www.vtpi.org

Info@vtpi.org

250-360-1560

Changing Vehicle Travel Price Sensitivities

The Rebounding Rebound Effect

24 November 2011

Todd Litman

Victoria Transport Policy Institute

Abstract

There is growing interest in transportation pricing reforms to help achieve objectives such as congestion reductions, traffic safety and emission reductions. Their effectiveness is affected by the price sensitivity of transport, that is, the degree that travelers respond to price changes, measured as *elasticities* (the percentage change in vehicle travel caused by a percentage change in price). Lower elasticities (price changes have little impact on travel activity) imply that price reforms are not very effective at achieving objectives, higher prices significantly harm consumers, and *rebound effects* (additional vehicle travel caused by increased fuel efficiency) are small so strategies that increase vehicle fuel efficiency are relatively effective at conserving fuel. Higher elasticities imply that price reforms are relatively effective, consumers are able to reduce vehicle travel, and rebound effects are relatively large. Some studies found that price elasticities declined during the last quarter of the Twentieth Century but recent evidence suggests that transport is becoming more price sensitive. This report discusses the concepts of price elasticities and rebound effects, reviews information on vehicle travel and fuel price elasticities, examines evidence of changing price elasticities, and discusses policy implications.

Introduction

Reducing transportation prices tend to increase transportation costs. Conversely, transport price increases can reduce costs. This may seem a paradox, so let me explain. *Prices* are the direct fees consumers pay for goods. *Costs* are the resources used to produce goods. Low road, parking and fuel prices increase vehicle travel and therefore costs such as congestion, facilities, accidents and pollution. Conversely, among the most effective ways to reduce these costs are pricing reforms that increase motorists' fees.

Although most experts agree that prices affect travel activity and therefore transport costs, there is considerable debate about the details, where the devil often resides. This report investigates exactly how transport prices affect travel activity, and therefore the effectiveness of pricing reforms, such as those listed below, at solving transport problems.

Table 1 **Transportation Pricing 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 about transport pricing reform benefits. They believe that pricing has little effect on travel activity so pricing reforms are ineffective and economically harmful. It is true that, as normally measured, vehicle travel is *inelastic*, meaning that price changes cause proportionately smaller changes in mileage and fuel consumption,[1] but it is inaccurate to claim that prices have *no* impact, or that price reforms necessarily harm consumers and businesses overall.

A key factor in this analysis is the price sensitivity of transportation, 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 (Litman 2011). Some research indicates that transport elasticities declined in the U.S. during the last quarter of the Twentieth Century, but there is growing evidence that these elasticities are now increasing. This can be considered good news because it expands the range of solutions that can be applied to solving transport problems.

This paper examines 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.

---

[1] Vehicle travel seems inelastic because most price changes only affect a subset of total vehicle costs. For example, if the elasticity of vehicle travel with respect to fuel is -0.3 (considered inelastic) and fuel represents 25% of total vehicle costs, the elasticity of vehicle travel with respect to total costs is -1.2 (considered elastic).

Transportation Elasticities

Pricing impacts are measured as *elasticities*: the percentage change in consumption (vehicle travel or fuel use) caused by a percentage change in price (Litman 2011). Several factors can affect transport elasticities:

- *Magnitude of price changes.* Prices tend to affect consumption in proportion to their share of household budgets. In particular, road, parking and fuel prices appear to affect consumers if they represent a significant portion of travelers' budgets.
- *Perceived durability of price changes.* 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.
- *Type of consumer.* Wealthier consumers tend to choose different types of goods and respond differently to price changes than lower-income consumers. For example, fuel price increases tend to cause more travel changes among lower-income travelers than those with higher incomes.
- *Quality of alternatives.* A key factor affecting transport pricing effects is the quality of options available to a particular traveler. For example, a given transport price increase tends to reduce automobile commuting much more on corridors where there is high quality public transit than on automobile-dependent corridors.
- *Time period analyzed.* Elasticities tend to increase over time as consumers are able to consider prices in longer-term decisions. For example, if fuel prices increase, in the short-run consumers can only respond by changing their driving behavior (e.g. slowing down), destinations and mode, but over the longer run they may purchase more fuel efficient vehicles or choose more accessible home and job locations. For this reason economists often measure separately short-run (typically less than two years), medium-run (typically one to five years), and long-run (typically more than five years) price effects.

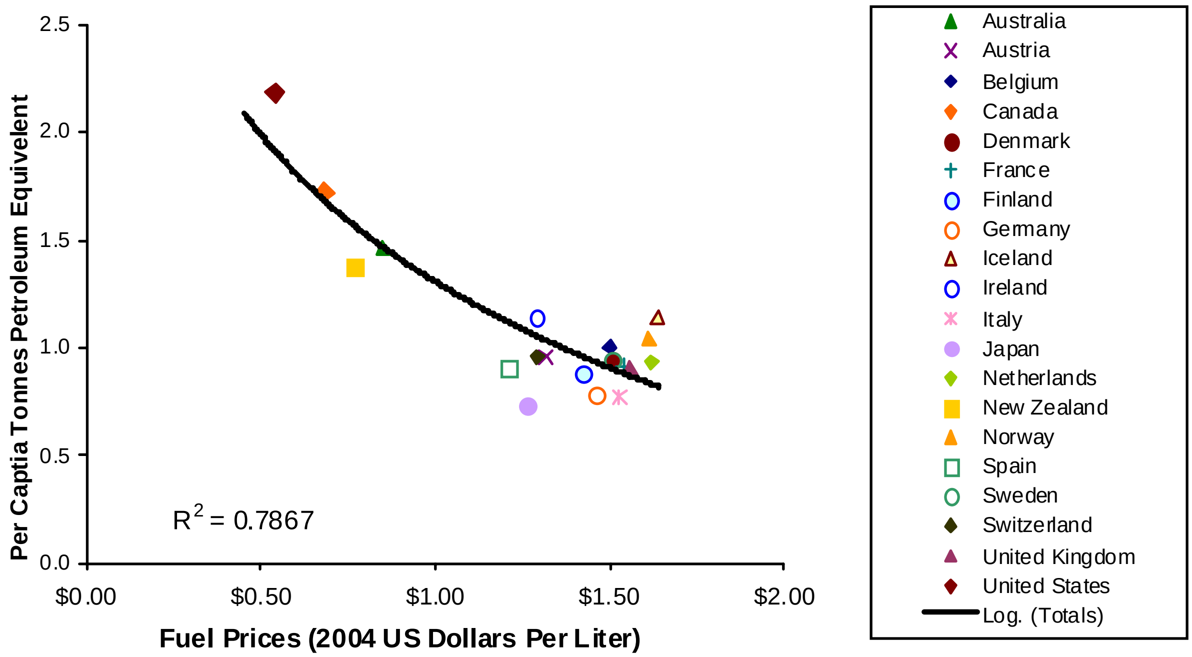
Lower elasticities (price changes cause relatively small changes in consumption) imply that pricing reforms have small impacts and benefits, and that consumers lack viable alternatives and so are significantly burdened by price increases (what economists call a loss of *consumer surplus*). In addition, low price elasticities imply that *rebound effects* (additional vehicle travel that results from increased fuel efficiency) 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.

