Gas Prices, Traffic, and Freeway Speeds in Los Angeles*

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Abstract

Using weekly data on six Los Angeles freeways from 2001 to 2006, we investigate how gasoline prices affect traffic speeds. We find that drivers do not respond to rising gasoline prices by slowing down, despite survey results and theoretical predictions to the contrary. However, a one dollar increase in the price of gasoline can increase average freeway speeds by nearly ten percent when higher gas prices reduce congestion. As a result, higher gasoline prices are approximately welfare neutral for drivers on congested freeways: increased fuel costs are roughly offset by the value of time saved.

Keywords: congestion, transportation, fuel cost

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1 Introduction

In light of the nearly three-fold increase in gasoline prices since the year 2001, we ask: What is the impact of gasoline prices on freeway speeds? Economists have long studied how fuel costs affect gasoline demand, yet the relationship between price and freeway speeds has received less attention. Increases in gas prices raise the cost of driving at fuel-inefficient speeds, and both economic theory and consumer surveys suggest that drivers respond by slowing down. Empirically, however, we do not find evidence of this response. Instead, we find a significant increase in traffic speeds on congested freeways. In fact, speeds may increase enough to offset the welfare loss from higher gas prices, at least for individuals who continue to drive.

To analyze how drivers respond to an increase in gas price, we consider two stylized cases. In the first, a lone driver on an empty highway is unconstrained by other drivers’ decisions. She is free to choose her optimal speed, which balances the costs of time, gasoline, and law enforcement. Driving speed affects fuel economy and thus fuel costs. On average, every five miles per hour (mph) that a driver exceeds 60 mph is roughly equivalent to paying an additional $0.20 per gallon for gasoline.\textsuperscript{1} Results from an April 2006 survey\textsuperscript{2} suggest that drivers recognize these costs: 38 percent say that they will reduce their driving speed in response to rising gasoline prices. Assuming cost-minimizing behavior, our analytical model predicts that freeway speeds, in the absence of congestion, will decrease due to an increase in gasoline prices, as drivers adjust to more fuel-efficient speeds.

In the second stylized model, congestion slows traffic such that the driver’s speed is determined by the volume of cars around her. When roads are congested, slow speeds impose significant time costs. In 2003, each driver in Los Angeles lost an average of 93 hours due to congestion (Schrank and Lomax, 2005). If people respond to rising gasoline prices by driving less, traffic will move faster and the amount of time lost due to congestion will fall. Our analytical model predicts that freeway speeds will increase with gasoline prices, as some drivers substitute toward other forms of transportation and driving for the remaining drivers becomes less congested.

To test our analytical predictions, we use data on weekly freeway speeds for six major routes in Los Angeles County from 2001 to 2006. To determine whether drivers slow down under uncongested conditions, we regress average freeway speeds during off-peak hours against gasoline prices and find that

\textsuperscript{1}From http://www.fueleconomy.gov/feg/driveHabits.shtml, based on an assumed fuel price of \$2.91/gallon.

\textsuperscript{2}Consumer Reports’ National Research Center
drivers do not respond to a change in price. This suggests that despite the overwhelmingly negative public response to rising fuel costs, gasoline prices have not increased sufficiently—relative to the opportunity cost of time—to cause drivers to significantly reduce their speeds.

We then estimate the effect of gasoline price on average speeds during rush hour periods. We find that a one dollar increase in the price of gasoline increases average speeds by 3.4 mph. Consistent with our analytical model, we argue that speeds increase because freeways become less congested, as drivers substitute toward other transportation modes or take fewer trips. To support this conclusion, we provide evidence from regressions of public transit ridership on gasoline prices. Finally, we note that for drivers in congested conditions, the increase in fuel cost is roughly offset by the value of time saved as speeds increase. This suggests that any welfare loss due to an increase in gasoline price is borne by those who switch to other modes of transportation or take fewer trips.

The remainder of the paper is organized as follows. Section 2 offers a brief literature review of previous gasoline price research. Section 3 provides the analytical model and predictions, which we test using empirical data in Section 4. Section 5 discusses the empirical results, and Section 6 concludes.

2 Consumer Response to Gas Prices

The effect of gasoline prices on consumer behavior has received a great deal of attention in the economics and transportation literature. The energy crises in the early 1970s spurred interest in how gasoline prices affect demand for fuel (Houthakker et al., 1974), and there are now dozens of studies\(^3\) estimating the demand elasticity of gasoline with respect to price and income. Data from recent estimates (Goodwin et al., 2004) suggest that the short-run elasticity with respect to price is negative but relatively small, approximately -2.5 percent. Similarly, the long-run price elasticity is negative and somewhat larger, around -6.0 percent. The elasticity with respect to income follows a similar pattern: elasticities are positive and of larger magnitude in the long run.

