

## Changing Vehicle Travel Price Sensitivities

### *The Rebounding Rebound Effect*

10 September 2012

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### Abstract

There is growing interest in transportation pricing reforms to help achieve various planning objectives such as congestion, accident and emission reductions. Their effectiveness is affected by the price sensitivity of transport, that is, the degree that prices affect travel activity, measured as *elasticities* (percentage change in travel caused by a one-percent price change). Lower elasticities imply that price reforms are relatively ineffective at achieving planning objectives, price increases significantly harm consumers, and *rebound effects* (additional vehicle travel caused by increased fuel economy) are small so strategies that increase vehicle fuel economy are effective at conserving fuel. Higher elasticities imply that price reforms are relatively effective at achieving planning objectives, consumers can easily reduce their travel, and rebound effects are large. Some studies found very low transport elasticities during the last quarter of the Twentieth Century but recent evidence suggests that price sensitivities have since increased. This report discusses the concepts of price elasticities and rebound effects, reviews vehicle travel and fuel price elasticity estimates, examines evidence of changing price sensitivities, and discusses policy implications.

Summarized in,

“Changing North American Vehicle-Travel Price Sensitivities: Implications For Transport and Energy Policy,” *Transport Policy*, July 2012 (<http://dx.doi.org/10.1016/j.tranpol.2012.06.010>)

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## Introduction

There is growing interest in various transport price reforms to help achieve various planning objectives including traffic and parking congestion reductions, improved traffic safety, energy conservation and emission reductions. Table 1 lists examples of these reforms.

**Table 1 Transportation Price Reforms (VTPI 2010)**

Name	Description
Road pricing	Road tolls and mileage fees with rates that increase under congested conditions.
Parking pricing	Direct user financing of parking facilities with rates that vary by time and location.
Fuel pricing	Reduced subsidies and increased fuel taxes.
Distance-based pricing	Basing insurance and registration fees directly on the amount a vehicle is driven.

*Transport pricing reforms are advocated to achieve various planning objectives including traffic and parking congestion reductions, traffic safety, energy conservation and emission reductions.*

Many people are skeptical. They believe that pricing has little effect on travel activity so pricing reforms are ineffective and harmful to consumers and the economy, and other strategies are more effective at achieving planning objectives. A key factor in this analysis is the price sensitivity of transport, that is, the amount that price changes affect travel activity and fuel consumption, measured as *elasticities*: the percentage change in consumption caused by a percentage change in price.

Lower elasticities (price changes cause relatively small changes in consumption) imply that pricing reforms have small impacts and benefits, and that consumers lack viable alternatives and so are significantly burdened by price increases (what economists call a loss of *consumer surplus*). In addition, low price elasticities imply that *rebound effects* (additional vehicle travel that results from increased fuel economy<sup>1</sup>) are small, so regulations and incentives that encourage the purchase of more fuel efficient vehicles are effective at reducing total fuel and emissions. Conversely, high elasticities (price changes cause relatively large changes in consumption) imply that price reforms are relatively effective and beneficial, that consumers can reduce vehicle travel and fuel consumption with minimal harm, and rebound effects are large so regulations and incentives that encourage vehicle fuel efficiency are less effective and cause large increases in external costs.

Some research indicates that vehicle travel became less price sensitive during the last quarter of the Twentieth Century, but there is growing evidence that the very low elasticities reported during that time period were an anomaly, reflecting unique demographic and economic conditions, and transport elasticities are increasing to more normal levels. This report explores these issues. It discusses the concepts of price elasticities and rebound effects, reviews information on vehicle travel and fuel price elasticities, examines evidence of changes in price elasticity values, and discusses policy implications.

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<sup>1</sup> *Fuel economy* refers to the amount of fuel used per vehicle-mile or –kilometer.

## Transportation Elasticities

Price sensitivity is often measured using *elasticities*, defined as the percentage change in a good's consumption caused by each one-percent change in its price or other characteristics such as speed. A negative sign indicates the effect is opposite from the cause, so for example, a -0.5 elasticity of vehicle use *with respect to* (abbreviated *WRT*) vehicle operating expenses means that each 1% expense increase causes vehicle travel to decline 0.5%.

Elasticity values are classified by magnitude. *Unit elasticity* refers to a 1.0 absolute value (1.0 or -1.0) elasticity, meaning that price changes cause proportional consumption changes. Elasticities of less than 1.0 absolute value are called *inelastic*, meaning that prices cause less than proportional consumption changes. Elasticity values greater than 1.0 absolute value are called *elastic*, meaning that price changes cause more than proportional consumption changes. As normally measured, vehicle travel is considered *inelastic*, meaning that changes in fuel, parking and road toll prices generally cause proportionately smaller changes in mileage and fuel consumption, but this reflects the way these impacts are measured. People often focus on short-run (within a year) impacts, which are typically only a third of long-run effects, and most price changes only affect a subset of total vehicle costs. For example, if the short-run elasticity of vehicle travel with respect to fuel is -0.1, the long-run elasticity is about -0.3, and since fuel only represents about 25% of total vehicle costs, the elasticity of vehicle travel with respect to total costs is -1.2, which is considered elastic.

Various factors affect transport elasticities (Goodwin, Dargay and Hanly 2004; Litman 2011):

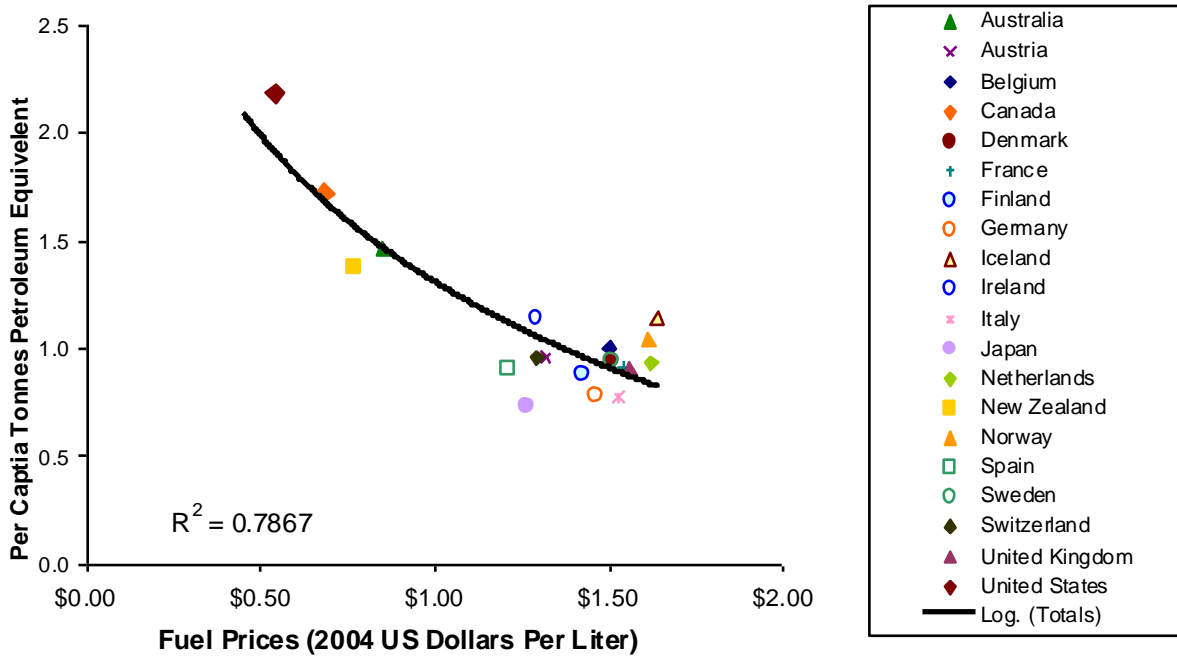
- Higher value travel, such as business and commute travel, tend to be less price sensitive than lower value travel.
- Wealthy people tend to be less sensitive to pricing and more sensitive to service quality than lower-income people.
- Prices tend to affect consumption in proportion to their share of household budgets. Elasticities tend to increase as fuel prices rise.
- Consumers tend to be more responsive to price changes they consider durable, such as fuel tax increases, compared with oil market fluctuations perceived as temporary.
- Pricing impacts tend to increase over time. Short-run (first year) effects are typically a third of long-run (more than five year) effects.
- Travel tends to be more price sensitive if travelers have better options, including different routes, modes and destinations.
- Travelers tend to be particularly sensitive to visible and frequent prices, such as road tolls, parking fees and public transit fares.
- How fees are promoted, structured and collected can affect their impacts.

The following section describes estimates of various transport elasticities.

*Fuel Consumption With Respect to Fuel Price*

Numerous studies using various methodologies and data sets have investigated fuel price elasticities (Litman 2011). Fuel price increases tend to cause fuel consumption to decline, in the short-term by reducing total vehicle travel and driving speeds, and shifting travel to more fuel-efficient vehicles in multi-vehicle households, and in the long-term by increasing vehicle fuel economy and land use accessibility (Lipow 2008). Figure 1 illustrates the relationship between per capita fuel price and consumption for members of the Organization for Economic Cooperation and Development (OECD), which includes most economically developed countries in the world. This indicates a strong negative relationship.

**Figure 1 Fuel Price Versus Per Capita Transport Energy Consumption (OECD 2005)**



*As fuel prices increase, per capita transportation energy consumption declines.*

A meta-analysis of 101 U.S. gasoline demand studies (Espey 1996) concluded that fuel price elasticities average -0.26 short-run (less than one year), and -0.58 long-run (more than 1 year). A review of selected studies by Lipow (2008) estimated that fuel price elasticities are typically -0.17 short run and -0.4 long run.

