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"Efficiency - Equity - Clarity"

Transportation Elasticities

How Prices and Other Factors Affect Travel Behavior

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Abstract

This report investigates the influence that prices and service quality have on travel behavior. It summarizes research on various types of transportation elasticities and describes how to use this information to predict the travel impacts of specific price reforms and management strategies.

Contents

Introduction

Life is full of trade-offs. People must constantly decide how to spend the limited amounts of money and time they have available. The choices that people make when faced with these trade-offs reflects their knowledge, preferences and values.

This report describes techniques used to define and quantify these trade-offs, which can help predict how various changes to the transportation system are likely to affect travel behavior.[1] This information can be very helpful in evaluating potential transportation pricing reforms and management strategies (VTPI, 2005).

Prices are the direct, internal, variable, perceived costs involved in consuming a good, that is, the factors that directly affect decisions by individual people and organizations (called *firms*) concerning what goods and services to consume. The term is sometimes limited to monetary costs, but it can include non-monetary costs such as time, discomfort and risk. For example, the price of an airplane trip includes the financial cost of the ticket, expenses for getting to the airport, plus the time and risk of travel. Factors such as discomfort and risk can be considered to affect travel time costs: a minute spent by travelers in comfort and safe conditions imposes less cost to consumers than the same minute spent in uncomfortable or unsafe conditions ("Travel Time Costs," Litman, 2005).

Price changes often affect consumption decisions. For example, you may consider a particular product too expensive at its regular price, but you buy it when it is discounted. Similarly, a price increase may motivate you to use less of a product or shift to another brand.

Such decisions are said to be *marginal*, that is, the decision is at the margin between different alternatives, and may therefore be affected by a small price change. Although individually these decisions may be quite variable and difficult to predict (you might succumb to a sale one day, but forego the same offer the next day), in aggregate they tend to follow a predictable pattern: when the price of a good declines its consumption increases, and when a good's price increases its consumption declines. This is called the "law of demand."

Transportation activities tend to follow this pattern. When the monetary, time, discomfort or risk costs of travel decline, the amount of mobility (measured in trips, person-miles or ton-miles) tends to increase. When costs increase, mobility declines. Price changes can have a variety of impacts on travel, affecting the number of trips people take, their destination, route, mode, travel time, type of vehicle (including size, fuel efficiency and fuel type), parking location and duration, and which type of transport services they choose (Institute for Transport Studies, 2004).

Even a small price difference can have a large effect on travel decisions, particularly if consumers have many competitive options to choose from. For example, in a city with many destination and travel options, a modest parking fee or road toll can significantly

[1] For good general discussions of elasticities see Oum, Van Ooststroom and Yoon, 1996; TRACE, 1999; and the BTE Transport Elasticities Database Online.

affect where and how people travel. In addition, transportation prices can affect how businesses organize manufacturing and distribution activities, and even product design. For example, declining shipping costs have greatly increased international trade, resulting in more centralized production of many goods, and allowing more prepackaging.

Economists measure price sensitivity using *elasticities*, defined as the percentage change in consumption of a good caused by a one-percent change in its price or other characteristics (such as traffic speed or road capacity). For example, an elasticity of -0.5 for vehicle use with respect to vehicle operating expenses means that each 1% increase in these expenses results in a 0.5% reduction in vehicle mileage or trips. Similarly, a transit service elasticity is defined as the percentage change in transit ridership resulting from each 1% change in transit service, such as bus-miles or frequency. A negative sign indicates that the effect operates in the opposite direction from the cause (an increase in price causes a reduction in travel). Elasticities can be calculated based on ratios, rather than absolute price values, such as the ratio between transit fares and automobile operating costs, or vehicle costs as a percentage of average income or wages.

Economists use several terms to classify the relative magnitude of elasticity values. *Unit elasticity* refers to an elasticity with an absolute value of 1.0, meaning that price changes cause a proportional change in consumption. Elasticity values less than 1.0 in absolute value are called *inelastic*, meaning that prices cause less than proportional changes in consumption. Elasticity values greater than 1.0 in absolute value are called *elastic*, meaning that prices cause more than proportional changes in consumption. For example, both a 0.5 and –0.5 values are considered *inelastic*, because their absolute values are less than 1.0, while both 1.5 and –1.5 values are considered *elastic*, because their absolute values are greater than 1.0.

Several methods are used to compute elasticities, some more accurate than others. These methods and their application are described in detail, along with examples, in Pratt (2003), Appendix A, “Elasticity Discussion and Formulae” and in TRL, 2004.

The most frequently used form of elasticity (symbolized η) in transportation analyses is the *arc elasticity*, or its variation, the *mid-point* (or *linear*) *arc elasticity*. Arc elasticity is based on both the original and final values of demand and price or service, while elasticities involving a free fare (price equals zero before or after the change) must be calculated using the mid-point formulation. Arc elasticity is defined by a logarithmic formulation and, except for very large changes in price or service (P), and quantity demanded (Q), is closely approximated by a mid-point formulation which makes use of the average value of each independent variable (Pratt, 1999). A more simplistic form, encountered mostly in older transit fare analyses, is known as a *shrinkage ratio* or *shrinkage factor*.

Definitions

Arc Elasticity

$$(\eta) = (\Delta \log Q)/(\Delta \log P)$$

or

$$(\eta) = (\log Q_2 - \log Q_1) / (\log P_2 - \log P_1)$$

Mid-Point (or Linear) Arc Elasticity

$$(\eta) = [(\Delta Q)/(Q_1 + Q_2)/2] \div [(\Delta P)/(P_1 + P_2)/2]$$

or

$$(\eta) = [\Delta Q(P_1 + P_2)] \div [\Delta P(Q_1 + Q_2)]$$

or

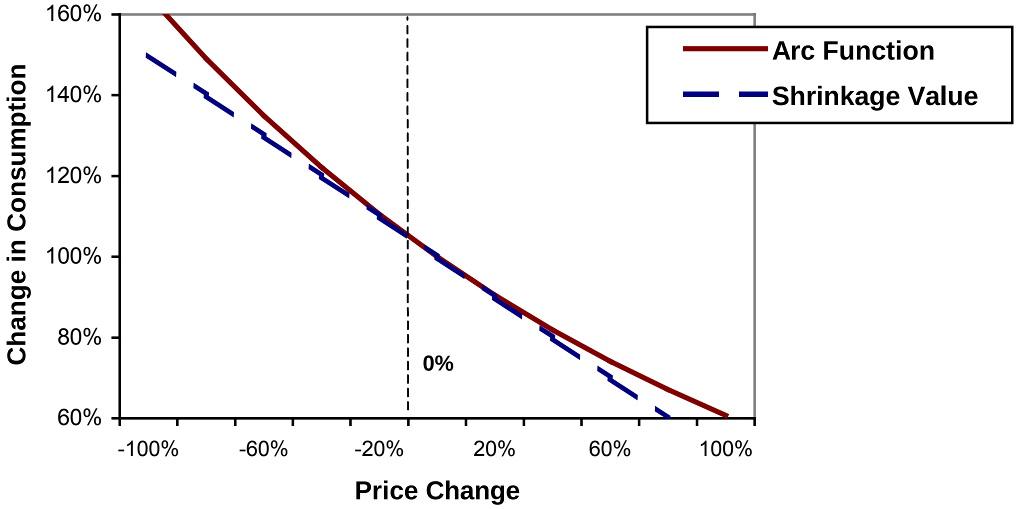
$$(\eta) = [(Q_2 - Q_1)(P_1 + P_2)] \div [(P_2 - P_1)(Q_1 + Q_2)]$$

where η is the elasticity value, Q_1 and Q_2 are the demand before and after, and P_1 and P_2 are the price or service before and after.

An *arc* elasticity reflects the change in consumption that results from each 1% change in price, calculated in infinitesimally small increments. Measured in this way, a large price change consists of numerous small incremental changes. For example, a –0.5 price elasticity applied to a 10% price increase can be calculated as ten 0.5% reductions in consumption (e.g., trips taken, miles driven, fuel consumed, etc.). The first reduces current consumption by 0.5% to 99.5%, the second reduces this by another 0.5%, which is reduced by another 0.5% in the third step, and so on a total of ten times. Note that each step affects an incrementally smaller base, resulting in an exponential function. Reasonably accurate arc elasticities can be calculated using a calculator or spreadsheet as $[(1\text{-}e) \times (1\text{-}e) \times (1\text{-}e) \ldots]$, or $(1\text{-}e)^n$ where e = elasticity and n = the percentage change in price. The results are an approximation, but accurate enough for most applications (for example, in the calculation described above, ten 1% increments gives a 4.889% reduction, while the log arc elasticity application formula in Pratt, 1999, Appendix A, page 19, gives a slightly smaller 4.654% percent reduction).

A *shrinkage ratio* is defined as the change in demand relative to original demand divided by the change in price relative to the original price. Shrinkage ratios have historically been used as a means of reporting response to transit fare changes, primarily fare increases, but this method is not very accurate, particularly for large price changes. Figure 1 illustrates the difference between arc elasticities and shrinkage values. The differences are insignificant for small price changes, but become important when larger price changes are evaluated (greater than 50%).

Figure 1 **Arc and Linear Elasticities**

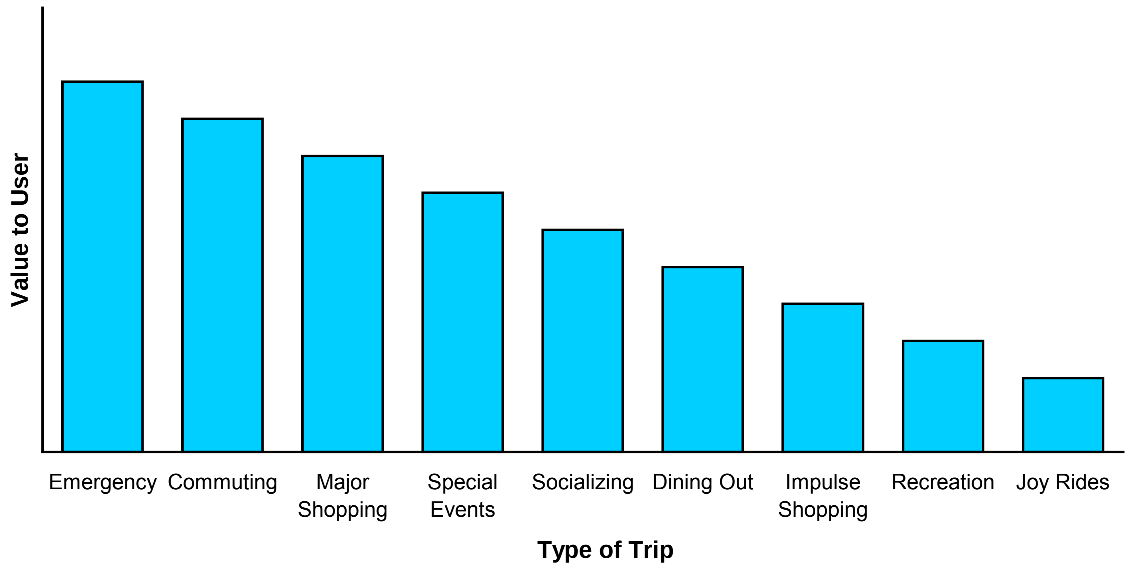


This figure compares arc elasticities and shrinkage values. Arc elasticities are based on an exponential function that is more accurate for evaluating larger price changes.