The following sections investigate these factors individually.

Fuel Consumption With Respect to Fuel Price

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.

Numerous studies using various methodologies and data sets have investigated fuel price elasticities (Litman 2011). 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 200, 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 conditions for factors such as vehicle ownership 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.

However, these results may reflect unique factors during that period, including growing per-capita vehicle ownership, increasing female workforce participation, peak Baby Boom driving years, declining real fuel prices and increases in real incomes (which reduced fuel prices relative to incomes), highway expansion and sprawling development policies. Recent studies suggest that fuel price elasticities began to increase after about 2005 (CERA 2006). Komanoff (2008) estimates that the short-run U.S. fuel price elasticity reached a low of -0.04 in 2004, but this 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 a 4.0% reduction in fuel consumption, indicating a short-run price elasticity of -0.13. Accounting for population and economic growth during that period increases the 10-month fuel consumption price elasticity to about -0.17.

Li, Linn and Muehlegger (2011) used data on U.S. gasoline consumption, vehicle travel, vehicle ownership, and new vehicle purchases 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 oil market fluctuations. They estimate the elasticity of gasoline demand with respect to fuel price is -0.235, with greater elasticities for taxes than for tax-exclusive price fluctuations. This analysis suggests that the declining elasticities of fuel consumption with respect to price during the last quarter of the Twentieth Century may reflect, in part, the decline in the tax share of fuel prices, a factor not generally considered in elasticity studies. This study 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.

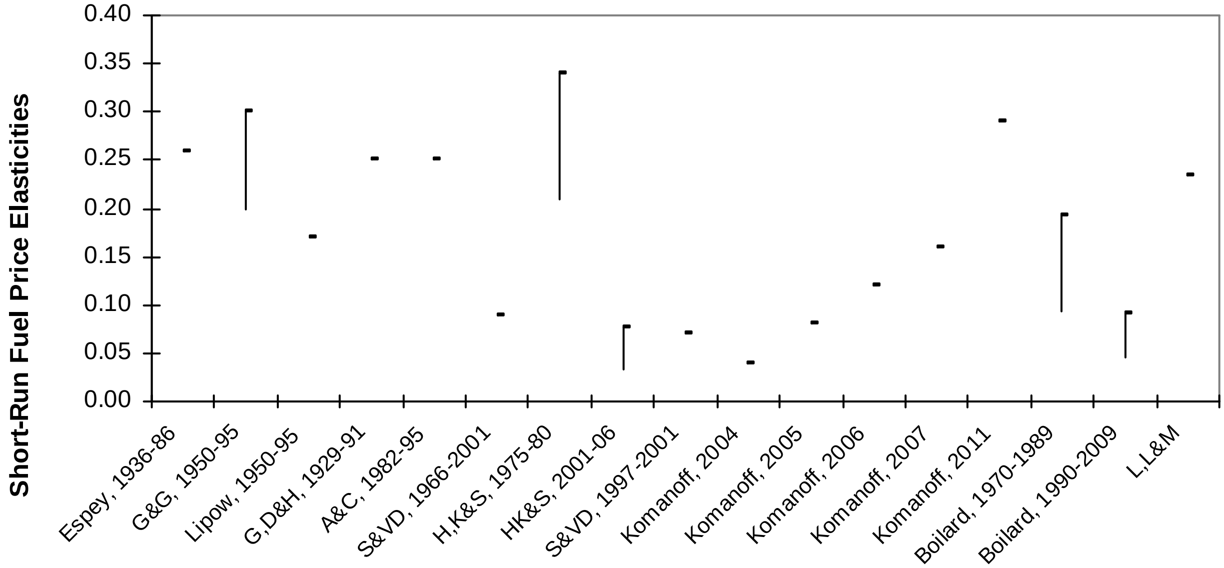
Table 3 summarizes these studies. They vary significantly in scope and methodology. Many older studies used relatively simple models, more recent studies tend to account for more demographic, economic and geographic factors. These studies indicate that fuel price elasticities declined during the last 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 (Komanoff 2008-2011).

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

Study	Study Type	Scope	Major Results
Espey (1996)	Review of 101 gasoline price elasticity studies.	1936 to 1986, U.S.	-0.26 short-run -0.58 long-run
Agras and Chapman (2001)	Gasoline price elasticity.	1982-1995, U.S.	–0.25 short-run –0.92 long run
Glaister and Graham (2002)	Review of various fuel price and income elasticity studies.	Second half of the Twentieth Century. 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.	Second half of the Twentieth Century. Mostly North America and Europe	-0.17 short run, -0.4 long run
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
Small and Van Dender (2005)	Gasoline price elasticities. Comprehensive model.	U.S. State Data, 1966-2001	*1966-2001* –0.09 short run –0.41% long run *1997 to 2001* –0.07 short run –0.34% long run
Hughes, Knittel and Sperling (2006)	Gasoline price elasticities. Comprehensive model.	1975 to 2006, U.S.	*1975-1980* –0.21 to –0.34 short-run *2001-2006* –0.034 to –0.077 short-run
Hymel, Small and Van Dender (2010)	State-level cross-sectional time series of gasoline price elasticities. Comprehensive model.	1966 to 2004, U.S.	–0.055 short run –0.285 long run
Komanoff (2008-2011)	Short run fuel price elasticity. Simple model.	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
Boilard (2010)	Fuel price elasticities. Comprehensive model.	1970 to 2009, Canada	*1970-1989* -0.093 to -0.193 short run -0.762 to -0.45 long run *1990-2009* -0.046 to -0.091 short run -0.085 to -0.256 long run
Li, Linn and Muehlegger (2011)	Fuel price elasticities with tax increases and price fluctuations analyzed separately. Comprehensive model.	1968-2008, U.S.	-0.235

