions from travel.

In Freight increases in emissions can be attributed to changes in mode shifts and fuel mix, on top of activity. As the importation of finished goods is on the rise as well as the transport of consumer package goods, fresh foods, and high value items like electronics, the increase in the use of trucking is likely to continue [29], maintaining the aforementioned trends. Transport reforms can address these trends by shifting some trucking fees to variable costs based on actual km driven and applying congestion pricing to encourage trucking firms to reduce distances per shipment or tonne-km.

While the ASIF decomposition provides a strong analysis tool to identify the necessary policies to address transport emissions, experience suggests that achieving such policies may be challenging. The next section further discusses the impact of past regulation in the context the ASIF formula.
v. The Impact of Regulation

The ASIF decomposition can shed light on the effectiveness of transport policies, by understanding what components regulation has addressed and what components have been neglected. A prevailing national policy approach is supply-side regulation, early on dominated by CAFÉ—Corporate Average Fuel Economy standards instituted by congress in 1975, and more recently characterized by biofuel production subsidies.

In the context of the ASIF formula, fuel economy standards affect vehicle energy intensity (I). The ASIF decomposition makes it apparent that the gains obtained through fuel economy standards can be largely offset by increases in travel volume (A) and modal share (S). In fact, since VKT per capita had increased almost forty percent over its 1973 level by 1990, and nearly sixty percent by 2007, and GDP per capita—a driver of both VKT and oil use—increased even more, the lack of growth in oil use per capita through 2008 is a sign that CAFÉ standards had a strong effect [11]. CAFÉ standards provoked producers to produce more fuel efficient cars than otherwise would be demanded in the market with short-term gasoline price swings. Despite the effectiveness of CAFÉ standards to slow the pace of rising emissions levels, regulating fuel efficiency is a necessary but an insufficient step to achieve actual reduction in emissions.

A more recent trend in national transport regulation is both supply-side and demand-side subsidies. On the supply-side, subsidies for biofuels and other fuel alternatives were provided with the justification of reducing carbon emissions. Whether biofuels provide any carbon savings is still a contested issue, but in terms of the ASIF decomposition, such policies affect the F component (carbon content), where A and S components remain the large drivers of change for aggregate fuel use and carbon emissions.

On the demand side, subsidies for hybrid purchases and the cash for clunkers program are examples of targeted policies that affect new vehicles fleet fuel efficiency (the I component of ASIF formula). But these programs achieve questionable relative gains for their high costs to the public.

A recent addition to policy discussions has been Feebates, or bonus/malus [30,31]. The idea was proposed many decades ago in California [30]. New vehicles emitting less than a certain balance point of emissions (which could be the —standard) receive a rebate on new purchase price, proportional to the amount by which they lie below the standard, while cars over that standard value are taxed on top of the price. The balance point can correspond to the sales-weighted standard or other value, and can be reduced over time. The steepness of the slope of taxation or rebate per gram/CO₂ can also be varied. Preliminary results from France [31] suggest a measurable effect. Since this program was introduced, new light duty vehicle CO₂/km in France went from fourth lowest to lowest in EU, and many other countries have developed such programs recently [30]. The overall impact of such policy design will be seen as a deceleration in intensity (I) for car travel, assuming vehicle occupancy is constant.

A final point that is frequently overlooked but has tremendous impact on actual effectiveness of transport policy is the regulatory context in the U.S. in general and in transport in particular. The size and fragmentation of the U.S. transport sector makes it particularly
challenging to regulate. On the consumer level, millions of decision makers make daily choices that have a cumulative effect on global GHG emissions. Additionally, regional, state and federal governments share duties of taxing, funding and building transport infrastructure. Different agencies within each governing body are in charge of different components. For example, National Highway Traffic Safety Administration sets the CAFÉ standards, while Environmental Protection Agency has to set air pollution standards. 2010 marks the first year where these two agencies are cooperating to obtain complimenting fuel efficiency standards.