Cross-elasticities refer to the percentage change in the consumption of a good resulting from a price change in another, related good. For example, automobile travel is complementary to vehicle parking, and a substitute for transit travel. As a result, an increase in the price of driving tends to reduce demand for parking and increase demand for transit travel. To help analyze cross-elasticities it is useful to estimate *mode substitution* factors, such as the change in automobile trips resulting from a change in transit trips. These factors vary depending on circumstances. For example, when bus ridership increases due to reduced fares, typically 10-50% of the added trips will substitute for an automobile trip, that is, one automobile trip is reduced for each two to ten additional transit trips. Other trips will shift from nonmotorized modes, ridesharing (which consists of vehicle trips that will be made anyway), or be induced travel (including chauffeured automobile travel, in which a driver makes a special trip to carry a passenger). Conversely, when a disincentive such as parking fees or road tolls causes automobile trips to decline, generally 20-60% shift to transit, depending on conditions. Pratt (1999) provides information on the mode shifts that result from various incentives, such as transit service improvements and parking pricing.

In order to understand how prices affect travel decisions, think of all of the trips you might make during a certain time period, as illustrated in Figure 2. Such a ranking for an entire community includes millions of potential trips. This is a travel demand curve (a graph of the relationship between prices and consumption). If prices decline, travel usually increases as lower-value trips become more affordable, and if prices increase, travel usually declines, as consumers choose to forego some lower-value trips, or shift to a cheaper mode or destination.

Figure 2 **Travel Ranked by User Value**



Trips range in value. High value trips will occur even if user costs are high. Some trips have relatively low value and will only occur if prices are low.

The steepness of this curve indicates how sensitive (or "elastic") a particular good is with respect to price. A high elasticity (i.e., a gradual curve) indicates that a relatively small change in price will cause a relatively large change in consumption. A low price elasticity (i.e., a steep curve) indicates that price changes have relatively little impact on consumption.

Elasticity analysis is normally based on *real* (inflation adjusted) prices, as opposed to *nominal* or *current* prices (unadjusted for inflation). For example, if during a time period there is 10% inflation and nominal prices do not change, real prices will have declined by 10%. If during that time period prices increase by 10%, real prices will have stayed constant. If nominal prices increase 20% during that period, real prices will have increased by approximately 10%.

Although elasticities are often reported as single, point estimates, there are actually many factors that can affect the price sensitivity of a particular good. In other words, elasticities are actually functions with several possible variables, including the type of market, type of consumer and time period. For example, although the elasticity of vehicle travel with respect to fuel price may be defined as –0.3 (a single value), the actual value will vary between –0.1 and –0.8 depending on the type of trip (commercial, commute, recreational, etc.), the type of motorist (rich, poor, young, old, etc.), travel conditions (rural, urban, peak, off-peak), and the time period being considered (short-, medium- or long-run). Some of these variables are discussed in more detail in the next section.

Is Driving Insensitive to Price?

Economists have plenty of solid research showing that prices affect travel behavior, but non-economists often cite anecdotal evidence that travel is insensitive to price, and so argue that price reforms are an ineffective way to affect travel behavior. For example, they will point to a news article showing that a recent jump in fuel prices had little effect on automobile use, or data showing that people who live in countries with high fuel taxes continue to drive automobiles. "Motorists love their cars too much, they won't give them up, " the claim.

Such claims are partly true and largely false.

As it is usually measured, automobile travel is *inelastic*, meaning that a percentage price change causes a proportionally smaller change in vehicle mileage. For example, a 10% fuel price increase only reduces automobile use by about 1% in the short run and 3% over the medium run. Even a 50% fuel price increase, which seems huge to consumers, will generally only reduce vehicle mileage by about 5% in the short run, a change too small for most people to notice, although this will increase over time as consumers take the higher price into account in longer-term decisions, such as where to live or work.

But fuel prices are a poor indicator of the elasticity of driving, because over the long term consumers will purchase more fuel-efficient vehicles. Over the last few decades the real (inflation adjusted) price of vehicle fuel has declined significantly, and vehicle-operating efficiency has increased. Real fuel costs are now a third lower, and an average car is nearly twice as efficient. For example, the $0.35 paid for a gallon of gasoline in 1955 dollars is worth $2.35 in current dollars, and an average car of that time could only drive 12 miles on a gallon. Not surprisingly, consumers have responded to these trends by purchasing larger and more power vehicles, and driving more miles per year. Had fuel prices increased with inflation, fewer SUVs would be sold and motorists would drive fewer annual miles.

Residents of countries with high fuel taxes tend to purchase more fuel-efficient vehicles and drive fewer annual miles per capita. For example, fuel taxes are about 8 times higher in the U.K. than in the U.S., resulting in fuel prices that are about three times higher. U.K. vehicles are about twice as fuel efficient, on average, so per-mile fuel costs are only about 1.5 times higher, and automobiles are driven about 20% less per year, so annual fuel costs are only 1.25 higher than in the U.S. Since per capita vehicle ownership is lower, average per capita fuel expenditures are similar in both countries. Similar patterns can be found when comparing other countries with different fuel prices. This indicates that automobile use is sensitive to price.

The relatively low elasticity of driving with respect to fuel prices hides a much higher overall elasticity of driving. Fuel is only about a quarter of the total cost of driving (Litman, 2005). An elasticity of –0.3 for vehicle travel with respect to fuel price indicates that the overall price elasticity of driving is about –1.2, making driving an elastic good with respect to total vehicle costs. Various types of pricing reforms result in motorists paying more directly the costs of roads, parking (VTPI, 2005).

The price sensitivity of driving is more evident when measured with respect to parking fees and tolls. A modest parking fee or road toll can have a major effect on travel demand. Some of this reflects changes in destination and route, but it also includes changes in mode and travel distance (Pratt, 1999). When per-mile or per-trip costs increase, motorists tend to drive less and rely more on other modes.

Factors Affecting Price Sensitivity

Various factors described below can affect how much a change in prices impacts travel activity.

Type of Price Change

Different types of charges can have different impacts on travel behavior. Fixed vehicle purchase and registration fees can affect the number and type of vehicles purchased. Fuel prices and emission fees affect the type of vehicle used. A road toll may shift some trips to other routes and destinations, while congestion pricing (a time-variable fee, higher during congested periods) may shift travel times, as well as changing mode and the total number of trips that occur. These impacts depend on the specific type of pricing – for example, an increase in residential parking fees is most likely to affect vehicle ownership, and a time-variable parking fee can affect when trips occur.

Table 1 **Impacts of Different Types of Pricing**

Type of Impacts	Vehicle Fees	Fuel Price	Fixed Toll	Congestion Pricing	Parking Fee	Transit Fares
Vehicle ownership. Consumers change the number of vehicles they own.	✓				✓	✓
Vehicle type. Motorist chooses different vehicle (more fuel efficient, alternative fuel, etc.)	✓	✓				
Route Change. Traveler shifts travel route.			✓	✓	✓	
Time Change. Motorist shifts trip to off-peak periods.				✓	✓	
Mode Shift. Traveler shifts to another mode.		✓	✓	✓	✓	✓
Destination Change. Motorist shifts trip to alternative destination.		✓	✓	✓	✓	✓
Trip Generation. People take fewer total trips (including consolidating trips).		✓	✓	✓	✓	
Land use changes. Changes in location decisions, such as where to live and work.			✓		✓	✓

Different price changes have different impacts on travel behavior.

Type of Trip and Traveler

Commute trips tend to be less elastic than shopping or recreational trips. Weekday trips may have very different elasticities than weekend trips. Urban peak-period trips tend to be price inelastic because congestion discourages lower-value trips, leaving only higher-value automobile trips. Travelers with higher incomes tend to be less price sensitive than lower-income travelers. Travelers on business tend to be less price sensitive than people traveling for personal activities.

Quality And Price Of Alternative Routes, Modes And Destinations.

Price sensitivity tends to increase if alternative routes, modes and destinations are good quality and affordable. For example, highway tolls tend to be more price sensitive if there is a parallel untolled roadway. Driving is less price sensitive in automobile-dependent areas where transportation alternatives are inferior (e.g., walking, cycling and transit are poor substitutes for driving).

Scale and Scope of Pricing

In general, narrowly defined transport is more elastic than broadly defined transport, because consumers have more alternatives. For example, demand for *peak-period automobile travel on a certain road* is usually more elastic than for *total personal travel along a corridor*, since a higher price for driving at a particular time at a particular road may shift travel to alternative routes, destinations, modes and travel times.

Most individual price components of driving (fuel, parking, tolls) are considered inelastic because they each represent a small portion of users *total* costs. Driving is actually quite elastic with respect to total costs. For example, since fuel is only about 15% of total vehicle costs, a -0.2 elasticity of driving with respect to fuel price represents an elasticity of -1.3 with respect to total financial cost. This implies that if all user costs were converted into variable charges, each 1% increase in this charge would reduce driving by -1.3%.

Time Period

Transportation elasticities tend to increase over time as consumers have more opportunities to take prices into effect when making long-term decisions. For example, if consumers anticipate low automobile use prices they are more likely to choose an automobile dependent suburban home, but if they anticipate significant increases in driving costs they might place a greater premium on having alternatives, such as access to transit and shops within convenient walking distance. These long-term decisions affect the options that are available. For example, if consumers are in the habit of shopping in their neighborhood, local stores will be successful. But if they always shop at large supermarkets, the quantity and quality of local stores will decline.

For this reason, it may take many years for the full effect of a price change to be felt. Studies cited by Button (1993, p. 41) estimate that short-term elasticities are typically one-third of long-term elasticities. Short run is typically less than two years, medium run is two to 15 years, and long run is 15 years or more, although definitions vary. Large price changes tend to be less elastic than small price changes, since consumers make the easiest accommodations first. Dargay and Gately (1997) conclude that about 30% of the response to a price change takes place within 1 year, and that virtually all takes place within 13 years. Dargay and Goodwin (1995) argue that the common practice of using static rather than dynamic elasticity values overestimate welfare losses from increased user prices and congestion, because it ignores society's ability to respond to changes over time. Static elasticities skew investments toward increasing highway capacity, and undervalues transit, TDM, and "No Build" options.