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

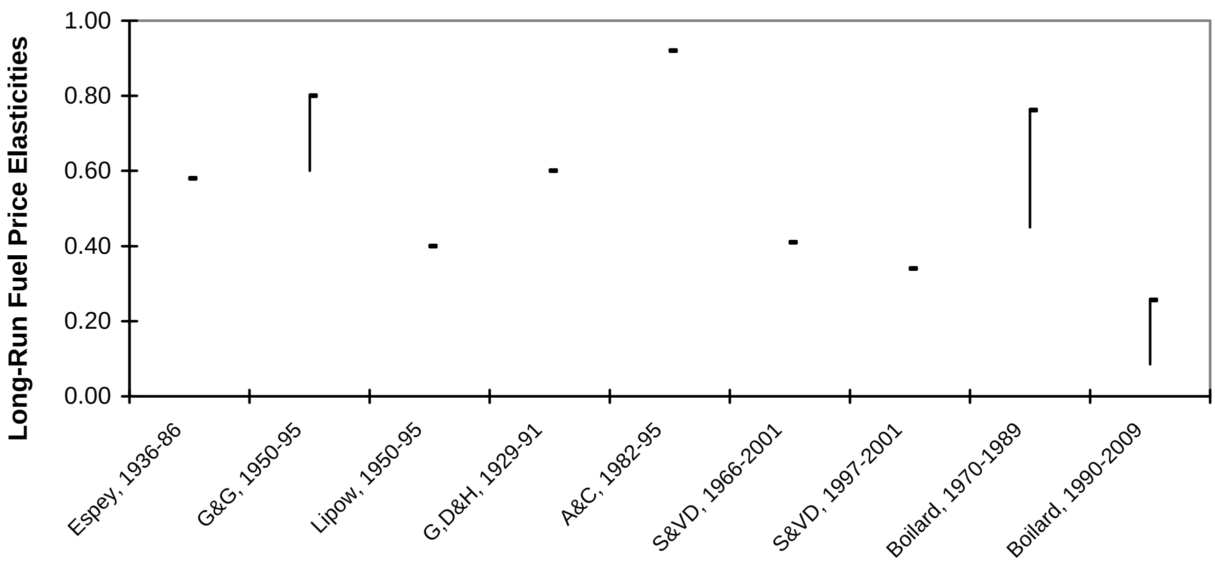
Figure 2 **Short Run Fuel Price Elasticities** (absolute values)



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)

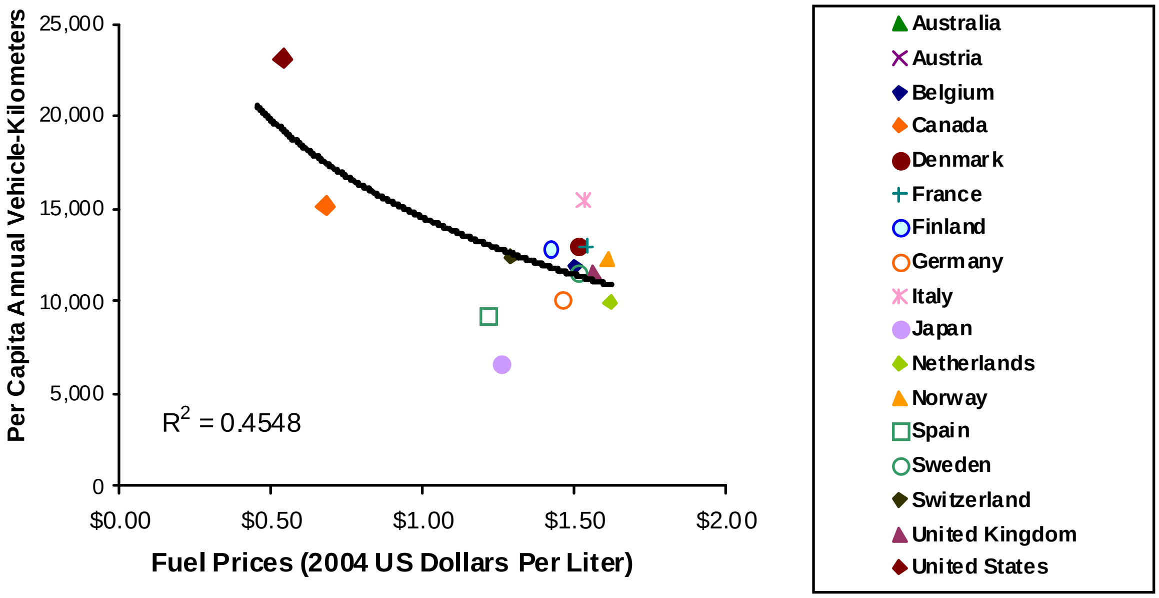


This figure illustrates estimated long-run fuel price elasticities from the studies listed in Table 3, roughly ordered from oldest to more recent time periods.

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.

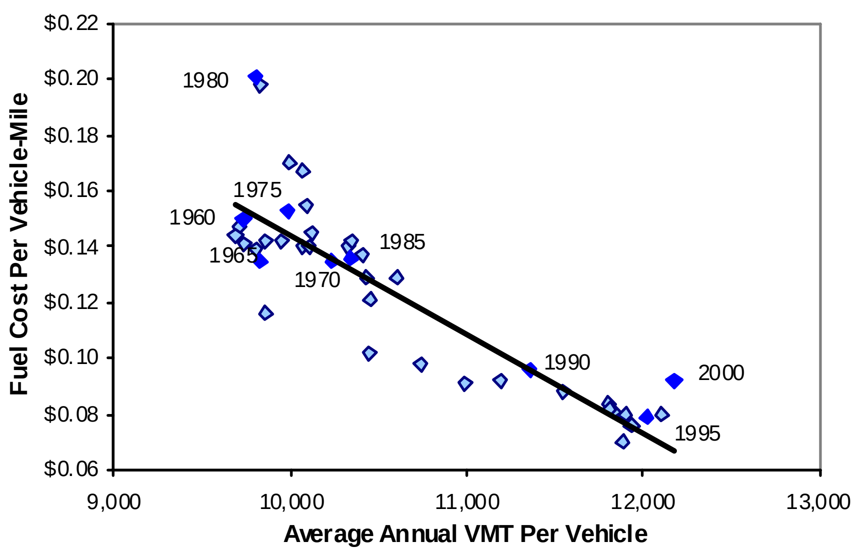
Figure 4 **Fuel Price Versus Per Capita Vehicle Travel** (OECD 2005)



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 typically averages about –0.3 (Johansson and Schipper 1997). Schimek (1997) found the elasticity of vehicle travel with respect to fuel price in the U.S. to be -0.26 using 1950 to 1994 time series data, and 1988 to 1992 pooled data.