Although consumers respond to rising gasoline prices by reducing their consumption generally, there are a number of behavioral vectors through which this can occur. Drivers can change the frequency or length of trips, purchase more fuel-efficient vehicles, or change their driving behavior. Re-

\(^3\)Dahl and Sterner (1991) provides a review of the early literature. A survey of price and income elasticities since 1990 can be found in (Goodwin et al., 2004)
search suggests that an increase in fuel prices will cause drivers to reduce the number of miles they drive (Haughton and Sarkar, 1996; Goodwin et al., 2004), increase fuel efficiency (Goodwin et al., 2004), and own fewer vehicles (Goodwin et al., 2004). Changes in the price of gasoline can have indirect effects as well. For example, gasoline prices have been shown to be negatively correlated with vehicular accidents (Grabowski and Morrissey, 2004; Haughton and Sarkar, 1996). Others have explored the theoretical merits of a gasoline tax to reduce congestion (Parry, 2002). Recent work has explored the relative efficiency of gasoline taxes versus fuel-efficiency standards to reduce gasoline demand (West and Williams III, 2005). Bento et al. (2005) econometrically simulated the distributional and efficiency impacts of gasoline taxes, while Parry and Small (2005) considered the optimal gasoline tax in the United States and United Kingdom and identify congestion reduction as a key welfare gain from a gasoline tax.

However, empirical research on demand response has largely neglected the effect of gasoline prices on the way drivers operate their vehicles. Drivers can increase their fuel-economy by accelerating more slowly, inflating tires properly, using cruise control, and driving closer to fuel-efficient speeds.\footnote{“Good, Better, Best: How to Improve Gas Mileage.” Federal Trade Commission, September 2005.} Our focus here is on driving speed. In an early attempt to estimate the effect of gasoline price on driving speed, Dahl (1979) found that price is negatively correlated with rural road speed. Using cross-sectional data for one year at the state level, she estimates an elasticity of miles-per-hour with respect to gasoline prices of $-0.354$. We are able to look at freeway-level data that varies over both space and time. This allows us to estimate empirically how gasoline price affects driving speeds on specific freeways, at different hours of the day, and over a five-year period.

3 A Model of Traffic Speed

We begin by constructing two models of traffic speed, one for uncongested conditions and one for congested conditions. When a freeway is uncongested, drivers are free to choose their preferred, cost-minimizing speed. Under congested conditions, however, drivers are constrained by the volume of traffic. The two models provide testable predictions, which we examine empirically in sections 4 and 5.
3.1 A Sole Driver on a Lonely Highway

Consider the decision of an individual $i$ choosing between driving and not driving. If individual $i$ is the sole driver on an empty freeway, her chosen speed $S^*$ is unconstrained by other drivers. Furthermore, in the absence of congestion, the decision to drive or not drive is independent of any other driver’s decision. Thus, conditional on speed $S^*$, individual $i$ compares the costs of driving and not driving, $\min\{C_D(S^*(w, p)), C_{ND}(w)\}$. The cost of driving $C_D(S^*(w, p))$ is a function of speed $S^*(w, p)$, which will depend on the driver’s wage $w$—the opportunity cost of time—and the price of gasoline $p$, while the cost of not driving $C_{ND}(w)$ is assumed to depend only on wages. The decision to drive or not drive is characterized as:

$$D_i = \begin{cases} 
1 & \text{if } C_D(S^*(w, p)) < C_{ND}(w) \\
0 & \text{if } C_D(S^*(w, p)) \geq C_{ND}(w)
\end{cases}$$

(1)

where $D_i$ takes the value 1 if the costs of driving $C_D(S^*(w, p))$ are less than not driving, and 0 if the costs of not driving $C_{ND}(w)$ are less than the costs of driving.

Conditional on choosing to drive, $D_i = 1$, the driver knows three things: Driving quickly will reduce her driving time, deviating from 55 mph\(^5\) will increase her fuel-per-mile consumption, and traveling faster than the posted speed limit increases the chance of getting a speeding ticket. If $w$ is the driver’s wage rate and $p$ is the price of gasoline then we can write the driver’s cost minimization problem as:

$$\min_S C_D = w \cdot t(S) + p \cdot g(S) + L(S)$$

(2)

where $t(S)$ is the time it takes to travel one mile at speed $S$, $g(S)$ is the gasoline used per mile at speed $S$, and $L(S)$ is the expected law enforcement cost\(^6\) from travelling faster than the speed limit at speed $S$. Intuitively, $t(S)$ is a decreasing convex function such that \(\frac{\partial t}{\partial S} < 0\) and $\frac{\partial^2 t}{\partial S^2} < 0$, while $g(S)$ is an increasing convex function with respect to deviations from 55 mph such

\(^5\)We assume that a car operates at its most fuel-efficient level at this speed. While different types of cars may have slightly higher or lower optimal speeds, typically drivers can maximize fuel economy at speeds around 55 mph. See discussion below.

\(^6\)While we have defined $L(S)$ to be law enforcement costs, it can also represent safety concerns or vehicle technical constraints whose costs also rapidly increase as speeds increase. See Ashenfelter and Greenstone (2004) for a derivation of optimal speed in the context of the value of a statistical life (VSL) that trades off travel time for increased risk of fatality.
that \( \frac{\partial g}{\partial S} > 0 \) if \( S > 55 \) mph and \( \frac{\partial g}{\partial S} < 0 \) if \( S < 55 \) mph and \( \frac{\partial^2 g}{\partial S^2} > 0 \). This non-monotonic relationship between fuel-efficiency and speed is shown in Figure 1. Finally, \( L(S) \) is an increasing convex function \( \frac{\partial L}{\partial S} > 0 \) and \( \frac{\partial^2 L}{\partial S^2} > 0 \) (and likely very steep).