Large and Cumulative Price Changes
Extra care should be used when calculating the impacts of large price changes, or when summing the effects of multiple changes, because each subsequent change impacts a different base, as explained earlier in the discussion of *arc elasticities*. As a result, travel reductions are multiplicative, not additive. For example, if prices increase 10% on a good with a –0.5 elasticity, the first one-percent of price change reduces consumption by 0.5%, to 99.5% of its original amount. The second one-percent of price change reduces this 99.5% by another 99.5%, to 99.0%. The third one-percent of price change reduces this 99.0% by another 99.5% to 98.5%, and so on for each one-percent change. Thus, the reduction in consumption of a 10% price increase is calculated as $(1\text{-}0.005)^{10}$ (one minus 0.005, or 0.995, to the tenth power), which is 4.9%, not a full 5% that would be calculated by simply multiplying –0.5 x 10. Similarly, if three strategies are proposed for implementation, which individually provide a 5%, 6% and 7% reduction in vehicle travel, the total predicted reduction is 17%, calculated as (1-0.05) x (1-0.06) x (1-0.07) = 17.0, not 18% (5 + 6 + 7 = 18).

Transportation Elasticity Estimates

This section summarizes the results of many transportation elasticity studies.

Summaries

The tables below summarize some transport elasticity studies. The elasticities of various types of price changes are described in individual sections in this report.

Table 2 **Estimated Long Run Transport Elasticities** (Johansson & Schipper, 1997, p. 209)

Estimated Component	Fuel Price	Income	Taxation (Other than Fuel)	Population Density
Car Stock (vehicle ownership)	-0.20 to 0.0 (-0.1)	0.75 to 1.25 (1.0)	-0.08 to -0.04 (-0.06)	-0.7 to -0.2 (-0.4)
Mean Fuel Intensity (fuel efficiency)	-0.45 to -0.35 (-0.4)	-0.6 to 0.0 (0.0)	-0.12 to -0.10 (-0.11)	-0.3 to -0.1 (-0.2)
Mean Driving Distance (per car per year)	-0.35 to -0.05 (-0.2)	-0.1 to 0.35 (0.2)	0.04 to 0.12 (0.06)	-0.75 to 0.0 (-0.4)
Car Fuel Demand	-1.0 to -0.40 (-0.7)	0.05 to 1.6 (1.2)	-0.16 to -0.02 (-0.11)	-1.75 to -0.3 (-1.0)
Car Travel Demand	-0.55 to -0.05 (-0.3)	0.65 to 1.25 (1.2)	-0.04 to 0.08 (0.0)	-1.45 to -0.2 (-0.8)

Summarizes various studies. Numbers in parenthesis indicate original authors' "best guess" values.

After a detailed review of international studies, Goodwin (1992) produced the average elasticity values summarized in Table 3. He noted that price impacts tend to increase over time as consumers have more options (related to increases in real incomes, automobile ownership, and now telecommunications that can substitute for physical travel).

Table 3 **Transportation Elasticities** (Goodwin, 1992)

	Short-Run	Long-Run	Not Defined
Petrol consumption WRT petrol price	-0.27	-0.71	-0.53
Traffic levels WRT petrol price	-0.16	-0.33	
Bus demand WRT fare cost	*-0.28*	*-0.55*	
Railway demand WRT fare cost	*-0.65*	*-1.08*	
Public transit WRT petrol price			*0.34*
Car ownership WRT general public transport costs			*0.1 to 0.3*

Summarizes various studies of long-run price effects. ("WRT" = With Respect To).

Table 4 **Consumer Demand Elasticities, European Data** (Mayeres, 2000)

	Price, Peak	Price, Off-Peak	Income
Mileage "Committed" (essential trips)	-0.16	-0.43	0.70
Mileage "Supplementary" (optional trips)	-0.43	-0.36	1.53
Bus, Tram, Metro passenger-kms	-0.19	-0.29	0.59
Rail passenger-kms	-0.37	-0.43	0.84

Table 5 **Australian Travel Demand Elasticities** (Luk & Hepburn, 1993)

Elasticity Type	Short-Run	Long-Run
Petrol consumption and petrol price	-0.12	-0.58
Travel level and petrol price	-0.10	
Bus demand and fare	-0.29	
Rail demand and fare	-0.35	
Mode shift to transit and petrol price	+0.07	
Mode shift to car and rail fare increase	+0.09	
Road freight demand and road/rail cost ratio	-0.39	-0.80

This table shows elasticity values adopted by the Australian Road Research Board for planning and modeling.

Table 6a **Passenger Transport Elasticities** (Small & Winston, 1999, Table 2-2)

	Auto	Bus	Rail	Air
Urban Passenger, Price	-0.47	-0.58	-0.86	
Urban Passenger, In-Vehicle Time	-0.22	-0.60	-0.60	
Intercity Passenger, Price	-0.45	-0.69	-1.20	-0.38
Intercity Passenger, Travel Time	-0.39	-2.11	-1.58	-0.43

Table 6b **Automobile Utilization Elasticities** (Small & Winston, 1999, Table 2-2)

	One-Vehicle Household	Two-Vehicle Household
Short-run Operating Costs	-0.228	-0.059
Long-run Operating Costs	-0.279	-0.099

Table 7 **European Travel Elasticities** (de Jong and Gunn, 2001)

Term/ Purpose	Car-Trips WRT Fuel Price	Car-Kms. WRT Fuel Price	Car-Trips WRT Travel Time	Car-Kms. WRT Travel Time
Short term:				
Commuting	-0.20	-0.12	-0.62	
HB business	-0.06	-0.02		
NHB business	-0.06	-0.02		
Education	-0.22	-0.09		
Other	-0.20	-0.20	-0.52	
Total	-0.16	-0.16	-0.60	-0.20
Long term:				
Commuting	-0.14	-0.23	-0.41	-0.63
HB business	-0.07	-0.20	-0.30	-0.61
NHB business	-0.17	-0.26	-0.12	-0.53
Education	-0.40	-0.41	-0.57	-0.76
Other	-0.15	-0.29	-0.52	-0.85
Total	-0.19	-0.26	-0.29	-0.74

WRT = “With Respect To” HB = “Home Based” NHB = “Not Home Based”

Table 8 **Overall results: Various elasticities** (Goodwin, Dargay and Hanly, 2003)

Dependent Variable	Short term	Long term
Fuel consumption (total)		
Mean elasticity	-0.25	-0.64
Standard deviation	0.15	0.44
Range	-0.01, -0.57	0, -1.81
Number of estimates	46	51
Fuel consumption (per vehicle)		
Mean elasticity	-.08	-1.1
Standard deviation	N/A	N/A
Range	-.08, -.08	-1.1, -1.1
Number of estimates	1	1
Vehicle kilometres (total)		
Mean elasticity	-0.10	-0.29
Standard deviation	0.06	0.29
Range	-0.17, -0.05	-0.63, -0.10
Number of estimates	3	3
Vehicle kilometres (per vehicle)		
Mean elasticity	-0.10	-0.30
Standard deviation	0.06	0.23
Range	-0.14, -0.06	-0.55, -0.11
Number of estimates	2	3
Vehicle stock		
Mean elasticity	-0.08	-0.25
Standard deviation	0.06	0.17
Range	-0.21, -0.02	-0.63, -0.10
Number of estimates	8	8

Based on a major review of elasticity studies Goodwin, Dargay and Hanly (2004) conclude that:

- Fuel consumption elasticities are greater than traffic elasticities, mostly by factors of 1.5 to 2.
- Long run elasticities are greater than short run, mostly by factors of 2 to 3.
- Income elasticities are greater than price, mostly by factors of 1.5 to 3.

They conclude that if the real (inflation adjusted) price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that the following occur:

- Volume of traffic will fall by about 1% within about a year, building up to a reduction of about 3% in the longer run (about 5 years or so).
- Volume of fuel consumed will fall by about 2.5% within a year, building up to a reduction of over 6% in the longer run.
- Efficiency of the use of fuel rises by about 1.5% within a year, and around 4% in the longer run.
- Total number of vehicles owned falls by less than 1% in the short run and 2.5% in the longer run.

The also conclude that if real income goes up by 10%, the following occurs:

- Number of vehicles, and the total amount of fuel they consume, will both rise by nearly 4% within about a year, and by over 10% in the longer run.
- The volume of traffic (i.e., total vehicle travel) will increase about 2% within a year and about 5% in the longer run, indicating that the additional vehicles purchased are driven less than average mileage.

DKS (2003) provides information on the impacts of various TDM programs, including various pricing strategies.

Table 9 **Estimated Elasticities of Vehicle Travel with Respect to User Cost**
(Moore & Thorsnes, 1994)

Cost Component	Short Run Effect	Long Run Effect
Out-of-Pocket Price		
Fuel (work)	- Low	- Low to Medium
Fuel (non-work)	- Medium	- Medium to High
Highway tolls	- Medium	- High
Parking fees	-Low	- High
Time Costs		
Riding time	- Low	- Medium
Parking search	- Low	- High
Congestion	- Low	- High
Cost of Alternatives		
Transit fare	+ Low	+ Low
Transit access time	+ Low	+ Low

Elasticities: Low = 0 to 0.5; Medium = 0.5 to 1.0; High = 1.0+

Individual Elasticities

The elasticities of different types of transportation prices found in various studies are discussed below.

Vehicle Operating (Out-of-Pocket) Expenses

This refers to the travel effects of vehicle operating expenses (i.e., variable monetary costs), including fuel, parking fees and road tolls. Button estimates the elasticity of driving with respect to out-of-pocket costs for various trips, shown in Table 10. Oum, Waters, and Yong (1992) estimate the elasticity of vehicle travel with respect to price is -0.23 in the short run and -0.28 in the long run. Oum, Van Ooststroom and Yoon (1996) found the elasticity of automobile travel in the Netherlands to range between -0.02 and -0.28. De Borger, et al, (1997) find elasticities for urban peak travel in Belgium to be -0.384 for automobile and -0.35 for public transit, with higher values for off-peak travel.

Table 10 **Elasticity Estimates for Various Trip Types** (Button, 1993)

Trip Type	Elasticity of Road Travel with Respect to Out of Pocket Expenses
Urban shopping	-2.7 to -3.2
Urban commuting	-0.3 to - 2.9
Inter-urban business	-0.7 to -2.9
Inter-urban leisure	-0.6 to -2.1

Small and Winston (1999) find that the price sensitivity of a particular motor vehicle's use increases over time and depends on whether or not it is a household's only vehicle, as shown in Table 6b. This has important implications for analyzing the effects that pricing can have on the use of vehicles that have desirable attributes, such as increased fuel efficiency or reduced pollution emissions.

Parking Price

Motorists tend to be particularly sensitive to parking price because it is such a direct charge ("Parking Pricing," VTPI, 2005). Compared with other out-of-pocket expenses, parking fees are found to have a greater effect on vehicle trips, typically by a factor of 1.5 to 2.0 (USEPA, 1998). For example, a $1.00 per trip parking charge is likely to cause the same reduction in vehicle travel as a fuel price increase averaging $1.50 to $2.00 per trip.