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 time period (1997- 2001) these elasticities were -0.026 and 0.121 (a 10% price increase reduces VMT 0.26% short run and 1.2% 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 and so are higher 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 over the entire time period is -0.045 (a 10% increase in total regional congestion reduces regional mileage by 0.45% over the long run), and this value increases with income, assumedly because the opportunity cost of time increases with wealth, and so is estimated to be 0.078 at 2004 income levels (a 10% increase in total regional congestion reduces regional mileage by 0.78% over the long run). They conclude that long-run travel elasticities are typically 3.4–9.4 times short-run elasticities.

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, and accounting for the base growth rates (between 1983 and 2004 VMT increased about 2.9% annually), the short-run VMT fuel price elasticity for the four months of July through October 2008 versus 2007 is about -0.30, and for the first ten months of 2008 versus 2007 it is -0.21.

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 mileage to more fuel-efficient vehicles. Rural, low-income residents driving pickups and SUVs appear to have lower elasticities, possibly because they require larger vehicles for work purposes and have fewer alternatives.

Li, Linn and Muehlegger (2011) find that the elasticity of vehicle travel with respect to gasoline prices ranges from -0.24 to -0.34, depending on time period and model specifications, with no significant difference between taxes and other price changes. Williams-Derry (2011b) summarizes research indicating that motorists are more sensitive to road tolls than most models predict.

Fuel prices influence household location decisions, with 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.

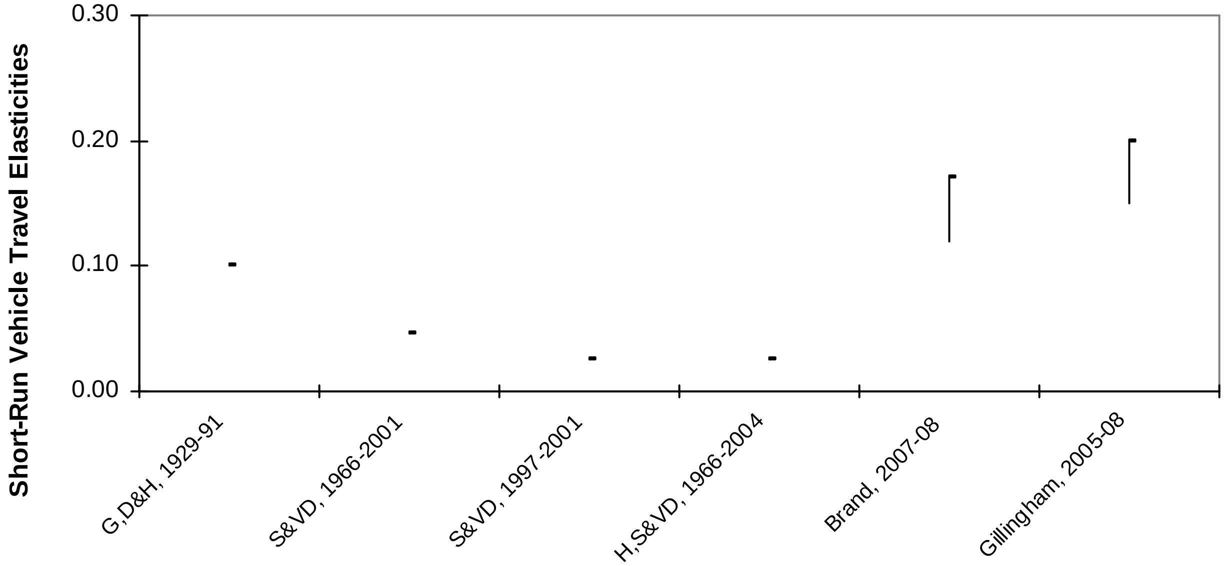
Table 4 summarizes these studies' results. As with the fuel price elasticity data, analysis quality varies, with more comprehensive models that account for more factors in recent studies. The results indicate that vehicle travel price sensitivities declined during the last quarter of the Twentieth Century, 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).

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)	Summarized results 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)	Vehicle travel elasticity with respect to fuel price. Comprehensive model.	1966-2001, U.S.	*1966 to 2001* -0.047 short run -0.22 Long run *1997 to 2001* –0.026 short run –0.121% long run
Hymel, Small and Van Dender (2010)	State-level cross-sectional time series gasoline price elasticities. Comprehensive model.	1966 to 2004, U.S.	-0.026 short run -0.131 long run
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)	Odometer and fuel consumption data. Comprehensive model.	2005-2008, California	-0.15 to -0.20 medium run, varies by vehicle type and location
Li, Linn and Muehlegger (2011)	Vehicle travel with respect to fuel price. Comprehensive model.	1968-2008, U.S.	-0.24 to -0.34

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

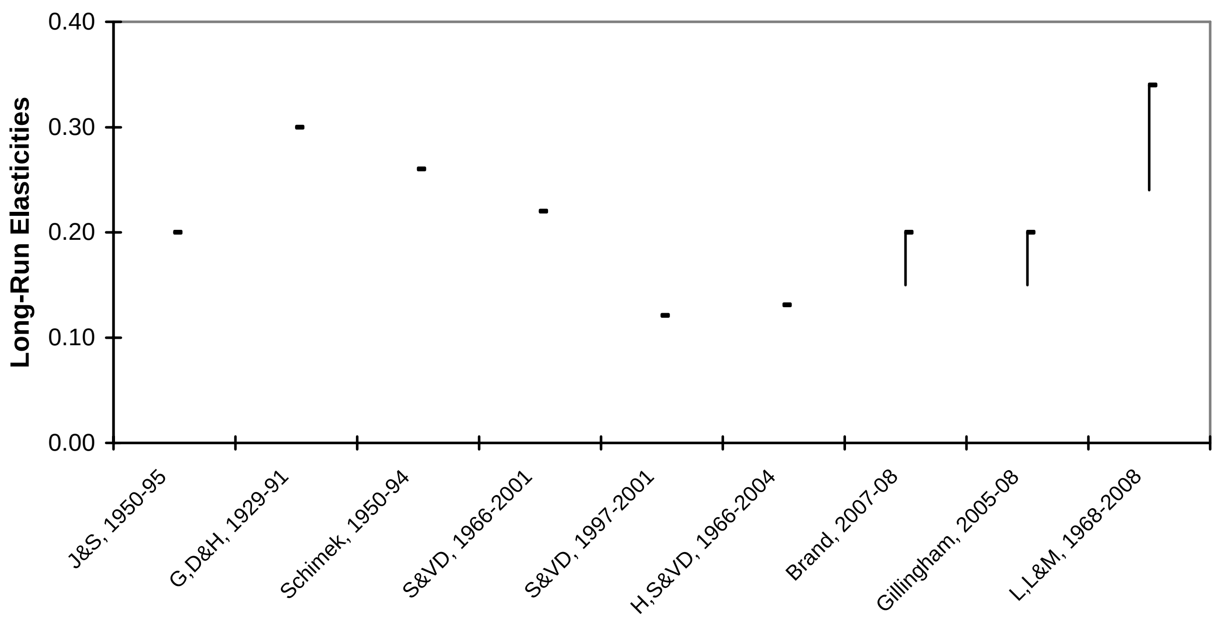
Figure 6 **Short-Run Vehicle Travel Elasticities** (absolute values)