The optimal driving speed \( S^* \) satisfies the First Order Condition:

\[
\frac{\partial C_D}{\partial S} = w \frac{\partial t}{\partial S} + p \frac{\partial g}{\partial S} + \frac{\partial L}{\partial S} = 0
\]

Clearly, on a freeway with a speed limit greater than or equal to 55 mph, it is never optimal to go under 55 mph, thus \( \frac{\partial g}{\partial S} > 0 \). The optimal speed chosen \( S^* \) balances the decrease in time cost \( w \frac{\partial t}{\partial S} < 0 \) against the increase in gasoline cost \( g \frac{\partial g}{\partial S} > 0 \) and law enforcement cost \( \frac{\partial L}{\partial S} > 0 \) as the driver increases her speed \( S \).

Rewriting (3), the F.O.C gives the relationship:
\[ p = - \frac{w \frac{\partial t}{\partial S} + \frac{\partial L}{\partial S}}{\frac{\partial g}{\partial S}} \]  

(4)

which requires that \( w \frac{\partial t}{\partial S} + \frac{\partial L}{\partial S} < 0 \) for an interior solution for \( S^* \).

We now differentiate the first order condition (4) with respect to price of gasoline \( p \) to determine implicitly how the choice of \( S^* \) varies with changes in price, which gives:

\[
1 = w \frac{\partial t}{\partial S} \frac{\partial^2 g}{\partial S^2} \frac{\partial S}{\partial p} - \frac{\partial g}{\partial S} \frac{\partial^2 t}{\partial S^2} \frac{\partial S}{\partial p} + \frac{\partial L}{\partial S} \left( \frac{\partial^2 g}{\partial S^2} \frac{\partial S}{\partial p} - \frac{\partial g}{\partial S} \frac{\partial^2 L}{\partial S^2} \right) \frac{\partial S}{\partial p} \]  

(5)

Rearranging and solving for \( \frac{\partial S}{\partial p} \) gives:

\[
\frac{\partial S}{\partial p} = \frac{\left( \frac{\partial g}{\partial S} \right)^2}{w \left( \frac{\partial t}{\partial S} \frac{\partial^2 g}{\partial S^2} - \frac{\partial g}{\partial S} \frac{\partial^2 t}{\partial S^2} \right) + \frac{\partial L}{\partial S} \left( \frac{\partial^2 g}{\partial S^2} \frac{\partial S}{\partial p} - \frac{\partial g}{\partial S} \frac{\partial^2 L}{\partial S^2} \right)} \]

(6)

which is equivalent to:

\[
\frac{\partial S}{\partial p} = \frac{\left( \frac{\partial g}{\partial S} \right)^2}{w \frac{\partial t}{\partial S} + \frac{\partial L}{\partial S} \frac{\partial^2 g}{\partial S^2} - \frac{\partial g}{\partial S} \frac{\partial^2 t}{\partial S^2} - \frac{\partial g}{\partial S} \frac{\partial^2 L}{\partial S^2}} \]

(7)

The numerator is unambiguously positive, while the first term in the denominator is negative by (4). The subtracted second and third terms are both positive per our definitions of \( t(S), g(S) \) and \( L(S) \). Thus, the denominator is negative, and therefore \( \frac{\partial S}{\partial p} < 0 \). An increase in gasoline price will lead to a decrease in speed. For the case of an uncongested freeway, we have derived the following prediction:

**Proposition 1**: When drivers are free to choose their own speed \( S \), an increase in the price of gasoline \( p \) will decrease speeds, \( \frac{\partial S}{\partial p} < 0 \).

We now turn to the magnitude of the speed response to gasoline prices. First, consider the case when the law enforcement term is zero. In the absence of law enforcement costs, a driver simply balances the marginal time savings of driving faster against the marginal cost of driving at fuel-inefficient speeds. An increase in the price of gasoline increases the marginal cost of driving at fuel-inefficient speeds, and thus should result in a decrease in speed towards 55 mph.
This is illustrated in figure 2 for two prices $p$, and $p' > p$, where again, $w \frac{\partial t}{\partial S}$ can be thought of as the marginal benefit of increasing speed above 55 mph, while $p' \frac{\partial g}{\partial S}$ can be thought of as the marginal cost of increasing speed:

![Figure 2: Marginal Costs and Benefits versus Speed without Law Enforcement](image)

Next consider the case where the law enforcement term is not zero. From (7), the presence of strong law enforcement in the form of rapidly increasing costs will decrease the sensitivity of speeds to gasoline prices\(^7\). This is illustrated in Figure 3 for prices $p$ and $p' > p$.