Several studies (K.T. Analytics, 1995; Shaw, 1997; Vaca and Kuzmyak, 2005) provide detailed reviews of parking price elasticities. Vaca and Kuzmyak (2005) summarizes studies from North America and Europe on the effects of parking price changes on travel behavior, taking into account demographic factors and travel conditions, and type of trip; including changes in the magnitude and structure of prices, elimination of employee parking subsidies, rideshare vehicle parking discounts and park-and-ride facility pricing.

Kuzmyak, Weinberger and Levinson (2003) describe how parking supply affects parking and travel demand, but this may actually reflect price impacts (reduced parking supply increases prices). These studies indicate that the elasticity of vehicle trips with regard to parking prices is typically in the –0.1 to –0.3 range, with significant variation depending on demographic, geographic, travel choice and trip characteristics. Pratt (1999, p. 13-40) finds significantly higher elasticities (-0.9 to -1.2) of parking price with regard to commercial parking gross revenues, since motorists can respond to higher prices by reducing their parking duration or changing to cheaper locations and times, as well as reducing total vehicle trips. Similarly, in a study of downtown parking meter price increases, Clinch and Kelly (2003) find that the elasticity of parking frequency is smaller (–0.11) than the elasticity of vehicle duration (-0.20), indicating that some motorists respond to higher fees by reducing how long they stay.

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to parking price under various conditions (e.g., level of vehicle ownership and transit use, type of trip, etc.). The table below summarizes long-term elasticities for relatively automobile-oriented urban regions.

Table 11 **Parking Price Elasticities** (TRACE, 1999, Tables 32 & 33)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Trips				
Commuting	-0.08	+0.02	+0.02	+0.02
Business	-0.02	+0.01	+0.01	+0.01
Education	-0.10	+0.00	+0.00	+0.00
Other	-0.30	+0.04	+0.04	+0.05
Total	*-0.16*	*+0.03*	*+0.02*	*+0.03*
Kilometres				
Commuting	-0.04	+0.01	+0.01	+0.02
Business	-0.03	+0.01	+0.00	+0.01
Education	-0.02	+0.00	+0.00	+0.00
Other	-0.15	+0.03	+0.02	+0.05
Total	*-0.07*	*+0.02*	*+0.01*	*+0.03*

Slow Modes = Walking and Cycling WRT = With Respect To

Hess (2001) assesses the effect of free parking on commuter mode choice and parking demand in Portland's (Oregon) CBD. He finds that with free parking, 62% of commuters will drive alone, 16% will commute in carpools and 22% will ride transit; with a $6.00 daily parking charge 46% will drive alone, 4% will ride in carpools and 50% will ride transit. The $6.00 parking charge results in 21 fewer cars driven for every 100 commuters, a daily reduction of 147 VMT per 100 commuters and an annual reduction of 39,000 VMT per 100 commuters.

Hensher and King (2001) model the price elasticity of CBD parking, and predict how an increase in parking prices in one location will shift cars to park at other locations and drivers to public transit (Table 12). Harvey (1994) finds that airport parking prices range from -0.1 for less than a day to -2.0 for greater than 8 days.

Table 12 **Parking Elasticities** (Hensher and King, 2001, Table 6)

	Preferred CBD	Less Preferred CBD	CBD Fringe
Car Trip, Preferred CBD	-0.541	0.205	0.035
Car Trip, Less Preferred CBD	0.837	-0.015	0.043
Car Trip, CBD Fringe	0.965	0.286	-0.476
Park & Ride	*0.363*	*0.136*	*0.029*
Ride Public Transit	*0.291*	*0.104*	*0.023*
Forego CBD Trip	0.469	0.150	0.029

This table shows elasticities and cross-elasticities for changes in parking prices at various Central Business District (CBD) locations. For example, a 10% increase in prices at preferred CBD parking locations will cause a 5.41% reduction in demand there, a 3.63% increase in Park & Ride trips, a 2.91% increase in Public Transit trips and a 4.69% reduction in total CBD trips.

One survey found that about 35% of drive-alone commuters would likely switch modes in response to $20 per month parking fees, even if offset by a transportation voucher (Kuppam, Pendyala and Gollakoti, 1999). This study found that mode shifting increases for lower income, and if transit, ridesharing and sidewalks are available. Trip Reduction Tables in Comsis Corporation, 1993 predict travel reductions resulting from parking fees and other commuter financial incentives. The table below shows an example from these tables ("Trip Reduction Tables," VTPI, 2005).

Table 13 **Commute Trip Reductions from Daily Parking Charges** (Comsis Corp. 1993)

	$1	$2	$3	$4
Suburb	6.5%	15.1%	25.3%	36.1%
Suburban Center	12.3%	25.1%	37.0%	46.8%
Central Business District	17.5%	31.8%	42.6%	50.0%

This table illustrates the reduction in automobile commute trips likely to result from a given daily parking fee at worksites. (1993 U.S. dollars)

Harvey and Deakin (1998) model the effect of parking charges on commuters in four California urban regions. Table 14 summarizes their results. It indicates, for example, that in the South Coast (Los Angeles) region, a $3 (1991 U.S. dollars) per day parking fee would reduce total vehicle trips by about 2.8%, but congestion delay would decline by a much larger amount (8.5%), because most of the travel reduction occurs during peak traffic periods.

Table 14 **Impacts of Employee Parking Fees in Year 2010**
(Harvey and Deakin, 1998, Table B.7)

Region	Price	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	$1.00	-0.8%	-0.9%	-2.7%	-1.0%	-0.8%	$473
	$3.00	-2.1%	-2.4%	-7.0%	-2.4%	-2.3%	$1,399
Sacramento	$1.00	-1.0%	-1.1%	-2.5%	-1.1%	-1.1%	$142
	$3.00	-2.6%	-2.8%	-6.5%	-2.7%	-2.8%	$419
San Diego	$1.00	-0.9%	-1.0%	-2.5%	-1.0%	-0.9%	$271
	$3.00	-2.4%	-2.6%	-7.0%	-2.5%	-2.5%	$800
South Coast	$1.00	-0.9%	-1.1%	-2.9%	-1.1%	-1.0%	$1,408
	$3.00	-2.5%	-2.8%	-8.5%	-2.7%	-2.6%	$4,151

Price = minimum daily parking fee for SOV commuters. *VMT* = change in total vehicle mileage. *Trips* = change in total vehicle trips. *Delay* = change in congestion delay. *Fuel* = change in fuel consumption. *ROG* = a criteria air pollutant. *Revenue* = annual revenue in millions of 1991 dollars. See report for additional notes.

Parking fees affect trip destinations as well as vehicle use. An increase in parking prices can reduce use of parking facilities at a particular location, but this may simply shift vehicle travel to other locations. Increased parking prices may result in spillover parking problems, as motorists find nearby places to park for free illegally ("Parking Management," VTPI, 2005). However, if parking prices increase throughout an area, there is effective enforcement of parking regulations, and there are good travel alternatives, parking price increases can reduce total vehicle travel. For some types of trips, pricing can affect parking duration, such as how long shoppers stay at a store.

The use of parking price elasticities can be confusing since most parking is currently free, so it is meaningless to measure percentage increases from zero price. The table below summarizes the commute mode shifts occurring at worksites that changed from free to priced parking. Other case studies find similar impacts. Shifting from free to priced parking typically reduces drive alone commuting by 10-30%, particularly if implemented with improvements in transit service and rideshare programs and other TDM strategies.

Table 15 **Changes in Workplace Travel Due to Parking Pricing**

	Canadian Study			**Los Angeles Study**		
	Before	After	Change	Before	After	Change
Drive Alone	35%	28%	*-20%*	55%	30%	*-27%*
Carpool	11%	10%	*+9%*	13%	45%	*+246%*
Transit	42%	49%	*+17%*	29%	22%	*-24%*
Other	12%	13%	*-8%*	3%	3%	*0%*

(Feeney, 1989, cited in Pratt, 1999)

Shiftan (1999) surveyed motorists driving to a commercial district in Haifa, Israel to determine how they would respond to higher fees. Of 200 motorists surveyed there, 78% currently parked for free (67% on-street, 11% at employee off-street parking lots). The table below summarizes their predicted reduction in vehicle trips for various parking fees

Table 16 **Effects of Parking Fees** (Shiftan, 1999)

New Israeli Shekels (NISs)/U.S. dollars per hour	5 NIS/$1.00	10 NIS/$1.00	10 NIS/$1.00
Local Car Trips Reduced	29%	50%	58%

As hourly parking fees increase, parking demand declines. Non-work trips tended to be more price-sensitive than work trips.

Shoup (1992) finds that charging employees for parking reduces solo commuting by 20-40%. A study by ICF (1997) indicates that a $1.37 to $2.73 increase in parking fees (1993 U.S. dollars) reduces auto commuting 12-39%, and if matched with transit and rideshare subsidies, can reduce total auto trips by 19-31%.

Parking supply can affect travel behavior by affecting parking convenience, parking price and pedestrian accessibility (Morrall and Bolger, 1996). Generous parking supply makes it impractical to charge for parking. The greater the parking supply the more commuters tend to drive rather than use transit or rideshare (Mildner, Strathman and Bianco, 1997).

Travel behavior can also be influenced by how parking prices are structured. Significant discounts for long-term parkers (e.g., lower-priced monthly leases) encourage use by commuters, while parking prices and management strategies that discount short-term parking (e.g., “First-Hour-Free” rates) favor shoppers and business trips. Rate increases of $1-2 per day directed at commuters are found to reduce long-term parking demand by 20-50%, although much of this may consist of shifts to other parking locations rather than alternative modes (Pratt, 1999).

Fuel Consumption With Respect to Fuel Price

Increased fuel prices cause a combination of reduced driving and increased fuel efficiency. Short-term fuel savings consist of reduced driving, and a shift toward using more fuel-efficient vehicles, particularly in multi-vehicle households where drivers have short-term choices (Institute for Transport Studies, 2004).

Long-term fuel savings consist primarily of purchases of more fuel-efficient vehicles. Agras and Chapman (1999) using 1982-1995 U.S. data find that the short-run price elasticities of VMT and MPG with respect to fuel price are –0.15 and 0.12 respectively, summing to an overall short-run gasoline price elasticity of –0.25. Their long-run fuel price elasticities are –0.32 for VMT and 0.60 for MPG, which sum to an overall long-run gasoline price elasticity of –0.92. This means that a 10% fuel price increase is likely to reduce driving by 1.5% and improve fuel economy by 1.2% in the short-run, and over the long run mileage will decline by 3.2% and fuel efficiency will increase by 6%, leading to a 9.2% overall reduction in fuel consumption.