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)



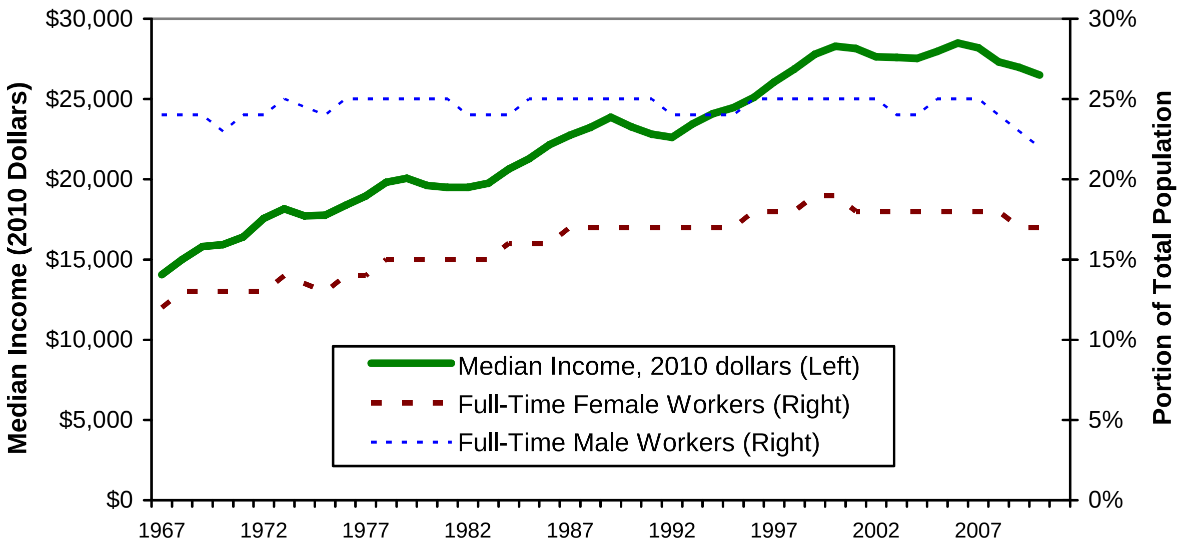
This figure illustrates estimated long-run vehicle travel elasticities from the studies listed in Table 4, roughly ordered from oldest to more recent time periods.

Discussion

As previously mentioned, several specific factors help explain the decline in fuel and vehicle travel price elasticities during the last decades of the Twentieth Century.

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. This income growth is partly explained by increased women's workforce participation which both increased households' ability to purchase fuel and travel demands as more women commuted. 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 that is likely to increase in the future.

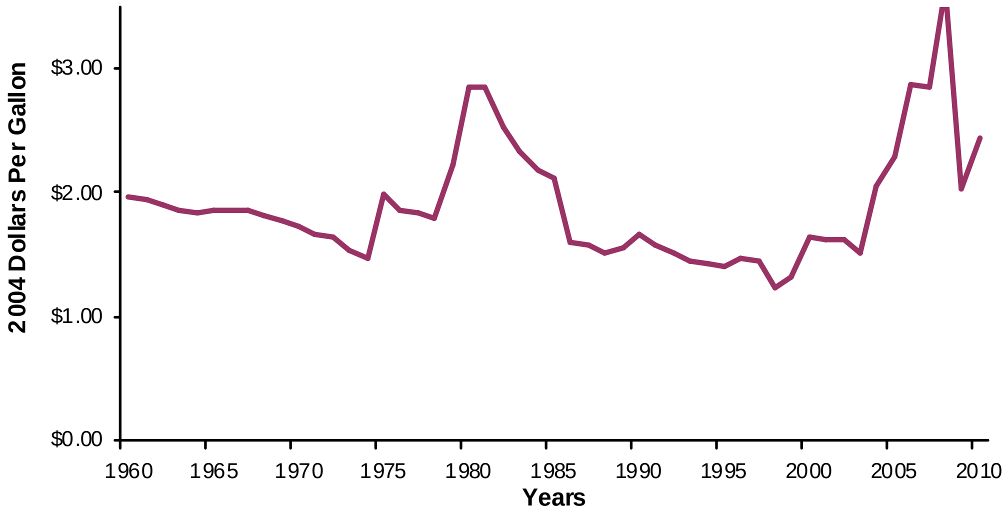
Figure 8 **Median U.S. Per Capita Income** (U.S. Census, 2010a)



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).

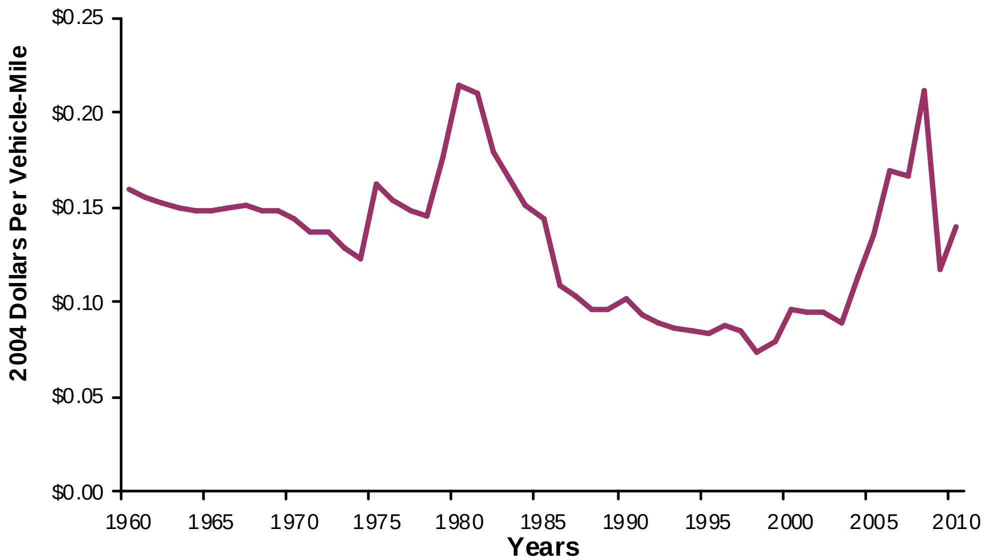
Figure 9 **U.S. Fuel and Fuel Tax Costs** (VTPI 2011)



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.