\(^7\)Consider the case of extremely stringent law enforcement such that marginal costs rise extremely steeply $\frac{\partial^2 t}{\partial S^2} >> 0$. Speeds in that case will be determined exclusively by the stringent law enforcement costs.
Figure 3: Marginal Costs and Benefits versus Speed with Law Enforcement

### 3.2 A Commute on a Congested Freeway

We now examine how speed changes in the presence of other drivers. When there are more drivers on the road, the speed at which traffic flows can be thought of in the context of fluid dynamics (Coscia et al., 2002). When relatively few units flow past a given point, their velocity is independent of interactions with other units (laminar flow). However, as more units flow past a given point their interactions with one another become more important, decreasing the overall velocity of the particles (turbulent flow).

In this context, the traffic velocity $v$ at a given point is then given by:

$$
v = \begin{cases} 
S^* & \text{if } \bar{D} < K, \\
S(\bar{D}) & \text{if } \bar{D} \geq K 
\end{cases}
$$

where $S^*$ is an individual’s choice of speed from (3), $\bar{D}$ is the number of cars on the road, $K$ is the laminar carrying capacity of the freeway, and speed
$S(\bar{D})$ is a decreasing function that describes the congestion effect on speed as a function of the number of cars on the road ($S(K) = S^*$).\textsuperscript{8}

As before, in deciding whether to drive, individual $i$ chooses the mode of transportation $D_i$ that minimizes costs per mile, $\min\{C_D(S(\bar{D})), C_{ND}(w)\}$. However, in the presence of congestion, individual $i$ is no longer free to travel at her optimal speed choice $S^*$. Instead, her speed depends on the number of other cars on the road, and thus the decisions of other drivers. The number of cars on the road $\bar{D}$ is then simply the sum of the number of individuals that choose to drive $\bar{D} = \sum_i D_i$.

In the case of rush hour congestion, we assume the total number of drivers exceeds the laminar capacity $\bar{D} > K$ such that $v = S(\bar{D})$, which is decreasing in the number of drivers. We also assume that congestion keeps speeds below the posted speed limit so that law enforcement costs are zero, $L(S) = 0$. We are interested in the effect of prices on congested speeds $S(\bar{D})$ where the number of drivers choosing to drive depends on price $\bar{D} = \bar{D}(P)$.

In equilibrium, we assume people decide to drive until the cost of driving equals the cost of not driving. As speeds decrease due to congestion, increasing time and fuel costs become large enough to make alternative transportation attractive:

$$
C_D(w, p) = w * t(v(p)) + p * g(v(p)) = C_{ND}(w)
$$

or substituting in from (8)

$$
C_D(w, p) = w * t(S(\bar{D}(P))) + p * g(S(\bar{D}(P))) = C_{ND}(w)
$$

which holds for some $\bar{D}(p)$,\textsuperscript{9} We differentiate (10) with respect to price to consider the effects of a change in price on this implicitly defined $\bar{D}(p)$.

$$
\frac{\partial \bar{D}}{\partial p} = -\frac{g(S(\bar{D}(p)))}{w \frac{\partial S}{\partial \bar{D}} + p \frac{\partial g}{\partial S} \frac{\partial S}{\partial \bar{D}}}
$$

\textsuperscript{8}See Evans (1992) for a graphical discussion of traffic flow, density, and congestion and Walters (1961) for a classic treatment of congestion.

\textsuperscript{9}Suppose it did not and $C_D > C_{ND}$, then there is a disincentive for drivers to drive, thus fewer people driving will increase speeds, decreasing time and monetary costs (if $v < 55mph$) until $C_D = C_{ND}$.
At any speed below $S^*$, the denominator is unambiguously positive\textsuperscript{10} and the numerator is positive, thus the negative sign in (12) ensures that $\frac{\partial D}{\partial p} < 0$. The demand for driving decreases as prices increase. Furthermore, by (8), a decrease in the number of drivers leads to an increase in speeds, $\frac{\partial S}{\partial D} \frac{\partial D}{\partial p} > 0$

Thus, by (12), we derive the following prediction that in congested conditions, an increase in the price of gasoline will decrease the demand for driving, thereby increasing the speed of the remaining drivers

\textit{Proposition 2: In the presence of congestion, higher gasoline prices $p$ will lead to an increase in speed $S$ as individuals substitute away from driving, $\frac{\partial S}{\partial D} \frac{\partial D}{\partial p} > 0$}

\section{Empirical Analysis of Freeway Speeds}

In this section we describe the data used to estimate the relationship between freeway speeds and gasoline prices. The data are unique in that they are real-time measurements of freeway conditions in Los Angeles County; consequently, they provide a detailed description of how drivers and freeway conditions evolve over time and with gasoline price. We begin by discussing the data sources and then describe the estimation process for the uncongested and congested scenarios.

\subsection{Data and Sources}

Our data on freeway speeds come from the Performance Monitoring System (PeMS), which aggregates data collected by the California Department of Transportation (Caltrans). In most of California’s urban areas, detectors embedded in roadways measure traffic flow and occupancy\textsuperscript{11} every 30 seconds at thousands of points throughout the freeway system. These detectors provide data on the speed at which vehicles are traveling on a given section of freeway during a specific time period. We use data from PeMS on freeway speeds averaged over one-week intervals for six major freeway routes in Los

\textsuperscript{10}At speeds below 55 mph, both terms are positive. For speeds between 55 mph and $S^*$, it has to be the case that $w \frac{\partial S}{\partial D} \frac{\partial S}{\partial p} > p \frac{\partial S}{\partial D} \frac{\partial S}{\partial p}$ ensuring that the denominator remains positive.