Glaister and Graham (2000) perform a comprehensive review of international studies of the effects of fuel price and income on vehicle travel and fuel consumption. They find short run elasticities range from –0.2 to –0.5, and long run elasticities range from –0.24 in the U.S. (with variations from –0.24 to –0.8) up to –1.35 in the OECD overall (with variations from –0.75 to –1.35). They identify a number of factors that tend to affect fuel price elasticity values, including the functional form, time span, geographic factors, and what other factors are included (such as vehicle ownership), 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. Summarizing international research, Goodwin (1992) estimates the price elasticity of gasoline to be -0.27 in the short run and -0.7 in the long run. He predicts that a 10% increase in vehicle fuel prices will have the following effects:

- In the short run it reduces vehicle travel by about 1.5%, and reduces fuel consumption by 2.7%, due in part to more fuel-efficient driving (such as shifting more driving to a household's most fuel efficient car).
- In the long run it reduces vehicle travel by 3-5%, split between a reduction in car ownership and per-vehicle use. It reduces petroleum consumption by 7% or more, due in part to the purchase of more fuel-efficient vehicles.

In a major review of price elasticity, Goodwin, Dargay and Hanly (2003) conclude that if the real (inflation adjusted) price of fuel goes, and stays, up by 10%, the result is a dynamic process of adjustment such that:

A. The volume of traffic will go down by approximately 1% within about a year, building up to a reduction of about 3% in the longer run (about five years or so).

B. The volume of fuel consumed will go down by approximately 2.5% within a year, building up to a reduction of over 6% in the longer run.

Fuel consumed declines more than traffic volume because price increases cause motorists to reduce per-mile fuel consumption by buying more fuel-efficient vehicles and driving more carefully. As a result, price increase cause:

C. Vehicle fuel efficiency increases approximately 1.5% within a year, and approximately 4% over the longer run.

D. Total vehicle ownership declines by less than 1% in the short run, and 2.5% in the longer run.

These results imply that the sensitivity of car ownership with respect to fuel price is rather large, constituting a larger part of the effect of price on traffic levels. However, many studies only assess the effects on car ownership, or on traffic, or per vehicle mileage, but not at the same time or using the same data, therefore this conclusion is based on drawing together quite different studies. Considerations of sample sizes suggest that the two effects (C) and (D) are somewhat less well supported than (A) and (B). Overall these results support for the idea that fuel prices affect car ownership, but are not necessarily an overwhelmingly large part of the overall effect.

Sipes and Mendelsohn (2001) survey motorists concerning their response to fuel price increases. They find an elasticity of -0.4 to -0.6 in the short-run and -0.5 to -0.7 in the long run, with greater price sensitivities for larger and poorer households.

Dargay (1992) reports higher values averaging -0.67 when price increases and decreases are calculated separately. Sterner et al (1992) found that fuel elasticities are relatively high in North America, greater than -1.0. Dahl and Sterner (1991) estimate the elasticity of fuel consumption to be -0.18 in the short run and -1.0 in the long run. DeCicco and Gordon (1993) conclude that the medium-run elasticity of vehicle fuel in the U.S. is -0.3 to -0.5. Eltony (1993) finds that elasticity of fuel consumption in Canada is approximately -0.3 in the short term and rises to approximately 1.0 after a decade, as vehicle fleet efficiency increases. Hagler Bailly (1999) conclude that the fuel price elasticity for gasoline is –0.15 in the short run and –0.6 in the long run, with separate estimates for air, freight and transit transport. Table 16 summarizes the price elasticities of various types of transportation fuel. Using 1980-2000 U.S. data, Zupan (2001) finds little relationship between fuel price and VMT in the short-term, but a relationship is found if price changes are evaluated with a 6-month lag, indicating that approximately 25% of VMT changes can be accounted for by fuel price.

Table 17 **Estimated Fuel Price Elasticities** (Hagler Bailly, 1999)

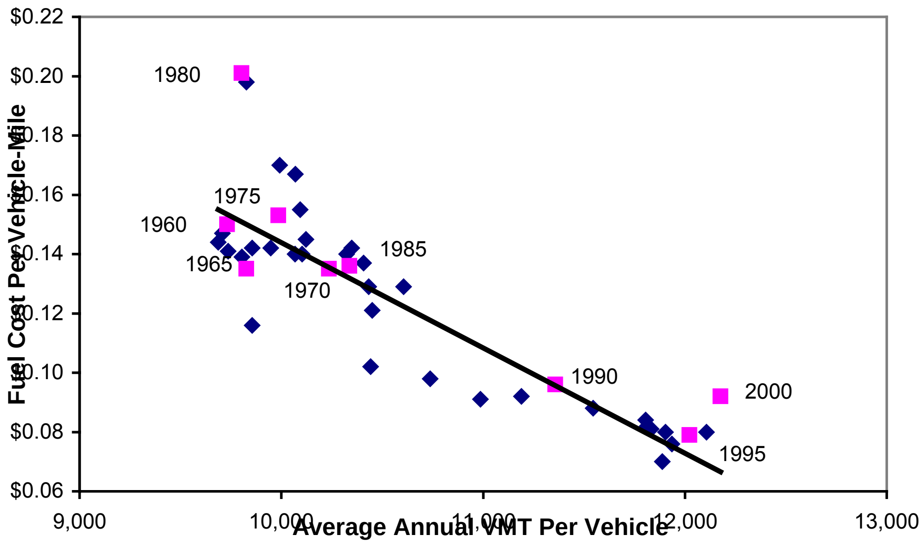
	Short Run Elasticity			**Long Run Elasticity**		
	Low	Base	High	Low	Base	High
Road Gasoline	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Road Diesel - Truck	-0.05	-0.10	-0.15	-0.20	-0.40	-0.60
Road Diesel - Bus	-0.05	-0.10	-0.15	-0.20	-0.30	-0.45
Road Propane	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Road CNG	-0.10	-0.15	-0.20	-0.40	-0.60	-0.80
Rail Diesel	-0.05	-0.10	-0.15	-0.15	-0.40	-0.80
Aviation Turbo	-0.05	-0.10	-0.15	-0.20	-0.30	-0.45
Aviation Gasoline	-0.10	-0.15	-0.20	-0.20	-0.30	-0.45
Marine Diesel	-0.02	-0.05	-0.10	-0.20	-0.30	-0.45

This table summarizes changes in consumption that are likely to result from changes in price for various types of vehicle fuel.

Komanoff (2005) maintains a spreadsheet of U.S. Department of Energy data from 2004 through the most recent available month to estimate the short-term price-elasticity of demand for gasoline (available at www.vtpi.org/gasoline_elasticity.xls). This analysis shows that the elasticity ranges from -0.01 to -0.23, and averages -0.11 for these months, indicating that a 10% increase in fuel price reduces short-term fuel consumption by at least 1% and possibly as much as 2%.

Vehicle Travel With Respect to Fuel Price
As fuel costs per vehicle-mile decline (taking into account inflation-adjusted fuel prices and vehicle fuel economy), average annual vehicle mileage tends to increase, as illustrated in Figure 3.

Figure 3 **Fuel Costs Versus Annual Vehicle Mileage** (BTS, 2001)



This figure illustrates the relationship between real (inflation-adjusted) per-mile fuel costs and average annual vehicle-mileage, based on 1960-2000 US data. As per-mile costs decline, mileage tends to increase. To obtain an Excel spreadsheet with the source data of this graph, click here: *FuelTrends*

As mentioned above, Agras and Chapman (1999) find that the short-run price elasticity of VMT with respect to fuel price is –0.15, and the long-run fuel price elasticity is –0.32. Similarly, Glaister and Graham (2000) conclude that the elasticity of vehicle travel with respect to fuel price is –0.15 in the short run and –0.3 over the long-run. This means that a 10% fuel price increase is likely to reduce driving by 1.5% in the short-run, and 3% over the long-run. Schimek (1997) finds the elasticity of vehicle travel with respect to fuel price in the U.S. to be -0.26. These results are consistent with international research (Johansson and Schipper, 1997). One study finds that a $0.40 to $2.00 increase in fuel prices would reduce Puget Sound region vehicle trips by 1.2-6.7%, and vehicle mileage by 1.4-7.2% (PSRC, 1994). INFRAS (2000) cites estimates of the long-term elasticity of vehicle use with respect to fuel price to typically average about –0.3.

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to fuel price under various conditions (level of vehicle ownership, transit use, type of trip, etc.). Table 18 summarizes fuel price elasticities of kilometers traveled in areas with high vehicle ownership (more than 450 vehicles per 1,000 population).

Table 18 **Elasticities WRT Fuel Price** (TRACE, 1999, Tables 8 & 9)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Trips				
Commuting	-0.11	+0.19	+0.20	+0.18
Business	-0.04	+0.21	+0.24	+0.19
Education	-0.18	+0.00	+0.01	+0.01
Other	-0.25	+0.15	+0.15	+0.14
Total	*-0.19*	*+0.16*	*+0.13*	*+0.13*
Kilometers				
Commuting	-0.20	+0.20	+0.22	+0.19
Business	-0.22	+0.05	+0.05	+0.04
Education	-0.32	+0.00	+0.00	+0.01
Other	-0.44	+0.15	+0.18	+0.16
Total	*-0.29*	*+0.15*	*+0.14*	*+0.13*

Slow Modes = Walking and Cycling WRT = With Respect To

This table shows the estimated elasticities and cross-elasticities of urban travel in response to a change in fuel price or other vehicle operating costs. For example, a 10% fuel price increase is predicted to reduce automobile trips by 1% and increase transit ridership by 2%.

Harvey and Deakin (1998) model the effect of a fuel tax increase on transportation impacts in four major urban regions in California. Table 19 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, an additional $2.00 per gallon tax would reduce total vehicle trips by about 12.5%, but congestion delay would decline by a much larger amount (28.5%).

Table 19 **Impacts of Fuel Tax Increase, Year 2010**
(Harvey and Deakin, 1998, Table B.8)

Region	Tax Increase	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	$0.50	-3.6%	-3.4%	-8.5%	-8.8%	3.5%	$1,332
	$2.00	-11.7%	-11.3%	-25.5%	-30.6%	11.6%	$4,053
Sacramento	$0.50	-4.1%	-3.9%	-7.0%	-9.3%	4.0%	$414
	$2.00	-13.2%	-12.7%	-22.0%	-31.8%	13.0%	$1,245
San Diego	$0.50	-3.9%	-3.5%	-8.0%	-9.1%	3.8%	$747
	$2.00	-12.5%	-12.0%	-23.0%	-31.1%	12.3%	$2,257
South Coast	$0.50	-4.2%	-3.5%	-9.5%	-9.3%	4.1%	$3,724
	$2.00	-13.0%	-12.5%	-28.5%	-31.6%	12.8%	$11,235

Tax Increase = additional fuel taxes applied in addition to current taxes. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

Research summarized in Davidson, Wit and Dings (2003) indicates the elasticity of air travel with respect to ticket price is about 1.0, and fuel costs represent about 10% of total operating costs, so doubling fuel costs or imposing other fees of this magnitude would reduce air travel mileage about 10%.