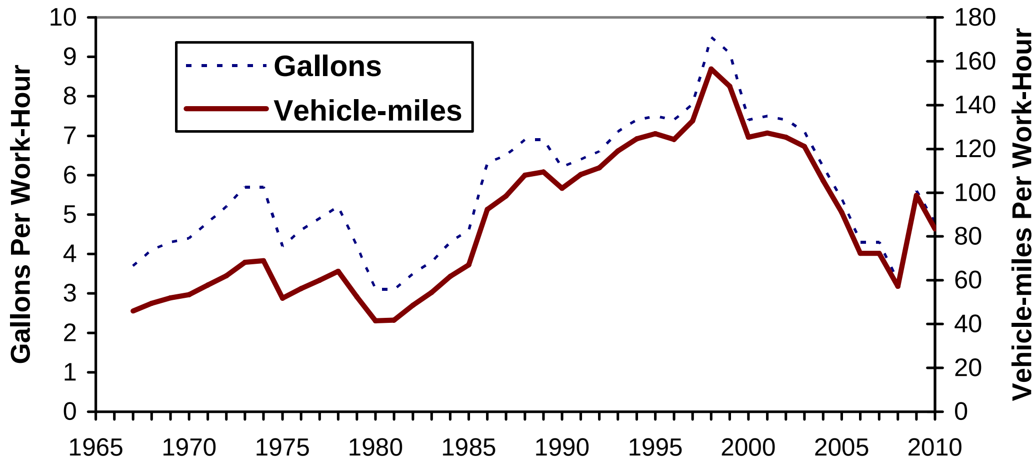
Figure 10 **U.S. Per-Mile Fuel Costs** (VTPI 2011)



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 annual median incomes were $2,464 per capita, gasoline costed $0.33 per gallon, and vehicles averaged 12.4 miles-per-gallon, an average work-hour could purchase 3.73 gallons of fuel or 46 vehicle-miles. In 2000, when median incomes were $22,346, gasoline costed $1.51 per gallon, and vehicles aveaged 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)

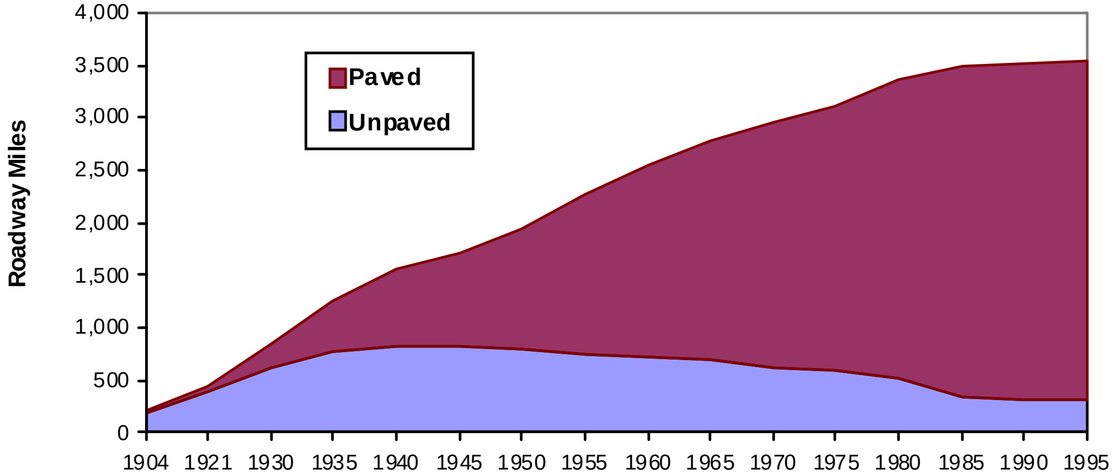


Fuel and vehicle travel affordability increased signficiantly between 1967 and 2000, but subsequently declined.

These trends help explain why fuel and travel elasticities declined between 1967 and 2000, since, 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 and this is unlikely to change due to stagnant incomes and rising fuel prices. Increasing vehicle fuel economy may offset 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 exapansion. 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)



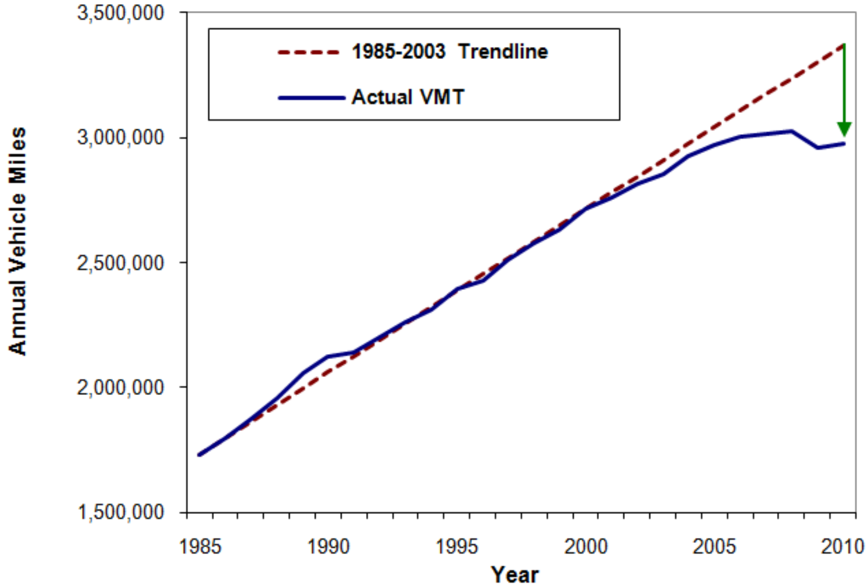
Roadway mileage grew significantly between 1900 and 1980. Little growth has occurred since.