Glaister and Graham (2002) review international studies on fuel price and income impacts on vehicle travel and fuel consumption. They find short run elasticities from -0.2 to -0.5, and long run elasticities ranging from -0.24 to -0.8 in the U.S., from -0.75 to -1.35 in the OECD overall. They identify factors that affect fuel price elasticities including functional form, time span, geography and model design, and find that long-term gasoline demand appears to be getting more elastic. They conclude that short-run elasticities are -0.2 to -0.3, and long-run elasticities are -0.6 to -0.8.

Based on a review of international studies Goodwin, Dargay and Hanly (2004) found that the elasticity of vehicle travel with respect to fuel price declined from -0.54 prior to 1974, -0.34 between 1974 and 1981, to -0.24 after 1981, while the elasticity of vehicle travel with respect to incomes increased. They conclude that a durable 10% fuel price increase causes:

- A. Vehicle travel declines by approximately 1% in the short run and 3% in the longer run.
- B. Fuel consumption declines approximately 2.5% within a year and 6% in the longer run.

Fuel consumed declines more than vehicle travel because motorists purchase more fuel-efficient vehicles and drive more carefully. As a result, a 10% price increase causes:

- C. Vehicle fuel efficiency increases about 1.5% within a year and 4% over the longer run.
- D. Total vehicle ownership declines less than 1% in the short run and 2.5% in the longer run.

Using 1982-1995 U.S. data, Agras and Chapman (2001) find short-run fuel price elasticities of -0.15 for vehicle mileage and 0.12 for fuel economy, summing to an overall short-run gasoline price elasticity of -0.25, and long-run elasticities of -0.32 for vehicle travel and 0.60 for fuel economy, summing to -0.92 in the long run.

Several studies indicate that North American fuel price elasticities declined during the last quarter of the Twentieth Century (CBO 2008). Using U.S. state-level data, Hughes, Knittel and Sperling (2006) found short-run fuel price elasticities of -0.21 to -0.34 during 1975-1980, but only -0.034 to -0.077 during 2001-2006. Using more comprehensive analysis Small and Van Dender (2005) found gasoline price elasticities to be -0.09 short run and -0.41% long run during 1966 to 2001, but only -0.07 short run and -0.34% long run during 1997 to 2001. Similarly, Hymel, Small and Van Dender (2010) used state-level cross-sectional time series data to evaluate the effects of income, fuel price, road supply, and traffic congestion on U.S. vehicle travel between 1966 and 2004. They find fuel price elasticities (based on 2004 vehicle ownership rates and incomes) to be -0.055 in the short run and -0.285 over the long run (a 10% fuel price increase reduces fuel consumption 0.55% in the short run and 2.85% over the long run) due to a combination of reduced mileage and more fuel efficient vehicles. They conclude that long-run travel elasticities are typically 3.4–9.4 times short-run elasticities.

Boilard (2010) used two methods to quantify fuel price and income elasticities using Canadian quarterly data for two periods of identical length: 1970-1989 and 1990-2009. One method used a *dynamic partial adjustment* model, which explains per capita gasoline consumption as a function of the average real price of gasoline, the real disposable income per capita during each quarter, a seasonal effect and per capita gasoline consumption during the preceding quarter. This method is commonly used because it is relatively simple and can easily distinguish between short-term and long-term elasticities, but can lead to biased results if the series are not stationary (i.e., risk of spurious correlation), and other confounding factors. The second approach, which uses an *estimation of an error correction model* (ECM), can avoid some of these pitfalls. The table below summarizes the results. They indicate that price elasticities declined during the 1990 to 2009 period.

**Table 2 Canadian Fuel Price and Income Elasticities (Boilard 2010)**

Approach	Elasticity	1970-1989		1990-2009	
		Short Term	Long Term	Short Term	Long Term
Dynamic Model	Price	-0.093	-0.762	-0.091	-0.256
	Income	0.046	0.377	0.249	0.699
Cointegration Model	Price	-0.193	-0.450	-0.046	-0.085
	Income	0.209	0.428	0.169	0.423

*This table summaries short- and long-term fuel price and income elasticities in Canada.*

These low values may reflect unique factors during that period, including growing per capita vehicle ownership, employment and incomes, combined with declining real fuel prices which reduced fuel prices relative to incomes, plus highway expansion and dispersed development patterns (Litman 2006). More recent studies suggest that fuel price elasticities began to increase after about 2005 (CERA 2006). Komanoff (2008) estimated the short-run U.S. fuel price elasticity reached a low of -0.04 in 2004, but increased to -0.08 in 2005, -0.12 in 2006, -0.16 in 2007 and -0.29 in 2011. Brand (2009) found that the 20% U.S. fuel price increase between 2007 and 2008 caused fuel consumption to decline 4.0%, a short-run price elasticity of -0.13, or about -0.17 accounting for population and economic growth during that period.

Li, Linn and Muehlegger (2011) used U.S. gasoline consumption, vehicle travel, vehicle ownership, and new vehicle purchase data to evaluate how price changes affected transport activity and fuel consumption between 1968 and 2008. They find that fuel tax increases, which are considered durable, have a greater effect on fuel consumption than market fluctuations. They estimate the elasticity of gasoline demand with respect to fuel price is -0.235, with greater elasticities for taxes than tax-exclusive oil price fluctuations. This suggests that the decline in fuel price elasticities between 1970 and 2000 may partly reflect the decline in the tax share of fuel prices, a factor generally overlooked elasticity studies. This suggests that increases in motor vehicle operating costs that consumers consider durable (fuel taxes, road tolls, parking fees and distance-based insurance and registration fees) are likely to cause much greater reductions in vehicle travel and fuel consumption than indicated by conventional models which use elasticity value based on responses to price changes that consumers considered temporary. Spiller and Stephens (2012) developed a comprehensive model using data from the 2009 National Household Travel Survey, U.S. Census, and monthly state-level gasoline prices to estimate household-level fuel price elasticities. They found the mean short-run price elasticity of gasoline to be -0.67, with significant variations by location and income.

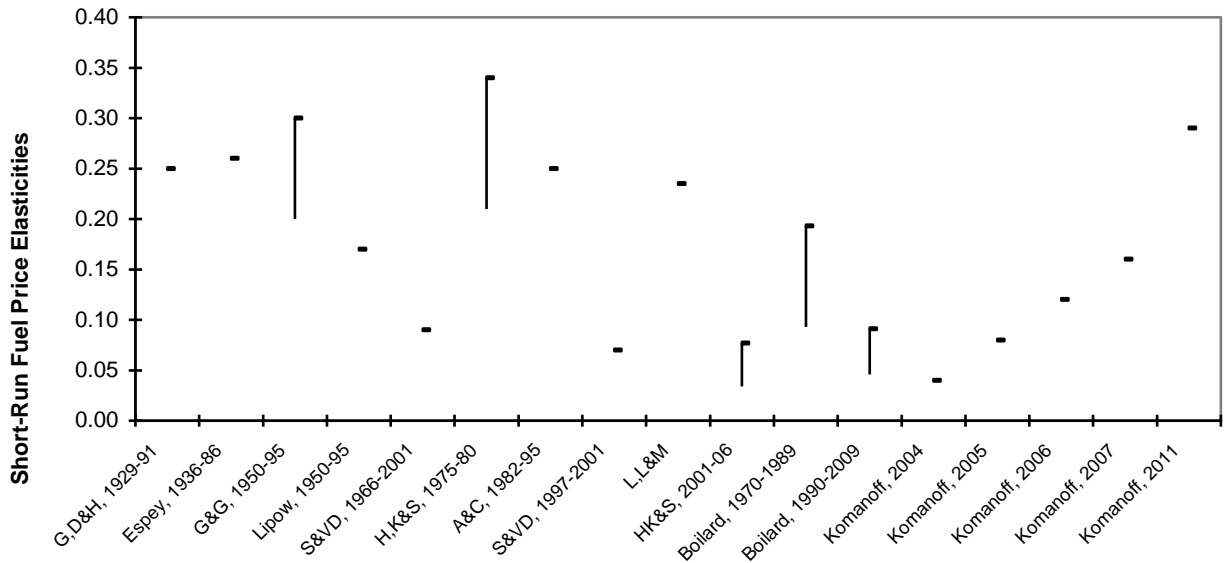
Table 3 summarizes these studies. They vary significantly in scope and methodology. Many older studies used relatively simple models, more recent studies tend to account for more demographic, economic and geographic factors. These studies indicate that fuel price elasticities declined during the last quarter of the Twentieth Century, under -0.1 short-run and under -0.4 long-run (Small and Van Dender 2005; Hymel, Small and Van Dender 2010), but higher elasticities have been measured during the first decade of the Twenty-first Century, between -0.1 and -0.2 short-run, and -0.2 to -0.3 medium-run (Boilard 2010; Komanoff 2008-2011; Spiller and Stephens 2012).