\textsuperscript{11}According to PeMS: Flow is a quantity measured by the detectors in the freeway. It is the number of vehicles which have passed by the detector in a give period of time. Occupancy is the percentage of time that a detector is on for a given time period.
Angeles.\textsuperscript{12} Weekly aggregation reduces the influence of random flow disruptions, such as traffic accidents. The data span the period from December 2001 to May 2006.

We focus on Los Angeles both for practical reasons and because the city has high traffic volumes. While the real-time freeway detector system is not unique to California—for example, similar systems are in place in Seattle, Washington and Houston, Texas—PeMS provides unprecedented data availability. Within California, Los Angeles has an extensive freeway system and persistent congestion problems, including four of the ten most congested interchanges in the country. In the future, it may be valuable to investigate freeway speeds in other cities in California or in other states. For now, we focus exclusively on Los Angeles.

Our primary explanatory variable of interest is the retail price for regular grade gasoline. The data on average weekly gasoline prices for Los Angeles are from the Energy Information Administration. We adjust price data for inflation, and all prices are in 2006 dollars. Other control variables include income, unemployment, and weather. Per-capita income data for Los Angeles County are from the Bureau of Economic Analysis.\textsuperscript{13} We control for weather with data on weekly rainfall, as measured in downtown Los Angeles, from the National Weather Service.\textsuperscript{14} Finally, monthly unemployment data are from the California Employment Development Department estimates of the unemployed percentage of the workforce in Los Angeles County.\textsuperscript{15}

\subsection{Uncongested Freeway}

To determine how drivers respond to a change in the price of gasoline when they are unconstrained by the behavior of other drivers on the road, we need to look at freeway speeds when the congestion constraint is not binding. Consequently, to test our lonely highway prediction, we focus on average freeway speeds between 2am and 4am. During early morning hours there are few drivers on the road, and individuals who choose to travel by freeway will

\textsuperscript{12}PeMS provides route data for US-101, CA-118, I-710, I-5, and two routes for I-10 (west and east of the city center). We include in our analysis all routes for which time series data on speeds are available.

\textsuperscript{13}The data can be found here: \texttt{<http://www.bea.gov/bea/regional/reis/CA1-3fn.cfm>}. Data for 2005 and 2006 are not yet available. We have estimated these data based on the relationship between Los Angeles and California income. Weekly values are imputed and all data are adjusted for inflation.

\textsuperscript{14}Rainfall data can be found here: \texttt{<http://www.weather.gov/climate/index.php?wfo=lox>}. All six routes we examine have a terminus in downtown Los Angeles.

\textsuperscript{15}The data can be found here: \texttt{<http://www.labormarketinfo.edd.ca.gov/>}.
face little to no congestion. Consequently, the dependent variable $speed_{it}^{NC}$ is the average speed in miles per hour on freeway route $i$ during week $t$ from 2-4am. Our primary regressor is the price of gasoline in dollars, and we include controls for income and rainfall. Lastly, to account for individual variation across freeways and through time, we include freeway and year fixed effects. The equation we estimate is:

$$speed_{it}^{NC} = \alpha + \beta_1 price_t + \beta_2 X_t + \gamma F_i + \tau Y_t + \epsilon_{it}$$ (13)

where $X_t$ are the control variables, $F_i$ are freeway fixed effects, and $Y_t$ are year fixed effects. Based on our theoretical model, we predict that the coefficient on price $\beta_1$ should be negative, as drivers reduce their speed in response to increased fuel costs.

4.3 Congested Freeway

To estimate the effect of gasoline prices under congested freeway conditions, we focus on freeway speeds during rush hour when travel demand is greatest. A freeway suffers from rush hour congestion if a large number of drivers travel predominantly toward the city center in the morning and in the opposite direction in the evening. As a result, the “inbound” lanes would be congested between 6am and 8am during the morning rush hour, and the “outbound” lanes would slow from 4pm to 6pm, during evening rush hour.\textsuperscript{16} Thus, we use the 6am to 8am time period for “inbound” lanes that go to downtown Los Angeles, and the 4pm to 6pm periods for “outbound” lanes leaving downtown Los Angeles.

Once again, the dependent variable, $speed_{it}^{C}$, is the weekday average freeway speed in miles per hour on freeway route $i$ for week $t$ during rush hour periods of 6-8am and 4-6pm. The control variables in our congestion regression are the same as those in the uncongested estimation, income and rainfall. We also control for unemployment, because travel demand during rush hour periods will be closely related to changes in the number of individuals making employment-related trips. We also include dummy variables for the Christmas holiday and summer periods. The holiday dummy controls for systematic travel demand changes during the last two weeks of each year, as individuals take significant time off of work and schools are out of session. The summer dummy controls for any changes in travel demand (e.g.,

\textsuperscript{16}In cities where there is no single city center, both inbound and outbound routes on a freeway may be congested simultaneously. On most LA freeways, both morning and evening rush hour periods show strong evidence of congestion, and often in both directions.
due to the academic cycle, vacations) that affect speeds but are unrelated to gasoline price.