Fuel Tax Survey (www.rideshare.511.org/research)
A survey of 1,520 San Francisco area commuters for the *511 Rideshare* program in June 2004 (after a jump in fuel prices) had the following results:

Have increased gas prices changed how you commute to work?

	Number	Percent
Yes	559	37%
No	961	63%

If your commute behavior has changed in the last four months, what mode of transportation do you use now? For the 557 Respondents who answered yes to question 1.

Mode	Number	Percent
Carpool	264	48%
Public Transit	141	25%
Telecommute	13	2%
Bicycle	18	3%
Walk	5	1%
Other	50	9%

Have increased gas prices changed your other (non-commute) travel behavior?

	Number	Percent
Yes	925	61%
No	589	39%

As gas prices increase are carpooling and transit more appealing modes of transportation for you?

	Number	Percent
Yes	1,363	91%
No	143	9%

If you currently drive alone, what price would gas have to reach for you to switch to an alternative mode of transit?

	Number	Percent
$3 per gallon	352	26%
$4 per gallon	139	10%
$5 per gallon	58	4%
Will not switch	89	8%
Already switched	692	52%

Respondents who have not already switched

	Number	Percent
$3 per gallon	352	55%
$4 per gallon	139	22%
$5 per gallon	58	9%
Will not switch	89	14%

Road Pricing and Tolls

Road Pricing means that motorists pay a toll for using a particular roadway or driving in a particular area ("Road Pricing," VTPI, 2005). There is growing interest in *Congestion Pricing*, which refers to tolls that are higher during peak periods and lower during off-peak periods in order to reduce traffic congestion. TCRP (2003) provides a good summary of recent road pricing experience and the resulting travel impacts, particularly in North America.

Matas and Raymond (2003) summarizes previous estimates of toll road elasticities, and develop a model of toll road demand using data from toll roads in Spain, 1980-1998. They find that demand varies depending on several factors, including economic activity (GDP), tourist activity, fuel prices, and travel conditions on parallel roads. Short-term toll road price elasticities range from -0.21 to -0.83, a somewhat higher and broader range than indicated in previous studies. They find that elasticities are greater where there are uncongested parallel roads.

Since February 2003 a congestion pricing fee (initially £5 and raised to £8 in 2005) has been charged for driving in downtown London during weekdays, which reduced private automobile traffic in the area by 38% and total vehicle traffic (including buses, taxis, and trucks) by 18%, a greater reduction than planners predicted indicating a higher price elasticity than economists expect, as described in Litman, 2003.

Hirschman, et al. (1995) find that New York area bridge and tunnel toll elasticities for automobiles average -0.1. Harvey (1994) finds similar results on San Francisco area bridge tolls, and higher values (-0.2) for trucks. Mekky found toll elasticities are as high as -4.0 for Toronto's Highway 407, and that traffic volumes and trip lengths decline significantly if tolls exceed 10¢ per vehicle kilometer (1999). When tolls were reduced from $1.75 to $1.00 (-43%) on the Dulles Greenway (which accesses the Washington DC Dulles Airport), vehicle traffic increased from about 10,000 to 26,000 trips per day (80%), indicating a price elasticity of –1.9 (UTM, 1996). A study by the New Jersey Turnpike found relatively low toll elasticities (around –0.2) for small price increases on U.S. toll roads (UTM, 2000).

Holguín-Veras, Ozbay and de Cerreño (2005) investigated the response of automobile and truck travel to E-ZPass tolls, which provide discounts for off-peak travel. The results indicate modest shift from peak to off-peak periods. The car short-term elasticities range between –0.31 and –1.97 for weekday and –0.55 and –1.68 for weekends depending on the time of the day.

Arentze, Hofman and Timmermans (2004) used a public survey to determine traveler response to congestion pricing incentives. They found that for commute trips, route and departure time changes are most likely to occur, while shifts to public transit and working at home are less likely. For non-commute trips, shifts to cycling also occur. This study indicates the price elasticity of overall vehicle travel is -0.13 to -0.19, and -0.35 to -0.39

for a particular congested road that is priced, taking into account shifts in route and time. A state-preference survey of suburban automobile long-distance commuters indicates that financial incentives are the most effective strategy for reducing automobile trips (Washbrook, 2002). A CA$5.00 (US$3.00) per round-trip road toll is predicted to reduce automobile commuting by 25%, and a CA$5.00 parking fee would reduce automobile commuting by 20%.

A marketing survey of congestion pricing on the Tappan Zee bridge (a commuter route to New York City) indicated that 72% of the 3,000 respondents have some flexibility in their trip scheduling, and that most travelers would respond to congestion pricing incentives by changing their travel timing, route or mode (Adler, Ristau & Falzarano, 1999).

Luk (1999) estimates that toll elasticities in Singapore are –0.19 to –0.58, with an average of –0.34. Singapore may be unique, because car ownership is restricted to higher-income residents which tend to make travel less sensitive to price, but this may be offset by the city's excellent public transit service, which may make car travel more price sensitive than other cities.

Harvey and Deakin (1997) model the effect of congestion pricing on transportation impacts in four major urban regions in California. Table 21 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, an a congestion fee averaging 19¢ per mile driven in congested conditions would reduce total vehicle trips by about 3.3%, but congestion delay would decline by 32%.

Table 20 **Congestion Pricing Impacts, Year 2010** (Harvey and Deakin, 1998, Table B.6)

Region	Avg. Fee	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	13¢	-2.8%	-2.7%	-27.0%	-8.3%	-6.9%	$2,274
Sacramento	8¢	-1.5%	-1.4%	-16.5%	-4.8%	-3.9%	$443
San Diego	9¢	-1.7%	-1.6%	-18.5%	-5.4%	-4.2%	$896
South Coast	19¢	-3.3%	-3.1%	-32.0%	-9.6%	-8.1%	$7,343

Avg. Fee = average congestion fee per mile applied to vehicle travel on congested roads. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 dollars. See report for additional notes and data.

The travel impacts and benefits of road pricing depend on the price structure. May and Milne (2000) used an urban traffic model to compare the impacts of four types of road pricing: cordon tolls, distance pricing, time pricing and congestion pricing. They found significant differences in the performance of these different strategies, in terms of the effectiveness that a particular price level would have in achieving TDM objectives. The table below shows the estimated price level required to achieve a 10% reduction in total vehicle trips in the region. They conclude that time-based pricing provides the greatest overall transportation benefits, followed by distance-based pricing, congestion pricing and finally cordon pricing.

Table 21 **Estimated Fee To Achieve 10% Vehicle Trip Reduction** (May and Milne, 2000)

Type of Road Pricing	Fee Required to Reduce Trips 10%
Cordon (pence per crossing)	45
Distance (pence per kilometer)	20
Time (pence per minute)	11
Congestion (pence per minute delay)	200

Mileage and Emission Charges

Harvey and Deakin (1998) model the effect of a 2¢ per vehicle-mile fee on transportation impacts in four major urban regions in California. Table 22 summarizes their results for the year 2010. It indicates, for example, that in the South Coast (Los Angeles) region, a 2¢ per mile fee would reduce total vehicle trips by 4.1%, but congestion delay would decline by 10.5%. INFRAS (2000) estimates kilometer fees have elasticities of –0.1 to –0.8, depending on the trip purpose, mode and price level.

Table 22 **Impacts of 2¢ Per Mile Fee, Year 2010** (Harvey and Deakin, 1998, Table B.9)

Region	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	-3.9%	-3.7%	-9.0%	-4.1%	-3.8%	$1,122
Sacramento	-4.4%	-4.1%	-7.5%	-4.4%	-4.3%	$349
San Diego	-4.2%	-4.0%	-8.5%	-4.2%	-4.1%	$629
South Coast	-4.3%	-4.1%	-10.5%	-5.2%	-4.2%	$3,144

VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

Table 23 shows the predicted change in travel by income class, based on 1991 dollars. The last column indicates the travel reduction based on 2001 dollars. The elasticity of vehicle travel with respect to a VMT charge is estimated to be -0.2 to -0.25 (Deakin & Harvey, 1998).

Table 23 **Vehicle Travel Reduction of VMT Fee by Income Quintile (Percent)** (USEPA, 1998, Table B21)

VMT Fee	Q1	Q2	Q3	Q4	Q5	Overall	*2001*
1¢	-7.0	-4.2	-2.6	-1.5	-0.5	-2.3	*-1.8%*
2¢	-13.3	-8.2	-5.1	-3.1	-1.0	-4.5	*-3.5%*
3¢	-19.1	-12.0	-7.5	-4.6	-1.6	-6.6	*-5.1%*
4¢	-24.3	-15.6	-10.0	-6.2	-2.2	-8.7	*-6.7%*
5¢	-29.1	-19.1	-12.4	-7.7	-2.8	-10.7	*-8.2%*
6¢	-33.5	-22.4	-14.7	-9.3	-3.5	-12.6	*-9.7%*
7¢	-37.4	-25.6	-17.0	-10.8	-4.1	-14.5	*-11.2%*
8¢	-41.0	-28.7	-19.2	-12.4	-4.8	-16.3	*-12.5%*
9¢	-44.2	-31.5	-21.4	-13.9	-5.5	-18.0	*-13.8%*
10¢	-47.2	-34.3	-23.5	-15.4	-6.3	-19.7	*-15.2%*

A quintile is one-fifth of the population. Values are based on 1991 dollars, except the last column, labeled 2001, which indicates travel reductions taking into account 30% inflation between 1991 and 2001.

In an experiment involving time- and mileage-based pricing of 20 volunteer motorists, with base fees averaging 6.4 Euro per trip which is reduced for shorter and off-peak trips, O'Mahony, Geraghty and Humphreys (2000) found that participants reduced peak period trips by 21.6%, and total trips by 5.7%, peak mileage by 24.8% and total mileage by 12.4%.

Harvey and Deakin (1998) also modeled the effect of two types of emission fee, a per-mile charge based on the average emissions for each vehicle model and year, or a fee based on actual emissions measured when a vehicle is operating. Table 24 summarizes their results for the year 2010. Distance based emission charges averaging about 0.5¢ per mile are estimated to reduce VMT by 1-7% and emissions by 14-35% (ICF, 1997). This shows that the in-use pricing options has much greater emission reducing impacts, because it discourages driving of gross-emitting vehicles.