**Table 3 Summary of Transport Fuel Price Elasticity Studies**

Study	Study Type	Scope	Major Results
Goodwin, Dargay and Hanly (2004)	Summarized various fuel price and income elasticity studies	1929 to 1991. Mostly North America and Europe	-0.25 short run -0.6 long run
Espey (1996)	101 fuel price elasticity studies	1936 to 1986, U.S.	-0.26 short-run -0.58 long-run
Glaister and Graham (2002)	Review of various fuel price and income elasticity studies	1950-2000, mostly North America and Europe	-0.2 to -0.3 short run -0.6 to -0.8 long-run
Lipow 2008	Review of selected energy price elasticity studies	1950-2000, mostly North America and Europe	-0.17 short run, -0.4 long run
Small and Van Dender (2005)	Comprehensive model using state-level cross-sectional time series of gasoline price elasticities	U.S. State Data, 1966-2001	<i>1966-2001</i> -0.09 short run -0.41% long run  <i>1997 to 2001</i> -0.07 short run -0.34% long run
Hymel, Small and Van Dender (2010)	Comprehensive model using state-level cross-sectional time series gasoline prices	1966 to 2004, U.S.	-0.055 short run -0.285 long run
Agras and Chapman (2001)	Gasoline price elasticity	1982-1995, U.S.88	-0.25 short-run -0.92 long run
Li, Linn and Muehlegger (2011)	Comprehensive model with tax increases and price fluctuations analyzed separately	1968-2008, U.S. 88	-0.235
Hughes, Knittel and Sperling (2006)	Comprehensive model using state-level cross-sectional time series gasoline prices	1975 to 2006, U.S.	<i>1975-1980</i> -0.21 to -0.34 short-run  <i>2001-2006</i> -0.034 to -0.077 short-run
Boilard (2010)	Comprehensive model of fuel price elasticities	1970 to 2009, Canada	<i>1970-1989</i> -0.093 to -0.193 short run -0.762 to -0.45 long run  <i>1990-2009</i> -0.046 to -0.091 short run -0.085 to -0.256 long run
Komanoff (2008-2011)	Simple model of short run fuel price elasticities	2004 to 2011 U.S. data	-0.04 in 2004 -0.08 in 2005 -0.12 in 2006 -0.16 in 2007 -0.29 in 2011
Spiller and Stephens (2012)	Comprehensive model of monthly state-level fuel price and VMT data	2009 U.S. travel survey data	-0.67 short run, with variations by household income and location

*Various types of studies covering various times and geographic areas have measured fuel price elasticities. Some of these are reviews of previous studies.*

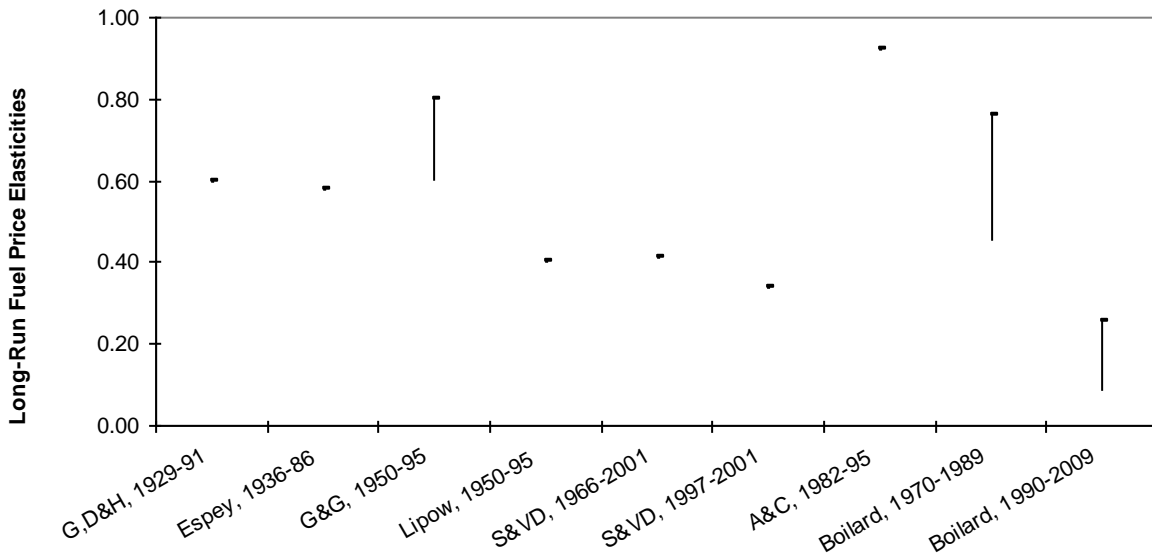
**Figure 2 Short Run Fuel Price Elasticities (absolute values)**



This figure illustrates estimated short-run fuel price elasticities from the studies listed in Table 3, roughly ordered from oldest to more recent time periods. Vertical bars indicate ranges.

Figures 2 and 3 illustrate the elasticity values from Table 3 (absolute values, so all values are positive), roughly progressing over time from left to right. This shows the relatively low values measured in the U.S. between 1970 and 2004, with higher values for other times and places, including more recent U.S. conditions. Komanoff's analysis shows a steady increase in fuel price elasticities between 2004 and 2011.

**Figure 3 Long-Run Fuel Price Elasticities (absolute values)**



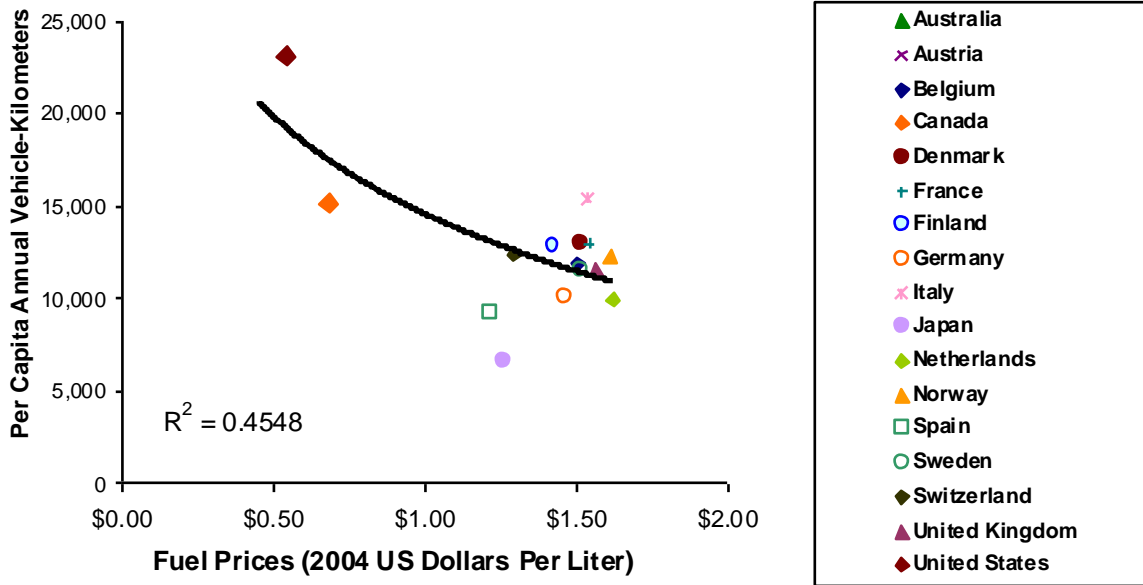
This figure illustrates estimated long-run fuel price elasticities from the studies listed in Table 3, roughly ordered from oldest to more recent time periods.



*Vehicle Travel With Respect to Fuel Price*

As mentioned above, about a third of the fuel savings that result from increased fuel prices consist of reduced vehicle mileage. This impact is particularly important when evaluating the ability of pricing reforms to reduce traffic and parking congestion, and accidents.

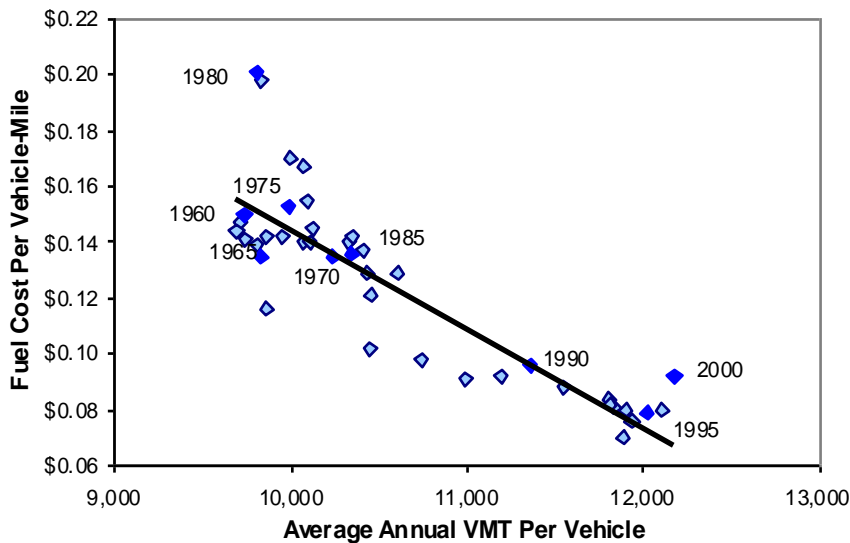
**Figure 4 Fuel Price Versus Per Capita Vehicle Travel (OECD 2005)**



*Higher fuel prices tend to reduce per capita vehicle travel.*

Figure 5 illustrates how changes in real fuel prices (adjusted for inflation and currency exchange) affect per capita annual vehicle travel.

**Figure 5 Fuel Costs Versus Annual Vehicle Mileage (BTS 2001)**



*Per capita vehicle mileage tends to increase when real (inflation-adjusted) per-mile fuel costs decline.*

Various international studies indicate that the long-term elasticity of vehicle travel with respect to fuel price normally averages about  $-0.2$  to  $-0.3$ , meaning that a 10% price increase reduces vehicle travel 2-3% over the long-run (Goodwin, Dargay and Hanly 2004; Johansson and Schipper 1997; Schimek 1997). Lee, Han and Lee (2009) found long-run elasticities of vehicle travel with respect to fuel prices to average  $-0.59$  in Korea between 2000 and 2008, a relatively high value possibly reflecting low average incomes or high quality travel alternatives.

As previously mentioned, some studies found much lower elasticities in the U.S. during the last quarter of the Twentieth Century. Small and Van Dender (2007) estimate the elasticity of vehicle travel with respect to fuel price at  $-0.047$  short run and  $-0.22$  long run (a 10% price increase reduces vehicle travel 0.47% in the short run and 2.2% in the long-run) with values that declined with income and over time. During the most recent period (1997- 2001) these elasticities were  $-0.026$  short-run and  $0.121$  long-run.