The equation we estimate is:

\[
\text{speed}_{it} = \delta + \zeta_1 \text{price}_t + \zeta_2 X_t + \eta F_i + \sigma Y_t + \lambda D_i + \nu_{it}
\]  

(14)

where again \( X_t \) are the control variables, \( F_i \) are freeway fixed effects, \( Y_t \) are year fixed effects, and \( D_i \) are the holiday and summer dummies. Based on our analytical model, we would expect the coefficient on price \( \zeta_1 \) to be positive as drivers substitute towards alternative transportation modes, thereby reducing congestion for the remaining drivers.

5 Results and Discussion

Table 1 gives the estimates for changes in weekly freeway speeds (mph) against the regressors listed below.
Dependent variable: miles per hour (mph)

<table>
<thead>
<tr>
<th>Regressor</th>
<th>No Congestion</th>
<th>Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline Price</td>
<td>-0.0393 (0.331)</td>
<td>3.37** (0.593)</td>
</tr>
<tr>
<td>Income</td>
<td>-0.0697 (0.108)</td>
<td>-2.59** (0.238)</td>
</tr>
<tr>
<td>Unemployment</td>
<td>-</td>
<td>0.779 (0.557)</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.224** (0.0800)</td>
<td>-0.139 (0.116)</td>
</tr>
<tr>
<td>Holiday</td>
<td>0.702** (0.306)</td>
<td>10.9** (0.961)</td>
</tr>
<tr>
<td>Summer</td>
<td>0.195 (0.128)</td>
<td>2.99** (0.279)</td>
</tr>
<tr>
<td>Freeway FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Constant</td>
<td>68.0 (3.75)</td>
<td>125.7 (9.83)</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.14</td>
<td>0.50</td>
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<tr>
<td>N</td>
<td>2724</td>
<td>2724</td>
</tr>
</tbody>
</table>

Notes: Robust standard errors reported in parentheses.  
**Significant at the 5-percent level

Table 1: Results for freeway speeds in Los Angeles County (2001-2006)

5.1 No Congestion

The results from the freeway speed regression in the absence of congestion suggests that while speeds may decrease, they do not decrease in an economically or statistically significant manner. The coefficient on gasoline price is -0.0393 but is not statistically significant. This non-result is consistent under various specifications,\textsuperscript{17} all of which generate small point estimates—the largest being around -0.5 mph per dollar—that are not significant.

\textsuperscript{17}Because drivers on the road between 2 and 4am may not be representative of the typical driver, we also considered how gasoline prices affect speeds between 9 and 11pm. We find similar results during this period: gasoline price has little to no effect on freeway speeds. We decline to report the 9-11 pm results because we are not certain that congestion effect are absent during that time period.
Contrast this with the earlier study Dahl (1979) which found a speed elasticity of -0.354 with respect to gasoline price. Roughly speaking, by that measure, with prices increasing nearly 200 percent from 2001 to 2006, road speeds should have decreased by a staggering 40 mph. Obviously it is inappropriate to extend the measure of elasticity over such a non-marginal change in price, but the point remains that under various specifications, we find no economically or statistically significant response by drivers—let alone anything approaching Dahl’s result.

We believe there are two likely explanations for the lack of a speed response during uncongested periods. First, drivers may not be aware that high speeds reduce fuel-efficiency, or they may be unaware of the magnitude of this effect. However, consumer surveys suggest otherwise: drivers indicate they the recognize the benefits of altering their driving behavior. Alternatively, even if people are aware of the significant effect of speed on fuel-efficiency, it is possible that, in Los Angeles at least, drivers have a high enough time value that it is ultimately law enforcement—and perhaps personal safety concerns—that determine freeway speeds in the absence of congestion.\textsuperscript{18} In the end, drivers may care about fuel costs, but they care more about time costs.

5.2 Congestion

While the decrease in freeway speeds in the absence of congestion are not economically or statistically significant, the impact of gasoline prices on freeway speeds in the presence of congestion is empirically strong and accords with our analytical predictions. For the specification shown in Table 1, we find that a one dollar increase in the price of gasoline is correlated with a 3.4 mph increase in freeway speeds. This result is robust to alternate specifications: estimates range from 2-4 mph per dollar, and are always statistically significant.

According to our analytical model, traffic speed on a congested freeway increases with gasoline prices because drivers either take fewer trips or substitute away from driving to alternative transportation modes. We believe our empirical findings reflect this effect: as prices rise congestion falls, thereby relaxing the constraint on driver’s speed.