Table 24 **Impacts of Emission Charges, Year 2010** (Harvey and Deakin, 1998, Table B.10)

Region	Fee Basis	VMT	Trips	Delay	Fuel	ROG	Revenue
Bay Area	Vehicle Model	-2.2%	-1.9%	-3.5%	-3.9%	-5.4%	$384
	Vehicle Use	-1.6%	-1.4%	-2.5%	-6.6%	-17.7%	$341
Sacramento	Vehicle Model	-2.6%	-2.3%	-4.5%	-4.0%	-5.7%	$116
	Vehicle Use	-2.3%	-2.1%	-5.0%	-7.4%	-20.2%	$102
San Diego	Vehicle Model	-2.5%	-2.2%	-3.5%	-4.1%	-5.5%	$211
	Vehicle Use	-1.9%	-1.7%	-3.5%	-7.1%	-19.5%	$186
South Coast	Vehicle Model	-2.5%	-2.3%	-5.5%	-3.9%	-5.5%	$1,106
	Vehicle Use	-2.1%	-1.9%	-6.0%	-7.2%	-18.9%	$980

Vehicle Model Fee Basis = a per-mile fee based on vehicle model and year. Vehicle Use Fee Basis = a fee based on measured tailpipe emissions of each individual vehicle, using electronic instrumentation. VMT = change in total vehicle mileage. Trips = change in total vehicle trips. Delay = change in congestion delay. Fuel = change in fuel consumption. ROG = a criteria air pollutant. Revenue = annual revenue in millions of 1991 U.S. dollars. See report for additional notes and data.

Generalized Costs

Transport modelers have developed various “generalized cost” coefficients that include combined values of travel time, vehicle costs, toll prices, fuel taxes, transit fares, and parking prices. These are usually determined empirically for a specific community based on local travel behavior and user survey data. A typical value is –0.5 (NHI, 1995). Booz, Allen, Hamilton (2003) estimate the generalized cost of travel in the Canberra, Australia region to be –0.87 for peak, -1.18 for off-peak, and –1.02 overall (peak and off-peak combined). TRL (2004) calculates generalized cost elasticities of –0.4 to –1.7 for urban bus transit, -1.85 for London underground, and -0.6 to –2.0 for rail transport.

Lee (2000) estimates the elasticity of vehicle travel with respect to Total Price (including fuel, vehicle wear and mileage-related ownership costs, tolls, parking fees and travel time, which is equivalent to generalized costs) is –0.5 to –1.0 in the short run, and –1.0 to –2.0 over the long run.

Travel Time

In general, increased speed and reduced delay (by congestion or transfers) tends to increase travel distance, and increased relative speed for a particular mode tends to attract travel from other modes on a corridor. Some research supports the *constant travel time budget* hypothesis, which means that the amount of time people devote to travel tends to remain constant (typically found to average 70-90 minutes per day), implying that the elasticity of travel with respect to speed is 1.0 (Mokhtarian and Chen, 2004)

A study by leading U.K. transportation economists concludes that the elasticity of travel volume with respect to travel time is -0.5 in the short term and -1.0 over the long term (SACTRA, 1994). This means that reducing travel time on a roadway by 20% typically increases traffic volumes by 10% in the short term and 20% over the long term. Another study found the elasticity values for vehicle travel with respect to travel time shown in Table 25. Pratt (1999) estimates the effects of service speed, frequency and reliability on public transit use, including the effects of HOV facilities.

Table 25 **Vehicle Travel Elasticities With Respect to Travel Time** (Goodwin, 1996)

	Short Run	Long Run
Urban Roads	-0.27	-0.57
Rural Roads	-0.67	-1.33

TRACE (1999) provides detailed estimates of the elasticity of various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business trips, etc.) with respect to car travel times under various conditions (e.g., level of vehicle ownership and transit use, type of trip, etc.). Table 26 summarizes long-term car travel time elasticities of kilometers traveled in areas with high vehicle ownership (more than 450 vehicles per 1,000 population). Booz, Allen, Hamilton (2003) estimate travel time costs, including separate values for car and bus in-vehicle time, and for walking and waiting times for transit travel.

Table 26 **Long Term Elasticities Of Kilometres With Respect to Car Travel Time** (TRACE, 1999)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow Modes
Commuting	-0.96	-1.02	+0.70	+0.50
Business	-0.12	-2.37	+1.05	+0.94
Education	-0.78	-0.25	+0.03	+0.03
Other	-0.83	-0.52	+0.27	+0.21
Total	-0.76	-0.60	+0.39	+0.19

This table summarizes the effects of changes in car travel time on travel demand for other modes for various types of trips. (Slow Modes = walking and cycling)

Research by Dowling Associates (2005) estimates the elasticity of travel with respect to travel time for individual modes and time periods, based on Portland, Oregon data. For example, it indicates that each 1% increase in AM Peak DA (Drive Alone) travel time reduces DA travel by 0.225% and increases demand for SR (Shared Ride) travel by 0.037% and transit by 0.036%.

Table 27 **Travel Time Elasticities and Cross Elasticities** (Dowling Asso., 2005)

		Am Peak			**Pm Peak**		
		DA	SR	TR	DA	SR	TR
AM Peak	DA	-0.225	0.030	0.010	-0.024	0	0
	SR	0.037	-0.303	0.032	0	-0.028	0
	TR	0.036	0.030	-0.129	0	0	-0.007
PM Peak	DA	-0.124	0	0	-0.151	0.015	0.005
	SR	0	-0.109	0	0.019	-0.166	0.016
	TR	0	0	-0.051	0.018	0.015	-0.040
Off-Peak	DA	-0.170	0	0	-0.069	0	0
	SR	0	-0.189	0	0	-0.082	0
	TR	0	0	-0.074	0	0	-0.014

DA = Drive Alone, SR = Shared Ride, TR = Transit

This table indicates the change in demand by three modes from changes in travel time by that mode and other modes during morning peak, afternoon peak and off-peak periods.

Vehicle Price and Income

A number of studies have examined how vehicle ownership and use are affected by price and income (Jansson, 1989; Golob, 1989). The elasticity of vehicle ownership with respect to price is estimated to be -0.4 to -1.0, meaning that a 10% increase in total vehicle costs reduces vehicle ownership by 4-10%. This is based on various studies, including analysis by Goodwin, Dargay and Hanly (2003) showing that a 10% increase in fuel prices reduces vehicle ownership 1.0 in the short-run and 2.5% over the long-run, and fuel represents about 25% of total vehicle costs. McCarthy (1996) estimates the price elasticity of vehicle purchases at –0.6 to –0.87. Glaister and Graham (2000) conclude that the long-run elasticity of vehicle fuel consumption with respect to income is 1.1 to 1.3, and the long-run elasticity of vehicle travel with respect to income is 1.1 to 1.8, with lower short-run values.

Generally, as people become wealthier vehicle ownership increases, but at a declining rate (Schafer and Victor, 2000). Kopits and Cropper (2003) find that vehicle ownership nearly levels off at about $16,000 (2003 dollars) per capita annual income, and some researchers suggest that above a certain level (estimated at $21,000 U.S. by Talukdar), automobile ownership levels may even decline slightly (Newman and Kenworthy, 1998). Karlaftis and Golias (2002) find that the purchase of a household's first vehicle is primarily dependent on socioeconomic factors (as income increases, so does the ownership of a vehicle), but the purchase of second and third vehicles is primarily dependent on the quality of travel alternatives (walking and transit service) in their community (if urban driving is faster and cheaper than transit, households will tend to own more automobiles).

In a major review of price elasticity, Goodwin, Dargay and Hanly (2003) conclude that if real income goes up by 10%:

- The number of vehicles, and the total amount of fuel they consume, will both go up by nearly 4% within about a year, and by over 10% in the longer run.
- The volume of traffic does not grow in proportion: 2% within a year and about 5% in the longer run, since much of that increase is in reduced fuel efficiency.

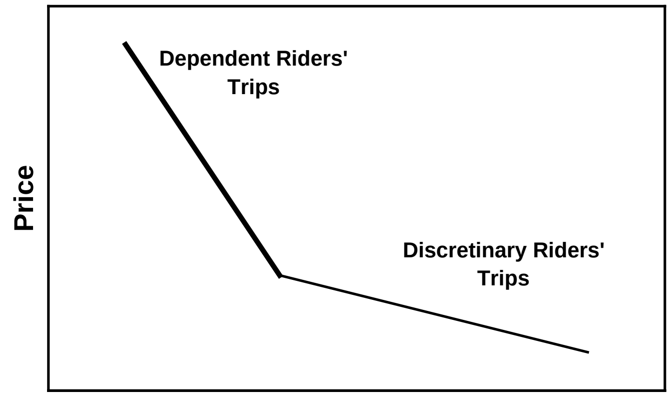
Transit Elasticities

Several factors can affect public transit elasticities (Pratt, 1999; Litman, 2002; Nash 2002; FTA, 2002; Wardman and Shires, 2003; TRL, 2004; Pratt and Evans, 2004; McCollom and Pratt, 2005):

- *User Type.* Transit dependent riders are generally less price sensitive than "discretionary" or "choice" riders (people who have the option of using an automobile for that trip). Certain demographic groups, including people with low incomes, non-drivers, people with disabilities, high school and college students, and elderly people tend to be more transit dependent. In most communities transit dependent people are a relatively small portion of the total population but a large portion of transit users, while discretionary riders are a potentially large but more price sensitive market segment.
- *Trip Type.* Non-commute trips tend to be more price sensitive than commute trips. Elasticities for off-peak transit travel are typically 1.5-2 times higher than peak period elasticities, because peak-period travel largely consists of commute trips.
- *Geography.* Large cities tend to have lower price elasticities than suburbs and smaller cities, which probably reflects the greater number of transit-dependent residents in such areas.
- *Type of Price Change.* Transit fares, service quality (service speed, frequency, coverage and comfort) and parking pricing tend to have the greatest impact on transit ridership. Fuel price tends to have relatively little impact. Elasticities appear be somewhat higher for higher fare levels (i.e., when the starting point of a fare increase is relatively high).
- *Direction of Price Change.* Transportation demand models often apply the same elasticity value to both price increases and reductions, but there is evidence that some changes are non-symmetric. Fare increases tend to cause a greater reduction in ridership than the same size fare reduction will increase ridership. A price increase or transit strike that induces households to purchase an automobile may be somewhat irreversible, since once people become accustomed to driving they often continue using that option.
- *Time Period.* Price impacts are often categorized as short-term (typically, within one year), medium-term (within five years) and long-term (more than five years). Elasticities increase over time, as consumers take price changes into account in more decisions (such as where to live or work). Long-term transit elasticities tend to be two or three times as large as short-term elasticities.
- *Transit Type.* Bus and rail often have different elasticities because they serve different markets, although how they differ depends on specific conditions.

Elasticity values depend on what portion of the demand curve is being measured. Price sensitivity is relatively low for transit travel demanded by dependent riders and relatively high for discretionary riders' demand, as illustrated in Figure 4. We can say that there is a "kink" in the demand curve (Clements, 1997). In general, basic transit that primarily serves transit dependent riders is in the less elastic portion of the demand curve, while service that attracts discretionary transit users is in the more elastic portion of the demand curve.

Figure 4 **A Kink In the Demand Curve**



Transit dependent riders tend to be less price sensitive than discretionary riders. Elasticity values tend to be significantly lower for the portion of the demand curve representing basic mobility by transit dependent travelers, and higher for the portion of the demand curve representing travel by discretionary riders.