Similarly, Hymel, Small and Van Dender (2010) find the elasticity of vehicle use with respect to per-mile fuel cost (based on 2004 conditions for factors such as vehicle ownership and incomes) is  $-0.026$  in the short run and  $-0.131$  in the long run (a 10% increase in per-mile fuel costs causes vehicle mileage to decline by 0.26% in the short run and 1.31% over the long run); these elasticity values tend to decline in magnitude with income, and increase in magnitude as fuel prices rise relative to incomes. They also find that the elasticity of vehicle travel with respect to total road mileage is  $0.037$  in the short run and  $0.186$  in the long run (a 10% increase in lane-miles increases VMT 0.37% in the short run and 1.86% over the long run), and the elasticity of vehicle use with respect to congestion  $-0.045$  (a 10% increase in regional congestion reduces regional mileage 0.45% over the long run), and this value increases with income, and so is estimated to be  $0.078$  at 2004 income levels (a 10% increase in total regional congestion reduces regional mileage 0.78% over the long run).

Recent studies indicate that vehicle travel elasticities began to increase after 2005. Brand (2009) found that the 20% U.S. fuel price increase between 2007 and 2008 caused a 3.5% reduction in VMT, indicating a short-run price elasticity of  $-0.17$  for the four-month July to October period of 2007 compared with the same months in 2008, and about  $-0.12$  when the first ten months of 2007 are compared with those of 2008. Accounting for the base growth rates (between 1983 and 2004 VMT increased about 2.9% annually) this indicates short-run elasticity of vehicle travel with respect to fuel price of  $-0.3$  for July through October 2008, and  $-0.21$  for the first ten months of 2008.

Gillingham (2010) used California 2005-08 emission inspection odometer data to calculate travel elasticities for various vehicle types and locations. The study found statistically significant medium-run (two-year) elasticities of vehicle travel with respect to gasoline price ranging from  $-0.15$  to  $-0.20$ , with variations by geographic area, income and vehicle type. These price effects appear to increase over time. The analysis found that for urban and suburban residents, higher fuel economy cars have a lower elasticity than SUVs and pickups, suggesting that multi-vehicle households respond to price increases by shifting travel to more fuel-efficient vehicles. Rural, low-income pickup and SUV drivers appear to have lower elasticities, possibly because they need such vehicles for work and have fewer alternatives.

Li, Linn and Muehlegger (2011) find that in the U.S. between 1968 and 2008 the elasticity of vehicle travel with respect to gasoline prices ranged from -0.24 to -0.34, depending on time period and model specifications, with no significant difference between taxes and other price changes. NCHRP (2006) and Williams-Derry (2011) summarizes research indicating that motorists are more sensitive to road tolls than most models predict. Fuel prices influence household location decisions in ways that can affect long-run impacts on travel activity. Molloy and Hui Shan (2011) found that a 10% gasoline price increase reduces demand for housing in locations with a long average commutes by 10% after a 4-year lag. Spiller and Stephens (2012) used data from the 2009 National Household Travel Survey, the U.S. Census, and monthly state-level gasoline prices to estimate vehicle travel elasticities. They found the mean short-run household-level elasticity of VMT to fuel price to be -0.67, with significant variations by location and income.

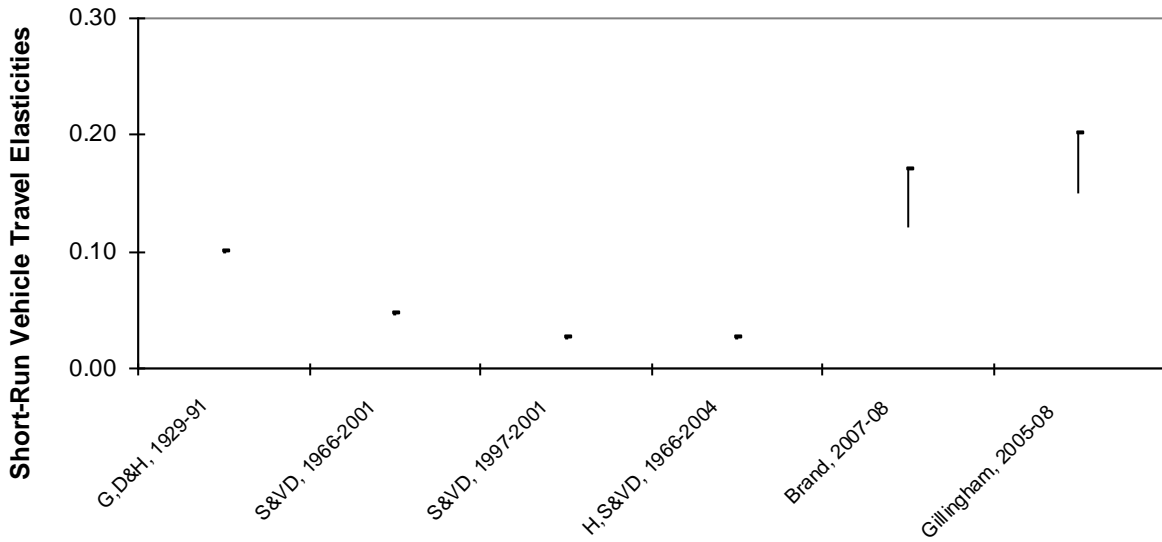
Table 4 summarizes these studies' results. As with the fuel price elasticity data, analysis quality varies. The results indicate that vehicle travel price sensitivities declined during the last quarter of the Twentieth Century, with elasticities below -0.1 short-run and -0.2 long-run (Small and Van Dender 2010; Hymel, Small and Van Dender 2010), but more recent studies based on data after 2000 indicate higher elasticities, -0.1 to -0.2 short-run, and -0.2 to -0.3 long-run (Brand 2009; Gillingham 2010; Spiller and Stephens 2012).

**Table 4 Summary of Vehicle Travel Price Sensitivity Studies**

Study	Study Type	Scope	Major Results
Johansson and Schipper (1997)	Summary of various previous studies	International	-0.2 long run
Goodwin, Dargay and Hanly (2004)	Summary of various fuel price and income elasticity studies	1929 to 1991, mostly North America and Europe.	-0.1 short run -0.3 long run
Schimek (1997)	Elasticity of vehicle travel with respect to fuel price	1950 to 1994 time-series and 1988 to 1992 pooled data, U.S.	-0.26
Small and Van Dender (2010)	Comprehensive model using vehicle travel elasticity with respect to fuel price	1966-2001, U.S.	<i>1966 to 2001</i> -0.047 short run -0.22 Long run  <i>1997 to 2001</i> -0.026 short run -0.121% long run
Hymel, Small and Van Dender (2010)	Comprehensive model using state-level cross-sectional time series gasoline price elasticities	1966 to 2004, U.S.	-0.026 short run -0.131 long run
Li, Linn and Muehlegger (2011)	Comprehensive model of vehicle travel with respect to fuel price	1968-2008, U.S.	-0.24 to -0.34
Brand (2009)	Gasoline price elasticities	2007-2008, U.S.	-0.12 to -0.17 short run -0.21 to -0.3 long run
Gillingham (2010)	Comprehensive model using odometer and fuel consumption data.	2005-2008, California	-0.15 to -0.20 medium run, with variation by vehicle type and location
Spiller and Stephens (2012)	Comprehensive model of monthly state-level fuel price and VMT data	2009 U.S. travel survey data	-0.67 short run, with variations by household income and location

*Numerous studies covering various times and geographic areas have measured the elasticity of vehicle travel with respect to fuel prices.*

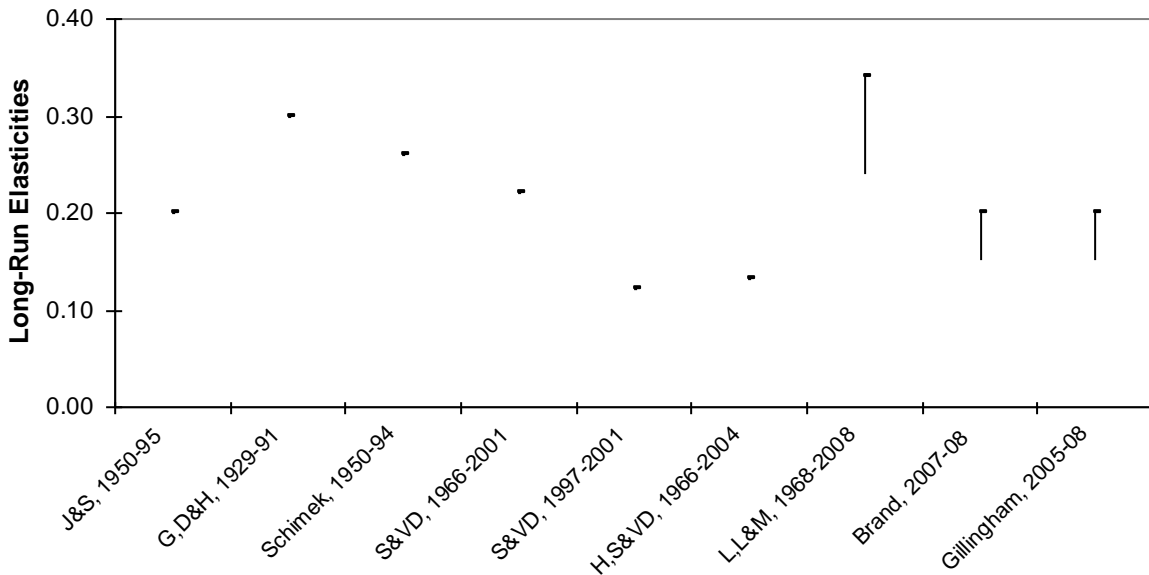
**Figure 6 Short-Run Vehicle Travel Elasticities (absolute values)**



This figure illustrates estimated short-run vehicle travel elasticities from the studies listed in Table 4, roughly ordered from oldest to more recent time periods. Vertical bars indicate ranges.

Figures 6 and 7 illustrate the elasticity values from Table 4 (absolute values, so all values are positive), roughly progressing over time from left to right. This shows the relatively low values measured in the U.S. between 1970 and 2004, with higher values for other times and places, including more recent U.S. conditions.