Although we cannot observe congestion directly,\textsuperscript{19} we do have some evi-

\textsuperscript{18} See (7) for analytical explanation

\textsuperscript{19} The freeway monitoring systems from which we acquire our data can report only the number of cars that pass over a point on a freeway in a given amount of time. While a high volume measurement could indicate a congested freeway, one with many cars traveling
idence to support the assertion that drivers respond to higher gasoline prices by taking public transportation. We collected monthly data on ridership for both bus and rail transit in Los Angeles from 2001 to 2006. If higher gasoline prices cause drivers to switch transportation modes, we should see a concomitant effect on demand for public transportation. As the regression results in Table 2 show, we find that this is the case.

<table>
<thead>
<tr>
<th>Regressor</th>
<th>Bus</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline Price</td>
<td>5954**</td>
<td>110.4**</td>
</tr>
<tr>
<td></td>
<td>(1276)</td>
<td>(14.26)</td>
</tr>
<tr>
<td>Income</td>
<td>-2768**</td>
<td>-10.28**</td>
</tr>
<tr>
<td></td>
<td>(509.6)</td>
<td>(5.697)</td>
</tr>
<tr>
<td>Unemployment</td>
<td>-3238**</td>
<td>10.56</td>
</tr>
<tr>
<td></td>
<td>(1164)</td>
<td>(13.01)</td>
</tr>
<tr>
<td>Rainfall</td>
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<td>-8.036**</td>
</tr>
<tr>
<td></td>
<td>(228.7)</td>
<td>(2.556)</td>
</tr>
<tr>
<td>Year FE</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Constant</td>
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<td>769.7</td>
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<tr>
<td></td>
<td>(21717)</td>
<td>(242.8)</td>
</tr>
<tr>
<td>R-squared</td>
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<td>0.69</td>
</tr>
<tr>
<td>N</td>
<td>209</td>
<td>209</td>
</tr>
</tbody>
</table>

*Notes: Robust standard errors reported in parentheses.*

**Significant at the 5-percent level

Table 2: Results for public transit ridership in Los Angeles (2001-2005)

The first column in Table 2 shows the effect of gasoline price on bus ridership, while the second column provides the same estimate for rail transit. In both regressions we control for income, unemployment, weather, and year fixed effects. There is a strong positive relationship between gasoline price and ridership for both modes of public transportation. For bus transit, a one dollar increase in gasoline price increases ridership by nearly six million trips. Similarly, a unit increase in fuel prices is correlated with a 110,000-trip increase very slowly, it could also reflect an uncongested freeway where the same number of cars travel faster because traffic density is lower. In a way, traffic speed is the best measure of congestion. As the example just given suggests, if we observe the same number of cars passing by a point on a congested freeway versus a freeway that is congestion-free, the primary observable difference is how fast the cars on each freeway are moving.
crease in rail ridership. In both cases, an increase in income reduces demand for public transit, while unemployment is negatively correlated with bus ridership but uncorrelated with rail demand. Rainfall has no significant effect on bus ridership but reduces demand for rail trips. We believe the results for public transportation ridership support the notion that higher gasoline prices increase freeway speeds because people substitute other transportation modes in favor of freeway driving.

5.3 Implications

What then are the implications of these results? First, the fact that drivers in Los Angeles did not slow down significantly in response to changes in gasoline prices suggests, perhaps somewhat surprisingly, that people make large changes in behavior (e.g., buy more fuel-efficient cars, take fewer trips) but do not make small, marginal changes in driving behavior. Given the strong public response to gasoline prices, we might expect that drivers would be willing to slow down, at least somewhat. In fact, people report that they plan to change their driving behavior—by reducing their speed—in response to rising gasoline prices.\footnote{Consumer Reports Auto Pulse Survey, May 2006.} There is also a strong political response to public pressure on gasoline prices, including proposals like a windfall taxes on energy companies, use of the Strategic Petroleum Reserve, suspension of the Federal gasoline tax, and Federal Trade Commission investigations into price gouging and market manipulation (\textit{Interim Report on Gasoline Pricing: A Report to Congress}, 2006).

Nevertheless, drivers do not seem to be voting with their gas pedal. If prices jumped one dollar per gallon overnight, there would likely be significant public response, as occurred when hurricane Katrina caused a rapid increase in gasoline prices in late August and early September of 2005. Yet our results suggest that drivers would continue to ply the interstates at high speeds with little regard to fuel costs, which can be substantial: driving 80 mph raises the cost of driving by nearly one dollar per gallon relative to a speed of 60 mph. This disconnect between the public response to gasoline prices and actual driving behavior is puzzling. When the rubber hits the road, talk about driving speed appears to be cheap.

Second, the speed response in the presence of congestion suggests that there may be potential for gasoline taxes to reduce both the pollution externality and the congestion externality of driving. Although not the most efficient instrument for reducing congestion, a gasoline tax may still produce...
significant benefits by reducing congestion (Parry, 2002). When congestion is a factor in driving speeds, our results suggest that, for the average driver, a gasoline tax would be approximately cost-neutral, with the value of time savings offsetting the cost of increased gasoline prices. It may even be possible for a gasoline tax to be welfare improving independent of pollution externalities if the opportunity cost of time is large enough for drivers in congested areas.\footnote{In the context of a gasoline tax, if the revenue raised was used to compensate former drivers who switch to public transportation, then the tax could be welfare-neutral for all commuters.}