Since market supply in transportation is a relatively concentrated market (12 automobile producers supply nearly all cars sold [32]), most regulation has been targeted at production. But industry centrcation has not made legislation any easier, since automobile manufacturers have been using their political and economic influence to contest regulation in courts, leading to prolonged periods between actual regulation and implementation. A prevalent outcome of court litigation is the adoption of lenient rules that appease plaintiffs. A notable example in transportation is the provision of CAFÉ credits for installation of vehicle safety features. The result of these political and structural challenges is apparent in the legislation that is finally adopted by Congress. Laws are often vague or specify goals without specifying the methods to obtain them, such as specifying a fuel efficiency standard by certain year without specifying the requirements from automobile makers. In addition, the actual laws that are adopted are those that are likely not to be contested by the public or strong market players. Thus subsidies are much more prevalent than taxes, many times at the cost of efficiency.

Given these challenges, an important consideration is that according to [33], congestion and traffic accidents have greater social costs per mile in comparison to the costs of environmental externalities. Thus, future regulation that can effectively address congestion and traffic volume of all traffic modes, will have significant co-benefits on emissions as well. Currently, this may be the easier route to take in order to affect future carbon emissions in the U.S., since price signals are grossly absent from the U.S. policy scene. Paradoxically, given the enormous weight put upon administrative and judicial rulings that take years to promulgate, price signals in the U.S. are even more significant if steady reduction in CO$_2$ emissions is to be made.

vi. Conclusion

The structure of the U.S. transportation system has changed significantly since 1960. The volume of people and goods moved has more than tripled, and the dominant modes providing that transport have largely become the most energy intensive ones. While individual modes, particularly air travel and rail freight have undergone large cuts in energy use per unit of activity, trucking and car travel also saw falling fuel and carbon intensities. However, the overall result of changes in transport activity is that emissions have more than tripled since 1960, driven largely by greater economic activity and higher car ownership. Emissions from travel increased 10% less than travel volume, while emissions from freight went up greater than the volume of freight, a result of strong growth in energy and emissions-intensive trucking. Reductions in the energy intensities of light duty vehicle travel, truck and rail freight, and air travel, had saved roughly 1/3 of all energy used for travel and freight through 2008 compared to a counterfactual of constant energy intensities from 1973 onward. This savings of roughly 12 EJ or slightly under 6 million barrels per day compares well with the slightly under 10 million barrels per day of oil and natural

The most recent U.S. Government (EIA) forecast for total carbon emission from transport using the National Energy modeling System (NEMS) shows almost no growth by 2030 over 2006 [34]. The reason is predominantly falling intensities of the key modes. But as the preceding analysis suggests, improvements in fuel intensity, may well be offset by trends in other components impacting carbon emissions. Significant emissions cuts, as proposed in U.S. and global climate resolutions, must translate to further declines in intensities and some combination of shifts back to less carbon intensive modes and slower increases in travel or freight.

In order to address aggregate impact of the transportation sector on carbon emissions, effective policy approach, as well as subsequent research, must address all the components of the ASIF formula. While setting new standards for carbon content through LFCS regulation adopted in California and strengthening CAFÉ standards, as was recently implemented by EPA and NHTSA, are significant policy tools, they are simply not enough to obtain the bold emissions reductions required by 2050. To obtain such an overarching impact on emissions, a combination of policies that address total travel volume and the transition to more fuel intensive travel modes (trucking and air) is necessary.
References and Notes


9. New data from the Bureau of Transport Statistics show that the absolute tonne-km of oil and natural gas sent by pipeline declined from 1980 to 2008, as did the share of these commodities in total freight. Thus the decline in tonne-km/GDP understates the rate at which the domestic economy became less freight-intensive.


14. The fact that ethanol was blended to make up 6% of car fuel by energy content had little real
impact on CO2, since preparing and burning the ethanol released almost as much CO2 as the
burning the gasoline replaced.

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25. Simple to compute, the drawback of these indices is that they do not account for the —cross
terms‖ that arise because two more of these components for any mode may have changed by
a great detail Think of expanding the product (A + delta A) × (S + delta S) × (I + delta I) × (F
+ delta F) without even taking into account L or V separately [22].
27. These include zero residuals, factor reversibility, time reversibility and log additivity. Ang
[21] provides a useful comparison of different methods.