**Figure 7 Long-Run Vehicle Travel Elasticities (absolute values)**



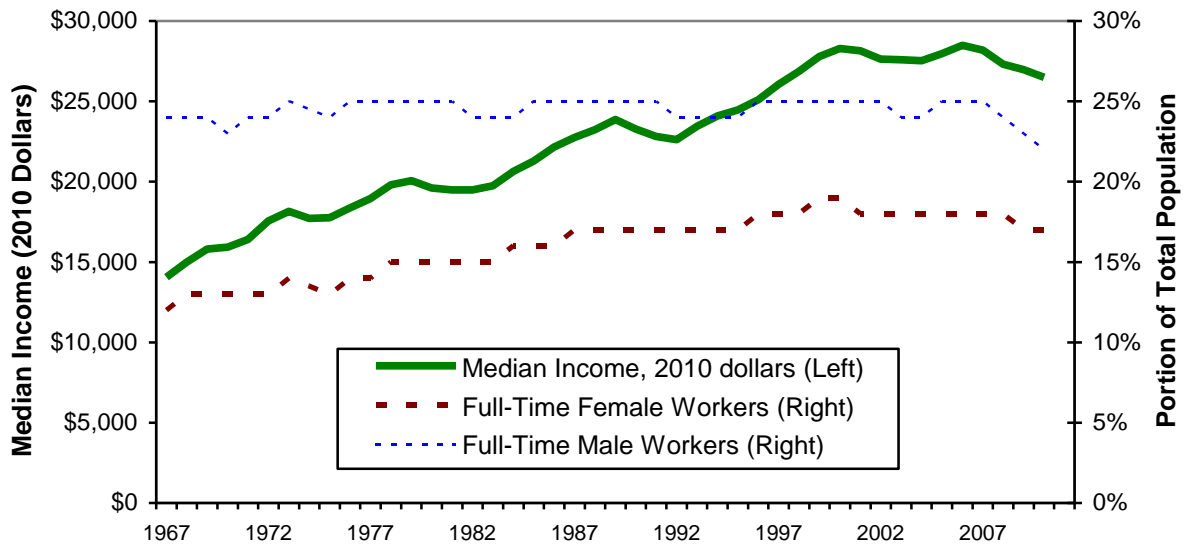
This figure illustrates estimated long-run vehicle travel elasticities from the studies listed in Table 4, roughly ordered from oldest to more recent time periods.

## Discussion

The transport elasticity changes identified here can be explained by various demographic and economic factors that affect vehicle travel demands, including ages, employment rates and incomes, fuel prices, transport options and land use development. During the Twentieth Century these factors tended to increase vehicle travel demand, but recent trends are reducing travel demands, which tends to increase fuel and vehicle travel elasticities (Litman 2006).

Between 1967 and 2000, real (inflation adjusted) median per capita incomes rose 88%, from \$14,999 to \$28,293 2010 dollars, but plateaued and declined slightly since, as illustrated in Figure 3. Much of this income growth resulted from increased women workforce participation which both increased households' ability to purchase fuel and commute travel demands. In 1967, 12.4% of the U.S. population consisted of women with full-time jobs, this increased more than a third to 18.6% in 2000, but has declined to 16.8% in 2010, as illustrated in Figure 8. The recent declines in both men's and women's workforce participation largely reflects aging population which is increasing the retired portion of the population, a trend projected to continue.

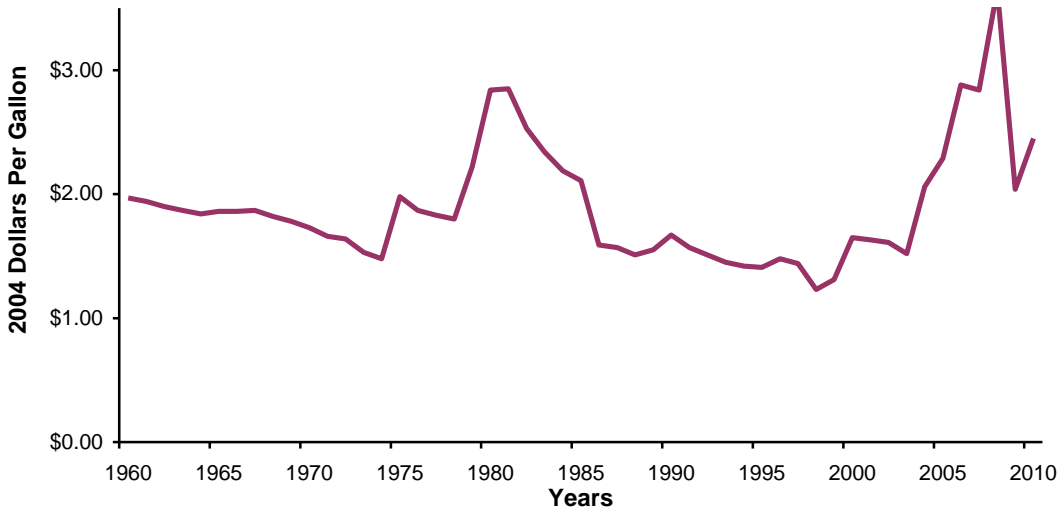
**Figure 8** Median U.S. Per Capita Income (U.S. Census, 2010a)



*Between 1967 and 2000, incomes and employment participation increased, but have since declined.*

Between 1960 and 2000, real fuel prices declined, but have since increased, as illustrated in Figure 9. Most projections indicate that fuel prices will increase in the future due to stagnant production and increasing international demand. For example, the U.S. Energy Information Administration's Reference Case (their best estimate) predicts that world oil prices will be \$95 per barrel in 2015 in real 2009 dollars and will increase to \$125 per barrel in 2035 (EIA 2010).

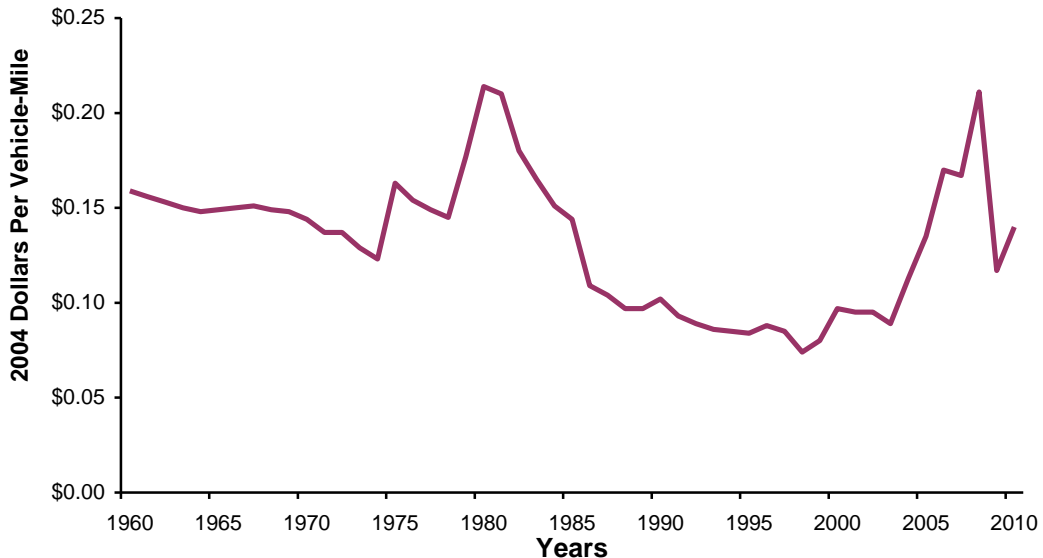
**Figure 9 U.S. Fuel and Fuel Tax Costs (VTPI 2011)**



*Inflation-adjusted fuel prices declined between 1960 and 2010, but have increased since.*

Vehicle manufactures and consumers responded to high fuel prices in the 1970s and 80s by increasing fuel economy (kilometers driven per liter of fuel), so fuel costs per vehicle-mile declined significantly between 1970 and 2000. Overall average fuel economy for all road vehicles (including large trucks) increased 38% from 12.4 miles-per-gallon (mpg) in 1960 to 17.0 mpg in 2000, reducing fuel costs per vehicle-mile, as illustrated in Figure 10.

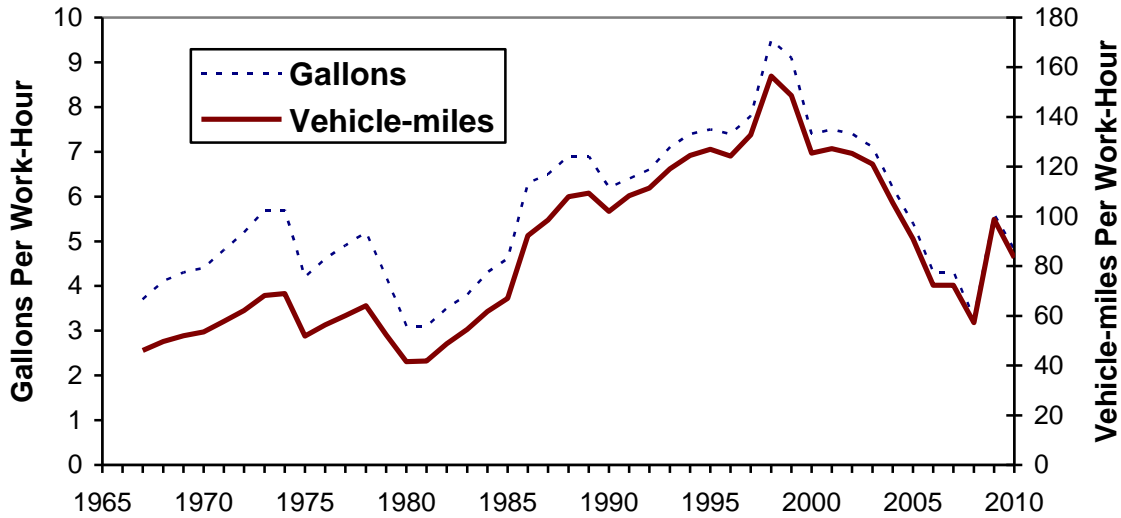
**Figure 10 U.S. Per-Mile Fuel Costs (VTPI 2011)**



*Fuel efficiency increased during the 1970s and 80s, reducing the fuel costs per mile or kilometer.*

These trends significantly reduced fuel and vehicle travel costs relative to incomes during the last quarter of the Twentieth Century. For example, in 1967, when median annual incomes were \$2,464 per capita, gasoline cost \$0.33 per gallon, and vehicles averaged 12.4 miles-per-gallon, a median work-hour could purchase 3.73 gallons of fuel or 46 vehicle-miles. In 2000, when median incomes were \$22,346, gasoline cost \$1.51 per gallon, and vehicles averaged 17.0 miles-per-gallon, an average work-hour could purchase 7.4 gallons of fuel and 126 vehicle-miles. In 2010, when median incomes were \$26,487, fuel averaged \$2.78 per gallon and vehicles averaged 17.5 miles per gallon, an average work-hour could purchase 4.7 gallons or 83 vehicle-miles. Figure 11 illustrates these trends.