We can calculate the per mile increase in costs due to gasoline prices compared to the per mile decrease in costs from the reduction of congestion. From (9), the benefit-per-mile for drivers who continue to drive following a price increase from \( p \) to \( p' \) is given by:

\[
\Delta C_D = w \times \left( \frac{1}{S(p)} - \frac{1}{S(p')} \right) - (p' - p) \times \frac{1}{\text{mpg}} \tag{15}
\]

For an income of $40,000 per year, the value of time for the average driver is \( $20/\text{hour}.\footnote{Deacon and Sonstelie (1985) find that the value of time spent waiting in a vehicle is close to after-tax wages.} \) At an initial freeway speed of 46 mph and a fuel-efficiency of 30 miles/gallon, we use (15) to calculate the change in cost-per-mile for an increase in gasoline price from $2.00 to $3.00 and a 2-4 mph increase in traffic speed. This gives a net cost over the interval \( (-0.015, 0.0015) \).\footnote{It is likely that drivers would benefit from an increase in fuel-efficiency as well, which would slightly decrease the costs of a gasoline price increase.}

That the interval spans $0 and is of a very small magnitude provides support for the equilibrium assumption behind (9). Drivers substitute for alternative modes of transportation in order to equate the costs of driving with those alternate modes. This result also suggests that for those drivers who face congestion on a daily basis and have near-mean incomes and near-mean fuel-efficiency, increasing gasoline prices do not raise net costs. Moreover, the typical driver in Los Angeles likely has an income—and thus opportunity cost of time—that is higher than the county average; consequently, our estimated interval should be considered a lower-bound.

In calculating the welfare effects of rising gasoline prices, our estimates indicate that the welfare gain due to increased freeway speeds (and thus reduction in travel times) should not be overlooked. Given that the average driver loses 93 hours per year to congestion, a one percent reduction in yearly travel time for the 7 million drivers in greater Los Angeles would translate

\[ \frac{93 \times 7 \times 10^6 \times 24 \times 365 \times 0.015}{3 \times 2 \times 60 \times 60} \]

\[ = 19,200,000 \]
into approximately $100 million in annual benefits. We find that a one
dollar increase in the price of gasoline increases speeds by approximately 6.5
percent. This corresponds to a 6.5 percent reduction in lost travel time—an
annual gain of around six hours per driver. Thus, the benefits of time-
saved from a one dollar price increase could be upwards of $650 million
dollars per year for Los Angeles.21 These calculations are admittedly crude,
and a rigorous analysis of the congestion-related welfare effects of a gasoline
tax would require detailed information on incomes of all commuters in Los
Angeles. Nonetheless, we believe that our results suggest strong potential
welfare gains from decreased congestion due to gasoline price increases.

6 Conclusion

While the effect of gasoline price on fuel demand has been studied in detail,
the impact on travel time and speed has been largely overlooked. Surveys
suggest that drivers respond to rising fuel costs by driving in a more fuel-
efficient manner. Moreover, each driver in Los Angeles loses an average of 93
hours per year due to congestion. We use data on weekly average freeways
speeds to investigate these effects in light of the tripling of gasoline prices
over the past five years.

We consider two stylized cases: in one case a lone driver on an empty
highway is free to choose her optimal speed, and in the other case congestion
slows traffic such that the driver’s speed is determined by the volume of
cars around her. Our analytical model predicts that, absent congestion,
freeway speeds will decrease due to an increase in gasoline prices. On the
other hand, in the presence of congestion, our analytical model predicts that
freeway speeds will increase due to an increase in gasoline prices, as drivers
substitute toward other forms of transportation thereby reducing congestion.

We use data on weekly freeway speeds for six major routes in Los Angeles
County from 2001 to 2006 to test our analytical predictions. We regress
average freeway speeds in the absence of congestion (from 2-4am) against
gasoline prices and find that drivers do not respond to a change in price.
This suggests that despite the overwhelmingly negative public response to
rising fuel costs, gasoline prices have not increased sufficiently—relative to
the opportunity cost of time—to cause drivers to reduce their speeds to more

21 The preceding calculations are based on Schrank and Lomax (2005), who find that
the total congestion costs for greater Los Angeles are $10.7 billion in 2003. The authors
estimate the cost of congestion for drivers during peak travel periods, assuming a time
cost of $13.75/hour.
fuel-efficient levels.

For congested conditions, we estimate the effect of gasoline prices on average speeds during the 6-8am and 4-6pm rush hour periods. We find that a one dollar increase in gasoline price increases average speeds by approximately 3 mph. Consistent with our analytical model, we argue that speeds increase because drivers substitute toward other transportation modes and freeways become less congested. Regressions of public transit ridership against gasoline prices support this conclusion. Finally, we note that on congested freeways, the cost of an increase in the price of gasoline is roughly offset by the value of time saved, as congestion falls and freeway speeds increase. Using estimates of the cost of congestion in Los Angeles, we conclude that increased gasoline prices may generate a substantial indirect welfare gain by reducing congestion.

References


Parry, I. W. and Small, K. A.: 2005, Does britain or the united states have the right gasoline tax, American Economic Review 95(4), 1276–1289.