Automobile-oriented land use development policies, such as restrictions on development density and mix, and generous minimum parking requirements, probably also contributed to vehicle travel growth between 1960 and 2000. In recent years, "smart growth" development policy reforms have been adopted in many jurisdictions to encourage more compact, multi-modal development, often with an explicit objective of reducing automobile travel and encouraging use of other modes. By improving travel 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 an 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.

For example, 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 those 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 supported increased driving. However, 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 incease.

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 convenience 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 off 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 x 4 million for the motorists who pay the toll, plus $1 x 1 million x 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 x 3 million for the motorists who pay the toll, plus $1 x 2 million x 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 x 1,000 x 0.5) per vehicle.[2] 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 x 2,000 x 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.). Vehicle travel forgone due to higher prices. Reduced vehicle performance (size, power and speed) due to higher fuel prices.	Incremental user savings (distance-based insurance and registration fees). Revenues used to reduce other taxes and fees or provide additional consumer benefits. 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.

[2] By changing insurance premimums 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).[3] 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.

[3] Rebound effects can also apply to other types of energy efficiency gains. For example, households may respond to increased home insulation by raising winter thermostate 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%.
• 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. • Consumers find it relatively difficult to reduce their vehicle travel and fuel consumption. Higher prices harm consumers and are inequitable. • 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.	• Pricing strategies (higher fuel taxes, road tolls, parking fees, and distance-based insurance and registration fees) are relatively effective and beneficial. • Consumers find it relatively easy to reduce their vehicle travel and fuel consumption. Higher prices are not very harmful to consumers or inequitable. • 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.

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)

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 a transportation professional organization to sponsor a meta-analysis of transportation elasticity studies which 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. This should describe 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 response 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 of -0.4 to -0.8, and long-run vehicle travel elasticities with respect to fuel price of -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 (e.g., -0.4 to -0.8 long-run fuel price elasticities and -0.2 to -0.3 vehicle travel elasticities).

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 transport alternatives. 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 probably provide far greater benefit (congestion reductions, accident reductions, energy conservation and emission reductions) than these policy analyses indicated.

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.

References

J. Agras and D. Chapman (1999), "The Kyoto Protocol, CAFE Standards, and Gasoline Taxes," *Contemporary Economic Policy*, Vol. 17 No. 3; http://onlinelibrary.wiley.com/doi/10.1111/j.1465-7287.1999.tb00683.x/abstract.

BLS (2007 and 2008), *Consumer Expenditure Survey*, Bureau of Labor Statistics (www.bls.gov); at www.bls.gov/cex/home.htm.

François Boilard (2010), "Gasoline Demand In Canada: Parameter Stability Analysis," *EnerInfo*, Vol. 15, No. 3, Fall 2010, Centre for Data and Analysis in Transportation, Université Laval (www.cdat.ecn.ulaval.ca); at www.cdat.ecn.ulaval.ca/english/enerInfo-en/enerinfoen-v15n3.pdf.

Dan Brand (2009), *Impacts of Higher Fuel Costs, Federal Highway Administration*, (www.fhwa.dot.gov); at www.fhwa.dot.gov/policy/otps/innovation/issue1/impacts.htm.

BTS (2001), *National Transportation Statistics*, Bureau of Transportation Statistics (www.bts.gov); at www.vtpi.org/fueltrends.xls.

CBO (2005), *Limiting Carbon Dioxide Emissions: Prices Versus Caps*, Congressional Budget Office (www.cbo.gov); at www.cbo.gov/ftpdoc.cfm?index=6148&type=0.

CBO (2008), *Effects of Gasoline Prices on Driving Behavior and Vehicle Markets*, Congressional Budget Office (www.cbo.gov); at www.cbo.gov/ftpdocs/88xx/doc8893/01-14-GasolinePrices.pdf.

CERA (2006), *Gasoline and the American People*, Cambridge Energy Research Associates (www2.cera.com/gasoline); at www2.cera.com/gasoline/summary.

Molly Espey (1996), "Explaining The Variation In Elasticity Estimates Of Gasoline Demand In The United States: A Meta-Analysis," *Energy Journal*, Vol. 17, No. 3, pp. 49-60; at www.allbusiness.com/marketing-advertising/567873-1.html.

Kenneth Gillingham (2010), *Identifying the Elasticity of Driving: Evidence from a Gasoline Price Shock in California*, Stanford University (www.stanford.edu); at www.stanford.edu/~kgilling/Gillingham_IdentifyingElasticityofDriving.pdf.

Stephen Glaister and Dan Graham (2002), "The Demand for Automobile Fuel: A Survey of Elasticities," *Journal of Transport Economics and Policy*, Vol. 36, No. 1, pp. 1-25; at www.ingentaconnect.com/content/lse/jtep/2002/00000036/00000001/art00001.

Phil Goodwin, Joyce Dargay and Mark Hanly (2004), "Elasticities of Road Traffic and Fuel Consumption With Respect to Price and Income: A Review," *Transport Reviews* (www.tandf.co.uk), Vol. 24/3, May, pp. 275-292; at http://economics.about.com/gi/dynamic/offsite.htm?zi=1/XJ&sdn=economics&zu=http%3A%2F%2Fwww.cts.ucl.ac.uk%2Ftsu%2Fpapers%2Ftransprev243.pdf.

Jonathan E. Hughes, Christopher R. Knittel and Daniel Sperling (2006), *Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand*, Working Paper No. 12530, National Bureau of Economic Research (www.nber.org); at http://papers.nber.org/papers/W12530.

Kent M. Hymel, Kenneth A. Small and Kurt Van Dender (2010), "Induced Demand And Rebound Effects In Road Transport," *Transportation Research B* (www.elsevier.com/locate/trb), Vol. 44, Issue 10, December, pp. 1220-1241; at www.socsci.uci.edu/~ksmall/Rebound_congestion_27.pdf.

INRIX (2008), *The Impact of Fuel Prices on Consumer Behavior and Traffic Congestion*, INRIX (www.inrix.com); at http://scorecard.inrix.com/scorecard.

Olof Johansson and Lee Schipper (1997), "Measuring the Long-Run Fuel Demand for Cars," *Journal of Transport Economics and Policy*, Vol. 31, No. 3, pp. 277-292.

Charles Komanoff (2008), *Gasoline Price-Elasticity Spreadsheet*, Komanoff Energy Consulting (www.komanoff.net/oil_9_11/Gasoline_Price_Elasticity.xls).