**Figure 11 Fuel and Vehicle-Travel Purchased Per Median Work-Hour (VTPI 2011)**



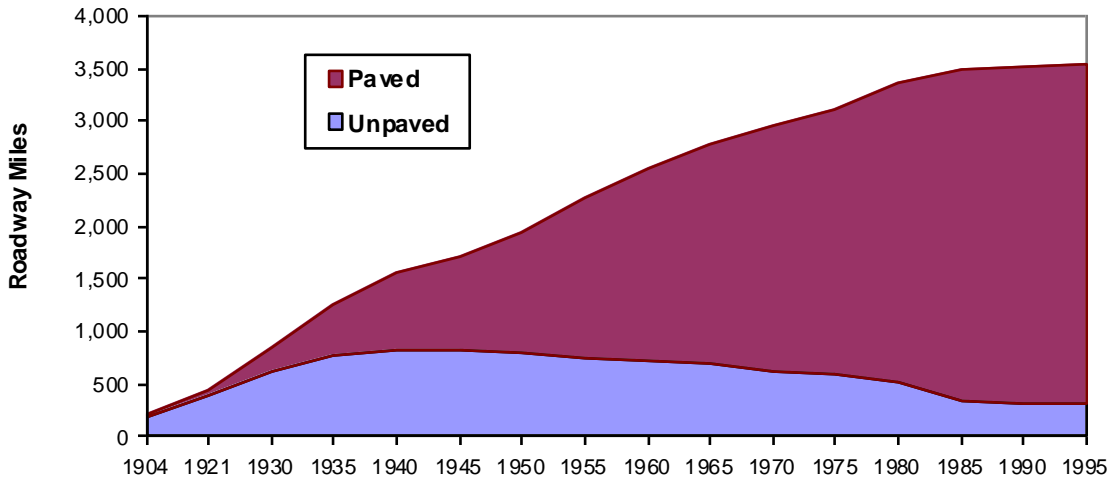
*Fuel and vehicle travel affordability increased significantly between 1967 and 2000, but then declined.*

This helps explain why fuel and travel elasticities declined between 1967 and 2000, since fuel and vehicle travel became significantly cheaper relative to incomes. These trends have since reversed – fuel and vehicle travel costs have returned to 1960s levels. Increasing vehicle fuel economy may offset future fuel price increases but are unlikely to make vehicle travel as affordable as it was during the 1990s. For most motorists, driving will seem less affordable in the future, which is likely to increase price responsiveness.

Another factor that probably stimulated vehicle travel and reduced its price sensitivity of was roadway expansion. An extensive body of literature indicates that roadway expansion induces vehicle travel (Litman 2001). For example, using U.S. state-level data, Hymel, Small and Van Dender (2010) found that the elasticity of vehicle use with respect to road lane-miles is 0.037 in the short run and 0.186 in the long run (a 10% increase in lane-miles increases vehicle travel 0.37% in the short run and 1.86% over the long run), and the elasticity of vehicle use with respect to congestion is -0.045 (a 10% increase in regional congestion reduces mileage 0.45% over the long run). Figure 12 shows how the U.S. road network expanded rapidly between 1940 and 1980, but has expanded little since. Increasing traffic congestion probably reduced vehicle travel and encouraged shifts to alternative modes on some corridors.



**Figure 12 US. Roadway Mileage** (MVMA 1995, p. 69)



*Roadway mileage grew significantly between 1900 and 1980. Little growth has occurred since.*

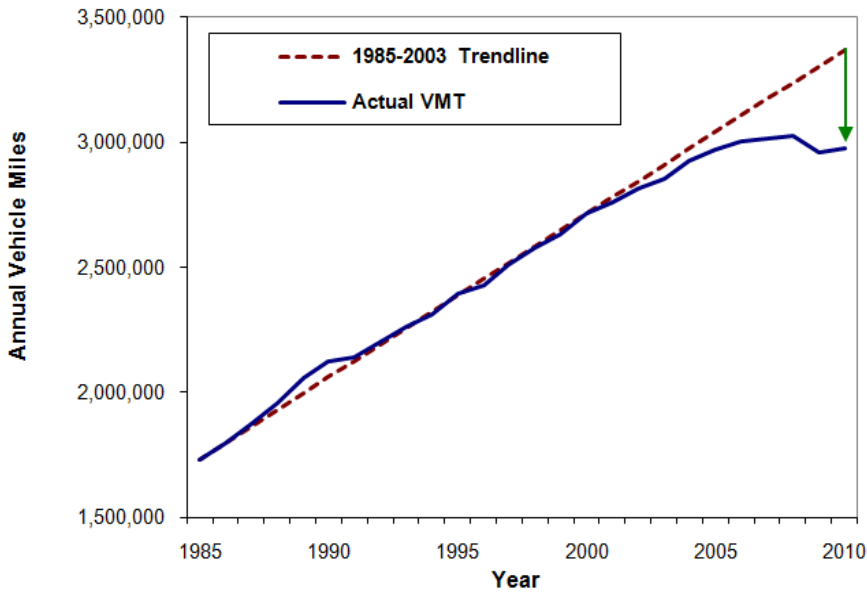
Vehicle travel tends to be more price sensitive if travelers have good alternatives. For example, a major road pricing study found that the elasticity of automobile commuting was four times higher than average (-0.16 versus -0.04) for workers with the best public transit service. Similarly Guo, et al. (2011) found that given financial incentives to reduce their vehicle travel, households in denser, mixed use, transit-accessible neighborhoods responded significantly more than comparable households in automobile dependent suburbs.

Dispersed, automobile-oriented land use development policies probably also contributed to vehicle travel growth between 1960 and 2000. In recent years, many jurisdictions have adopted smart growth development policies to improve accessibility options. These policies are likely to make driving more price sensitive.

There is also evidence of changing consumer travel preferences (Metz 2010). It indicates that many North Americans would prefer to drive less and rely more on alternative modes, provided that they are convenient and comfortable to use (Pearce 2011). There appears to be increased political support for policies and investments to improve alternative modes and create more compact, multi-modal communities. This may make vehicle travel more price sensitive if changes in prices, preferences and policies have synergistic effects.

As a result of these demographic and economic trends motor vehicle travel demand growth slowed after 2000 and stopped after 2007. By 2010, total motor vehicle travel was about 10% below the trend line, as indicated in Figure 13.

**Figure 13 U.S. Annual Vehicles Mileage (USDOT 2010)**



*US vehicle travel grew steadily during the Twentieth Century, but has since leveled off despite continued population and economic growth. By 2010 it was about 10% below the long-term trend.*

It is also interesting to compare U.S. conditions with other countries. Most economically developed countries have fuel prices two or three times higher than in the U.S. For example, in 2010, gasoline prices averaged \$0.76 per liter in the U.S., \$1.60 in Japan, \$1.90 in Germany, \$1.92 in the U.K., and \$2.12 in Norway (GIZ 2010/2011). Since elasticities are normally calculated based on percentage changes, fuel price elasticities will appear much larger in these countries than in the U.S. A \$0.25 per liter price increase represents a 33% change in the U.S. but only 13% in the U.K., although incremental cost burden relative to consumers' incomes is similar in both countries. This creates an illusion that U.S. motorists are less sensitive to fuel prices than motorists in other countries. For example, if a \$0.25 per liter fuel price change caused a 10% reduction in vehicle travel in both U.S. and the U.K., this would indicate an elasticity of -0.3 in the U.S. but -0.77 in the U.K.

These factors help explain why U.S. fuel and travel elasticities declined between 1960 and 2000, and why U.S. elasticity values tend to be lower than in other countries. During this period, vehicle travel became significantly more affordable to most consumers, so price fluctuations seemed relatively unimportant. In addition, transport and land use policies encouraged vehicle travel. Many of these factors are changing:

- Real U.S. incomes are stagnant and unlikely to grow as rapidly as in the past.
- Workforce participation has peaked and is expected to decline due to aging population which increases the number of retirees. This reduces commuting, which tend to be less price sensitive than other types of travel, particularly recreational travel common to retirees.
- Real fuel prices are likely to increase in the future due to declining production and increasing worldwide demand.
- Roadway networks are unlikely to expand significantly, and traffic congestion is likely to continue at current rates.

- Current transport and land use policies are likely to improve alternative modes and encourage more compact, multi-modal community development.
- Consumers' preferences appear to be shifting away from automobile travel and automobile-dependent locations, to favor other modes and more compact, multi-modal communities.
- Rising international oil prices may raise U.S. fuel prices relative to those in other countries.

As fuel and vehicle-travel costs increase relative to incomes, and as transport and land use options improve so consumers have better alternatives to driving and automobile-dependent communities, it is likely that fuel and travel price elasticities will tend to increase.

#### **Putting Fuel Prices Into Perspective**

Vehicle fuel is an inelastic good (a price change causes a proportionately smaller change in consumption, that is, the elasticity value is less than 1.0). To understand why it is useful to put fuel prices into perspective with respect to total vehicle costs.

Most motor vehicle monetary costs are considered fixed, including depreciation (although depreciation increases with vehicle use this is a long-term effect that probably has little effect on consumers' short-term travel decisions), financing, insurance, registration fees, and residential parking. For a typical automobile these costs total about \$4,000 annually, averaging about 33¢ per vehicle-mile. Travel time costs are also significant. If valued at \$10 per hour, time costs average 33¢ per mile at 30 miles-per-hour.

Typical fuel price fluctuations (say, between \$2.00 and \$3.00 per gallon, which increase costs from 10¢ to 15¢ per vehicle-mile) are relatively modest compared with these other costs. This helps explain why motorists have been relatively insensitive to typical fuel price changes: fuel was a relatively small portion of total vehicle costs. If the long-run elasticity of vehicle travel with respect to fuel price is -0.3 and fuel represents 25% of total vehicle costs, then the long-run elasticity of vehicle travel with respect to total vehicle costs is actually -1.2, making vehicle travel elastic overall.

## Consumer Impacts

Price sensitivities indicate the value consumers place on a good and their ability to change consumption when prices change. Low road, parking and fuel price elasticities indicate that motorists value driving and find it difficult to reduce mileage and conserve fuel, so price increases harm consumers. Higher elasticities indicate that consumers have less difficulty reducing vehicle travel and fuel consumption, so price increases cause less harm to consumers. These impacts can be quantified based on *consumer surplus* analysis, which can quantify the value that consumers place on travel forgone due to higher prices, using a method known as the *rule of half*, which is described in the following box.

### Explanation of the “Rule of Half”

Economic theory suggests that when consumers change their travel in response to a financial incentive, the net consumer surplus is half of their price change (called the *rule of half*). This takes into account total changes in financial costs, travel time, convenience and mobility as they are perceived by consumers.

Let’s say that the price of driving (that is, the perceived variable costs, or *vehicle operating costs*) increased by 10¢ per mile, either because of an additional fee (e.g., paid parking) or a financial reward, and as a result you reduced your annual vehicle use by 1,000 miles. You would not give up highly valuable vehicle travel, but there are probably some vehicle-miles that you would reduce, either by shifting to other modes, choosing closer destinations, or because the trip itself does not seem particularly important.

These vehicle-miles forgone have an incremental value to you, the consumer, between 0¢ and 10¢. If you consider the additional mile worth less than 0¢ (i.e., it has no value), you would not have taken it in the first place. If it is worth between 1-9¢ per mile, a 10¢ per mile incentive will convince you to give it up – you’d rather have the money. If the additional mile is worth more than 10¢ per mile, a 10¢ per mile incentive is inadequate to convince you to give it up – you’ll keep driving. Of the 1,000 miles forgone, we can assume that the average net benefit to consumers (called the *consumer surplus*) is the mid-point of this range, that is, 5¢ per vehicle mile. Thus, we can calculate that miles forgone by a 10¢ per mile financial incentive have an average consumer surplus value of 5¢. A \$100 increase in vehicle operating costs that reduces automobile travel by 1,000 miles imposes a *net cost* to consumers of \$50, while a \$100 financial reward that convinces motorists to drive 1,000 miles less provides a *net benefit* to consumers of \$50.

Some people complicate this analysis by trying to track changes in consumer travel time, convenience and vehicle operating costs, but that is unnecessary information. All we need to know to determine net consumer benefits and costs is the perceived change in price, either positive or negative, and the resulting change in consumption. All of the complex trade-offs that consumers make between money, time, convenience and the value of mobility are incorporated.

For example, if a \$1 per trip highway toll increase causes annual vehicle trips to decline from 5 million to 4 million, the reduction in consumer surplus is \$4,500,000 ( $\$1 \times 4 \text{ million}$  for the motorists who pay the toll, plus  $\$1 \times 1 \text{ million} \times 0.5$  for vehicle trips forgone). If the same \$1 toll causes vehicle trips to decline from 5 million to 3 million, the reduction in consumer surplus is a smaller \$4,000,000 ( $\$1 \times 3 \text{ million}$  for the motorists who pay the toll, plus  $\$1 \times 2 \text{ million} \times 0.5$  for vehicle trips forgone).

Transport pricing reforms can provide positive as well as negative consumer surplus impacts. For example, if pay-as-you-drive vehicle insurance premiums that average 10¢ per vehicle-mile cause affected vehicles to drive on average 1,000 fewer annual miles and save \$100 annually in reduced insurance premiums, the net consumer surplus averages \$50 ( $\$0.10 \times 1,000 \times 0.5$ ) per vehicle.<sup>2</sup> Similarly, if the same price incentive causes affected vehicles to drive 2,000 fewer annual miles and save \$200 annually in reduced insurance premiums, the net consumer surplus averages \$100 ( $\$0.10 \times 2,000 \times 0.5$ ) per vehicle.

In addition to these direct impacts, pricing reforms affect consumers indirectly by providing revenues that can reduce other taxes and fees or provide additional services, and reductions in external costs such as congestion, accident and pollution impacts, as illustrated in Table 5. All of these impacts should be considered when evaluating pricing reform impacts. Many consumer groups that appear harmed by pricing reforms may actually benefit overall when all savings and benefits are considered. For example, higher-mileage motorists will tend to bear a relatively high portion of increased road, parking and fuel prices, but also tend to benefit most from additional transportation investments, and reduced traffic congestion and accident risk imposed by other road users.

**Table 5 Pricing Reform Consumer Impacts**

Consumer Costs	Consumer Benefits
Incremental user charges (higher prices for roads, parking, fuel, etc.).	Incremental user savings (distance-based insurance and registration fees).
Vehicle travel forgone due to higher prices.	Revenues used to reduce other taxes and fees or provide additional consumer benefits.
Reduced vehicle performance (size, power and speed) due to higher fuel prices.	Reductions in external costs borne by consumers (congestion, accident risk, pollution, etc.).

*Pricing reforms can impose costs and provide benefits to consumers. These all should be considered when evaluating a particular price reform.*

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<sup>2</sup> By changing insurance premiums from a fixed cost to a variable cost, pay-as-you-drive pricing gives motorists a new opportunity to save money. Any mileage reduced in response represents lower-value miles that motorists value less than the savings, and therefore an increase in consumer surplus.

## Rebound Effects

For this analysis, the *rebound effect* refers to the increase in vehicle travel that result from increased fuel economy (more miles-per-gallon or fewer liters-per-100-kilometers of vehicle travel) or cheaper alternative fuels (UKERC 2007).<sup>3</sup> This reflects the elasticity of vehicle travel with respect to operating costs: lower costs per mile or kilometer allow motorists to drive more within their fuel budget. Rebound effects reduce net fuel savings, and by increasing vehicle travel tend to increase external costs such as congestion, road and parking infrastructure costs, and accidents (Litman 2009).

For example, if the elasticity of vehicle travel with respect to fuel price is -0.3, then a 10% increase in fuel economy (say, from 20 to 22 miles per gallon) will cause mileage to increase 3%. This 3% mileage increase reduces the net energy savings from 10% to 7%, provides consumer benefits (an increase in consumer surplus) and increases traffic externalities. Table 6 compares analysis of a strategy such as fuel efficiency regulations with and without consideration of rebound effects.

**Table 6 Evaluation With and Without Consideration of Rebound Effects**

	Ignoring Rebound Effects	Considering Rebound Effects
Benefits to consider	Large energy savings and emission reductions (ignoring effects of additional vehicle travel)	Smaller energy savings and emission reductions (considering fuel consumption and emissions from additional vehicle mileage)  Consumer benefits provided by the increased vehicle travel
Costs to consider	Higher vehicle production costs  Reduced vehicle performance	Higher vehicle production costs  Reduced vehicle performance  Increased externalities due to additional (congestion, accidents, sprawl, etc.)

*Considering rebound effects reduces net energy savings, and adds the additional benefits and external costs from increased vehicle travel.*

As the price sensitivity of vehicle travel declined during the last quarter of the Twentieth Century, some experts argued that rebound effects were becoming unimportant (Small and Van Dender 2007). If elasticities are increasing as the recent analysis suggests, the rebound effect will also increase. If this occurs, regulations and incentives that cause consumers to purchase more efficient vehicles or cheaper alternative fuels will provide less energy savings than predicted, and will exacerbate external costs such as congestion, facility costs and accidents.

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<sup>3</sup> Rebound effects can also apply to other types of energy efficiency gains. For example, households may respond to increased home insulation by raising winter thermostat settings or choosing larger homes.

## Policy Implications

This analysis has various policy implications, as summarized in Table 8.

**Table 8 Policy Implications Summary**

Lower Transport Elasticity Values	Higher Transport Elasticity Values
Price changes cause relatively small changes in fuel consumption and vehicle travel. For example, a 10% fuel price increase only reduces vehicle travel 1-2%.	Price changes cause relatively large changes in fuel consumption and vehicle travel. For example, a 10% fuel price increase reduces vehicle travel 3-6%.
<ul style="list-style-type: none"> <li>• Pricing strategies (higher fuel taxes, road tolls, parking fees, and distance-based insurance and registration fees) are ineffective. They provide relatively little energy savings or emission reductions.</li> <li>• Consumers find it relatively difficult to reduce their vehicle travel and fuel consumption. Higher prices harm consumers and are inequitable.</li> <li>• Rebound effects are small (increased fuel efficiency stimulates little additional vehicle travel), so strategies that increase fuel efficiency (CAFE standards and feebates) provide significant net energy savings and emission reductions.</li> </ul>	<ul style="list-style-type: none"> <li>• Pricing strategies (higher fuel taxes, road tolls, parking fees, and distance-based insurance and registration fees) are relatively effective and beneficial.</li> <li>• Consumers find it relatively easy to reduce their vehicle travel and fuel consumption. Higher prices are not very harmful to consumers or inequitable.</li> <li>• Rebound effects are large (increased fuel efficiency stimulates more vehicle travel), so strategies that increase fuel efficiency provide smaller net energy savings and emission reductions, and exacerbate problems such as congestion, road and parking facility costs, accidents and sprawl.</li> </ul>

Elasticity values are incorporated in the analysis of transport pricing reforms, energy conservation and emission reduction strategies, and traffic modeling (USDOT 2010; Morrow, et al. 2010). Such studies generally apply a single elasticity value, and the people who use the analysis results are often unaware of their assumptions and uncertainties.