Shanjun Li, Joshua Linn and Erich Muehlegger (2011), *Gasoline Taxes and Consumer Behavior*, Stanford (http://economics.stanford.edu); at http://economics.stanford.edu/files/muehlegger3_15.pdf.

Gar W. Lipow (2008), *Price-Elasticity of Energy Demand: A Bibliography*, Carbon Tax Center (www.carbontax.org); at www.carbontax.org/wp-content/uploads/2007/10/elasticity_biblio_lipow.doc.

Todd Litman (2001), "Generated Traffic: Implications for Transport Planning," *ITE Journal*, Vol. 71, No. 4, Institute of Transportation Engineers (www.ite.org), April 2001, pp. 38-47; at www.vtpi.org/gentraf.pdf.

Todd Litman (2005), "Efficient Vehicles Versus Efficient Transportation: Comparing Transportation Energy Conservation Strategies," *Transport Policy*, Vol. 12/2, March, pp. 121-129; at www.vtpi.org/cafe.pdf.

Todd Litman (2006), *The Future Isn't What It Used To Be: Changing Trends And Their Implications For Transport Planning*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/future.pdf; originally published as "Changing Travel Demand: Implications for Transport Planning," *ITE Journal*, Vol. 76, No. 9, (www.ite.org), September, pp. 27-33.

Todd Litman (2011), *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior*, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/elasticities.pdf.

Todd Litman (2009), *Transportation Cost and Benefit Analysis*, VTPI (www.vtpi.org/tca).

Nicholas P. Lutsey and Daniel Sperling (2005), "Energy Efficiency, Fuel Economy, and Policy Implications," *Transportation Research Record 1941*, TRB (www.trb.org), pp. 8 - 17.

McKinsey (2007), *Reducing U.S. Greenhouse Gas Emissions - How Much at What Cost - US Greenhouse Gas Abatement Mapping Project*, McKinsey & Company (www.mckinsey.com); at www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf.

Raven Molloy and Hui Shan (2011), *The Effect of Gasoline Prices on Household Location*, Federal Reserve Board (https://federalreserve.gov); at https://federalreserve.gov/pubs/feds/2010/201036/201036pap.pdf.

W. Ross Morrow, Kelly Sims Gallagher, Gustavo Collantes and Henry Lee (2010), *Analysis of Policies to Reduce Oil Consumption and Greenhouse-Gas Emissions from the U.S. Transportation Sector*, Kennedy School of Government, Harvard University (http://belfercenter.ksg.harvard.edu); at http://belfercenter.ksg.harvard.edu/files/Policies%20to%20Reduce%20Oil%20Consumption%20and%20Greenhouse%20Gas%20Emissions%20from%20Transportation.pdf.

OECD (2005), *OECD in Figures*, ISBN 9264013059, Organization for Economic Cooperation and Development (www.oecd.org/infigures); in www.vtpi.org/OECD2006.xls.

Robert Puentes (2008), *The Road…Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S.*, Brooking Institution (www.brookings.edu); at www.brookings.edu/reports/2008/1216_transportation_tomer_puentes.aspx.

SACOG (2008), *Impact of Gas Prices on Travel Behavior*, Sacramento Area Council of Governments (www.sacog.org); at www.sacog.org/rucs/wiki/index.php/Impact_of_Gas_Prices_on_Travel_Behavior.

Paul Schimek (1997), "Gasoline and Travel Demand Models Using Time Series and Cross-Section Data from the United States," *Transportation Research Record 1558*, TRB (www.trb.org), pp. 83-89.

Kenneth Small and Kurt Van Dender (2005), *The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using U.S. State Data, 1966-2001*, University of California Energy Institute's (UCEI) (www.ucei.berkeley.edu); at www.ucei.berkeley.edu/PDF/EPE_014.pdf.

Kenneth A. Small and Kurt Van Dender (2007), "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect," *Energy Journal*, Vol. 28, No. 1, pp. 25-51; at www.econ.uci.edu/docs/2005-06/Small-03.pdf.

Thomas Sterner (2006), "Fuel Taxes: An Important Instrument for Climate Policy," *Energy Policy*, Vol. 35. pp. 3194–3202; at www.hgu.gu.se/files/nationalekonomi/personal/thomas%20sterner/a78.pdf.

TRB (2009), *Strategies for Reducing the Impacts of Surface Transportation on Global Climate Change*, NCHRP 20-24, TRB (www.trb.org); www.trb.org/trbnet/ProjectDisplay.asp?ProjectID=2113.

VTPI (2010), *Online TDM Encyclopedia*, Victoria Transport Policy Institute (www.vtpi.org/tca).

VTPI (2011), *U.S. Fuel Trends Spreadsheet*, Victoria Transport Policy Institute (www.vtpi.org/fueltrends.xls).

UKERC (2007), *The Rebound Effect: An Assessment Of The Evidence For Economy-Wide Energy Savings From Improved Energy Efficiency*, UK Energy Research Centre (www.ukerc.ac.uk); at www.ukerc.ac.uk/support/tiki-index.php?page=ReboundEffect.

US Census (2010a), *CPS Population and Per Capita Money Income, All Races: 1967 to 2010*, Table P-1, U.S. Census Brueau (www.census.gov); at www.census.gov/hhes/www/income/data/historical/people/2010/P01AR_2010.xls.

US Census (2010a), *Work Experience--All Workers by Median Earnings and Sex: 1967 to 2010*, Table P-41, U.S. Census Brueau (www.census.gov); at www.census.gov/hhes/www/income/data/historical/people/2010/P01AR_2010.xls.

USDOT (2010), *Transportation's Role in Reducing U.S. Greenhouse Gas Emissions: Volume 1*, Report to Congress, U.S. Department of Transportation (www.dot.gov), at http://ntl.bts.gov/lib/32000/32700/32779/DOT_Climate_Change_Report_-_April_2010_-_Volume_1_and_2.pdf.

Clark Williams-Derry (2011a), "Dude, Where Are My Cars?" Sightline Institute (www.sightline.org) at http://daily.sightline.org/daily_score/series/dude-where-are-my-cars.

Clark Williams-Derry (2011b), *Toll Avoidance And Transportation Funding: Official Estimates Frequently Overestimate Traffic And Revenue For Toll Roads*, Sightline Institute (www.sightline.org); at www.sightline.org/research/sprawl/toll-avoidance-and-transportation-funding.

www.vtpi.org/VMT_Elasticities.pdf