For example, the methodology used in the USDOT Report to Congress, *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions*, is copied in the box on the next page. It applied a -0.45 elasticity to 69¢ per mile total average vehicle operating costs, which is approximately equivalent to a -0.12 elasticity applied to a 15¢ per vehicle-mile fuel price. This value is consistent with Small and Van Dender's analysis of the 1997-2001 time period and Hymel, Small and Van Dender's analysis of the 1966-2001 period, but is much lower than the values found in most other elasticity studies, including Brand's analysis of the 2007-08 period, Gillingham's analysis of the 2005-08 period, and Li, Linn and Muehlegger's findings for the 1968-2008 period.

This suggests that the USDOT study analysis probably underestimated the true impacts and benefits of pricing reforms, and the rebound effects of strategies that increase vehicle fuel efficiency. More efficient road, parking, insurance and fuel pricing probably provide two to three times as much total benefit (congestion reduction, accident reductions, energy conservation and emission reductions) as this study indicates, and impose less burden on consumers than implied by low price elasticities.

**Elasticity Methodology In The USDOT Report To Congress**

***Transportation's Role in Reducing U.S. Greenhouse Gas Emissions* (pp. A10-A11)**

[http://ntl.bts.gov/lib/32000/32700/32779/DOT Climate Change Report - April 2010 - Volume 1 and 2.pdf](http://ntl.bts.gov/lib/32000/32700/32779/DOT_Climate_Change_Report_-_April_2010_-_Volume_1_and_2.pdf)

The Small and Van Dender and Sperling studies provide the most recent estimates of those in the literature, and therefore are used as the primary basis for this report and the *Moving Cooler* study. Depending on the basis on which elasticities are applied, such as to “total operating costs” or to estimated “out of pocket costs” or to fuel costs, different elasticity values will be appropriate. FHWA includes in its *Highway Economic Requirement System* (HERS) model estimates for the operating costs of light duty and heavy duty vehicles. The latest HERS costs for 2006 included operating costs of 40 cents per mile for all vehicles and crash costs of 15 cents per mile for all vehicles. The crash costs include both insurance costs and uncompensated accident costs. Travel time costs for all vehicles were 54.5 cents per mile, and taxes paid were 2.4 cents per mile. Using the HERS estimates of only the monetary costs, the 2006 number would be 40 cents plus 15 cents plus 2 cents or 57 cents. Adjusting for fuel price to 2008 (\$2.27 per gallon in 2006 versus \$3.25 per gallon in 2008, at a fleet average of 17 mpg) would add 6 cents to the HERS estimate, making it 63 cents per mile. HERS also uses lower safety costs such as a lower cost of lives lost than is used by other agencies such as EPA and that adjustment would add several cents per mile.

The cost assumptions underlying the analyses present in the *Moving Cooler* study and this report were developed during a time in which costs have changed. The IRS had estimated costs of 58.5 cents per mile for light duty vehicles in 2008, and lowered that estimate to 55 cents when fuel prices dropped. It is expected that this figure will be adjusted again. Using the 2008 IRS allowed operating cost of 58.5 cents per mile, future light duty vehicle operating costs were estimated at 60 cents per mile, based upon an assumption of somewhat higher future fuel prices (starting at \$3.70 per gallon and increasing over time) than the average fuel price for 2008. Future total fleet operating costs were estimated at 69 cents per mile. The latter figure is based on the impacts of heavy trucks on the total operating costs of the vehicle fleet. Heavy trucks have over twice the operating cost per mile of light duty vehicles and including them in the calculations increases the average operating costs by 15.4 percent, according to the HERS operating cost factors. This yields 60 cents times 1.15 equals 69 cents per mile. Of this element, with fuel prices of \$3.70 per gallon for the AEO high case in 2008 and a fleet overall average of 17 mpg, fuel costs would be about 22 cents per mile, or about one third of total estimated costs.

For the purposes of the *Moving Cooler* study and this report, converting the Small and Van Dender long term elasticity for VMT or the Sperling elasticity for fuel prices to an elasticity for overall operating expenses would imply about a three or four times higher elasticity (since fuel cost represents only about one-third to one-fourth of total operating costs), or up to around three to four times - 0.057 (-0.17 to -0.23) for Small and Van Dender and up to around three to four times -0.2 (-0.6 to -0.8) for Sperling. No representation is made that the referenced researchers agree with this conversion. The overall elasticity selected for *Moving Cooler* and this study was -0.45, which is in the middle of these calculated conversions. This elasticity is close to the long-run fuel price elasticity of about -0.4 used in a 2008 Congressional Budget Office analysis of gasoline price effects. The -0.45 elasticity was applied for the response of VMT to total vehicle costs for all pricing measures. This elasticity is also comparable to the long-term elasticity used in the HERS model. The HERS input elasticities total to -0.65, but because of the way HERS is set up this results in a total elasticity of about -0.8. This applies to the total of all costs, including travel time costs. Since HERS assumes travel time costs of about 50 percent of total costs (54 cents out of \$1.07 per mile), the -0.45 elasticity is just slightly higher than the equivalent in HERS.



## Research Recommendations

This report highlights the value of improving our understanding transportation price sensitivities. Although numerous transport elasticity studies have been performed, many use relatively simple models that account for a limited set of factors.

It would be useful for transportation professional organizations to sponsor meta-analyses of transport elasticity studies to examine in detail the factors considered in previous studies and recommends best practices for future studies, including standardized definitions, factors to include in models, and analysis methodologies. Such research should identify how to best incorporate various demographic, geographic and economic factors when evaluating price effects, taking account insights from recent studies. For example, Li, Linn and Muehlegger (2011) indicate that it is important to differentiate between price changes that consumers consider temporary fluctuations with those that they consider durable. Other studies highlight the importance of disaggregating effects by geographic location (Gillingham 2010).

This study identifies several factors that deserve consideration in future research:

- Disaggregate the ways that consumers respond to higher fuel prices, including changes in vehicle travel speed, vehicle mileage, fleet fuel economy, and location decisions.
- Identify how various factors affect price sensitivities, including demographics (portion of residents in different age and income classes), the magnitude of fuel prices relative to household incomes, the magnitude and duration of price changes, geographic factors (how price sensitivities vary between urban, suburban and rural areas), price method and frequency (such as daily versus monthly parking fees), the quality of alternatives, the time period of analysis, and the type of information and marketing provided to consumers (such as information about transport options).
- Investigate how sensitivities vary by pricing type and method, with special attention to the transferability of fuel price elasticities to other types of transport pricing such as road, parking and insurance. This should include, for example, analysis of the elasticity of vehicle ownership in response to residential parking pricing.
- Track how price sensitivities vary from one time period to another. In particular, investigate the hypothesis that transport price sensitivities reached nadir in the last quarter of the Twentieth Century and have since increased.
- Apply sensitivity analysis to the evaluation of pricing reform impacts and benefits, particularly higher elasticity values for studies that compare pricing reforms with other congestion, energy conservation and emission reduction strategies.

## Conclusions

There is growing interest in transportation pricing reforms to help achieve various planning objectives such as congestion reduction, facility cost savings, traffic safety, energy conservation and emission reductions. Their impacts and benefits are affected by the price elasticities of fuel and vehicle travel. Low elasticities imply that such reforms are relatively ineffective at achieving objectives, that price increases significantly harm consumers, and that alternative strategies that increase vehicle fuel efficiency have minimal rebound effects. Conversely, high elasticities imply that pricing reforms are effective and beneficial, harm consumers relatively little, and strategies that increase vehicle fuel economy have significant rebound effects that reduce energy savings and increase external costs such as congestion, facility costs and accidents.

Most studies indicate long-run fuel price elasticities to be -0.4 to -0.8, and long-run elasticities of vehicle travel with respect to fuel price to be -0.2 to -0.3. Significantly lower elasticities (under -0.2 for fuel and -0.1 for vehicle travel) were found in the U.S. between 1970 and 2004, which probably reflected demographic and economic trends during that period including rising employment rates and real incomes, declining real fuel prices, highway expansions and suburbanization. Many of these trends are now reversing. As a result, elasticities are likely to increase to more normal levels.

Recent research provides insights useful for evaluating pricing reforms. Elasticities tend to increase over time as consumers incorporate price changes in more long-term decisions such as vehicle purchases and home locations. Elasticities tend to increase if consumers have better accessibility options. Elasticities are higher for price increases consumers consider durable, such as tax increases, than price increases that consumers consider temporary such as occasional oil price spikes.

Relatively low elasticity values have been incorporated into various policy analyses, which likely underestimated price reform effectiveness and benefits, and exaggerated the effectiveness higher vehicle fuel efficiency regulations and incentives. If price elasticities are returning to more normal levels, these reforms actually provide far greater benefit (congestion and accident reductions, energy conservation and emission reductions) than analyses indicate.

This issue deserves more research. Evidence of rising price elasticities is still preliminary. It is therefore important that policy analysts, modelers, and decision-makers understand these issues and trends. Analysts should apply sensitivity analysis, including relatively high elasticity values when evaluating transport policies.

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