Transit dependent riders represent a major share of current ridership for most transit systems, while discretionary rider represent a large potential market. Price changes may have relatively little impact on ridership for a basic transit system that primarily serves transit dependent users, but to attract significantly more riders and reduce automobile travel, fares will need to decline and service quality improve significantly to attract more price-sensitive, discretionary riders.

Many of the original studies that current elasticity values are based on were performed decades ago, when per capita drivers licenses, automobile ownership and real incomes were lower, and so transit dependency was higher. This suggests that transit elasticities have probably increased over time, and are likely to be somewhat higher than older, standard values.

Transit Elasticity Studies
Several publications have summarized public transit elasticity estimates, including Pham and Linsalata (1991); Oum, Waters, and Yong (1992); Goodwin (1992); Luk and Hepburn (1993); Pratt (1999); Dargay and Hanly (1999), TRACE (1999), Nash (2002), Booz Allen Hamilton (2003), Wardman and Shires (2003), and TRL (2004).

A frequently used rule of thumb, known as the *Simpson – Curtin* rule, is that each 3% fare increase reduces ridership by 1% (equivalent to an arc elasticity of –0.35 to –0.42). However, this has been widely criticized as being outdated and overly simplistic.

Ubillos and Sainz (2004) developed a nested logit model to evaluate the price, time and service frequency elasticities of transit travel by university students in Bilboa, Portugal. They found relatively high sensitivity to bus fare, rail service frequency and overall service quality, and so conclude that a combination of increased rail service and reduced bus fares would increase ridership to help reduce traffic congestion and pollution emissions.

Table 28 shows transit fare elasticity values published by the American Public Transportation Association, and widely used for transit planning and modeling in North America. This was based on a study of the short-term (less than two years) effects of fare changes in 52 U.S. transit systems during the late 1980s.

Table 28 **Bus Fare Elasticities** (Pham and Linsalata, 1991).

	Large Cities (More than One Million Population)	**Smaller Cities** (Less than One Million Population)
Average for All Hours	-0.36	-0.43
Peak Hour	-0.18	-0.27
Off-Peak	-0.39	-0.46
Off-peak Average	-0.42	
Peak Hour Average	-0.23	

This table summarizes U.S. transit fare elasticities published by the American Public Transit Association, which are widely used in North America.

Dargay and Hanly (1999) studied the effects of UK transit bus fare changes over several years using sophisticated statistical techniques to derive the elasticity values summarized in Table 29. They found that demand is slightly more sensitive to rising fares (-0.4 in the short run and –0.7 in the long run) than to falling fares (-0.3 in the short run and –0.6 in the long run), and that demand tends to be more price sensitive at higher fare levels. They found that the cross-elasticity of bus patronage to automobile operating costs is negligible in the short run but increases to 0.3 to 0.4 over the long run, and the long run elasticity of *car ownership* with respect to transit fares is 0.4, while the elasticity of *car use* with respect to transit fares is 0.3.

Based on extensive research, TRL (2004) calculates that bus fare elasticities average around –0.4 in the short-run, -0.56 in the medium run, and 1.0 over the long run, while metro rail fare elasticities are –0.3 in the short run and –0.6 in the long run. Bus fare elasticities are lower (-0.24) during peak than off-peak (-0.51).

A study by Bresson, et al. (2003) used data from British and French cities and a dynamic model to calculate transit price elasticities. They found that transit ridership is relatively price sensitive, with fare elasticities of -0.3 to -0.5 in the short-run, and -0.6 to -0.7 in the long-run. The study also found that transit ridership is sensitive to service quality, so fare increases may be offset by improved service. Nijkamp and Pepping (1998) found elasticities of transit ridership with respect to transit fares in the –0.4 to –0.6 range in a meta-analysis of European transit elasticity studies.

Table 29 **Bus Fare Elasticities** (Dargay and Hanly, 1999, p. viii)

Elasticity Type	Short-Run	Long-Run
Non-urban	-0.2 to –0.3	-0.8 to –1.0
Urban	-0.2 to –0.3	-0.4 to –0.6

This table shows elasticity values from a UK study.

Another study compared transit elasticities in the UK and France between 1975 and 1995 (Dargay, et al, 2002). It indicates that transit ridership declines with income (although not in Paris, where wealthy people are more likely to ride transit than in most other regions) and with higher fares, and increases with increased transit service kilometers. These researchers found that transit elasticities have increased during this period. The table below summarizes their findings.

Table 30 **Transit Elasticities** (Dargay, et al, 2002, table 4)

	England		**France**	
	Log-Log	Semi-Log	Log-Log	Semi-Log
Income				
Short Run	-0.67	-0.69	-0.05	-0.04
Long Run	-0.90	-0.95	-0.09	-0.07
Fare				
Short Run	-0.51	-0.54	-0.32	-0.30
Long Run	-0.69	-0.75	-0.61	-0.59
Transit VKM				
Short Run	0.57	0.54	0.29	0.29
Long Run	0.77	0.74	0.57	0.57
Annual Fare Elasticity Growth Rate		1.59%		0.66%

This table shows mean elasticity values based on 1975 to 1995 data.

With a log-log function elasticity values are the same at all fare levels, whereas with a semi-log function the elasticity value increases with higher fares. Log-Log functions are most common and generally easiest to use. Semi-log elasticity values are based on an exponential function, and can be used for predicting impacts of fares that approach zero, that is, if transit services become free, but are unsuited for very high fare levels, in which case semi-log may result in exaggerated elasticity values. For typical fare changes, between 10% and 30%, log-log and semi-log functions will provide similar results, so either can be used.

The table below summarizes transit elasticity estimates, based on a review of previous studies.

Table 31 **Factors Affecting Transit Ridership** (Kain & Liu, 1999)

Factor	**Elasticity**
Regional employment	0.25
Central city population	0.61
Service (transit vehicle miles)	0.71
Fare price	-0.32

This table shows the elasticity of transit use with respect to various factors. For example, a 1% increase in regional employment is likely to increase transit ridership by 0.25%, while a 1% increase in fare prices will reduce ridership by 0.32%, all else being equal.

Lee, Lee and Park (2003) surveyed motorists to determine what factors affect their willingness to shift to public transit. They have low fare elasticities so reducing fares is unlikely to attract many people out of cars. Car users are more sensitive to parking fees, travel time and crowding, indicating that improved transit service can increase transit ridership by discretionary users. Table 32 summarizes estimates of transit fare elasticities for different user groups and trips types, illustrating how various factors affect transit price sensitivities. For example, it indicates that car owners have a greater elasticity (-0.41) than people who are transit dependent (-0.10), and work trips are less elastic than shopping trips.

Table 32 **Transit Fare Elasticities** (Gillen, 1994, pp. 136-37)

Factor	Elasticity
Overall transit fares	-0.33 to –0.22
Riders under 16 years old	-0.32
Riders aged 17-64	-0.22
Riders over 64 years old	-0.14
People earning <$5,000	-0.19
People earning >$15,000	-0.28
Car owners	-0.41
People without a car	-0.10
Work trips	-0.10 to –0.19
Shopping trips	-0.32 to –0.49
Off-peak trips	-0.11 to –0.84
Peak trips	-0.04 to –0.32
Trips < 1 mile	-0.55
Trips > 3 miles	-0.29

This table shows elasticities disaggregated by rider and trip factors.

Booz Allen Hamilton (2003) used stated preference survey data to estimate own and cross-elasticities for various costs (fares, travel time, waiting time, transit service frequency, parking fees) modes (automobile, transit, taxi) and trip types (peak, off-peak, work, education, other) in the Canberra region. They developed generalized costs and travel time cost values, including estimates of the relative cost of walking and waiting time for transit users. Table 33 shows their estimated price and cross fare elasticities. Bresson, et al (2004) calculate the cross elasticity of transit demand relative to vehicle ownership and fuel price.

Table 33 **Australian Travel Demand Elasticities** (Booz, Allen Hamilton, 2003)

Mode	Peak	Off-Peak	Total
Bus	-0.18	-0.22	-0.20
Taxi	0.03	0.08	0.07
Car	0.01	0.01	0.01

This table shows elasticity and cross-elasticity values. It means, for example, that a 10% peak-period transit fare increase (decrease) will reduce (increase) peak-period transit ridership by 1.8%, and will increase (reduce) taxi travel by 0.3% and car travel by 0.1%.

Rail and bus elasticities often differ. In major cities, rail transit fare elasticities tend to be relatively low, typically in the –0.18 range, probably because higher-income residents depend on such systems (Pratt, 1999). For example, the Chicago Transportation Authority found that peak bus riders have an elasticity of -0.30, and off-peak riders -0.46, while rail riders have peak and off-peak elasticities of -0.10 and -0.46, respectively. However, fare elasticities may be relatively high on routes where travelers have viable alternatives, such as for suburban rail systems where most riders are discretionary. Table 34 summarizes travel demand elasticities developed for use in Australia, based on a review of various national and international studies.

Table 35 **Australian Travel Demand Elasticities** (Luk & Hepburn, 1993)

Elasticity Type	Short-Run	Long-Run
Petrol consumption and petrol price	-0.12	-0.58
Travel level and petrol price	-0.10	
Bus demand and fare	*-0.29*	
Rail demand and fare	*-0.35*	
Mode shift to transit and petrol price	*+0.07*	
Mode shift to car and rail fare increase	*+0.09*	
Road freight demand and road/rail cost ratio	-0.39	-0.80

This table shows elasticity values adopted by the Australian Road Research Board.

Several TDM strategies involve transit fare reductions. Commuter Transit Benefit programs, in which employers encourage and sometimes subsidize transit passes, are effective at increasing ridership (*Commuter Check*, www.commutercheck.com). Deep Discount transit passes can encourage occasional riders to use transit more frequently (Oram and Stark, 1996), and if implemented when fares are increasing, can avoid ridership losses. Many Campus Transport Management programs include free or discounted transit fares. Not all increased transit travel that results from fare discounts represents a reduction in automobile travel. A portion represents shifts from walking, cycling and ridesharing, or absolute increases in personal travel.

Vanpool Elasticity Studies

York and Fabricatore (2001) estimate the price elasticity of vanpooling at about 1.5, meaning that a 10% reduction in vanpool fares increases ridership by about 15%. For example, if vanpool fares that are currently $50 per month are reduced to $40 (a 20% reduction), ridership is likely to increase by about 30% (20% x 1.5).

Wambalaba, Concas and Chavarria (2004) find that the parameter of vanpool ridership with respect to fees is -2.6% using a 1997 data set and -14.8% using a less statistically robust 1999 data set. This indicates that each dollar decrease in vanpool fees is associated with a 2.6% to 14.8% increase in the predicted odds of choosing vanpool relative to driving alone. The same study found the elasticity of vanpooling with respect to price to be -0.61 (1997) and 13.4% (1999), meaning that for each 10% increase in vanpool price there is a 6% to 13% decrease in vanpool choice with respect to auto. Using a nested logit model the study found the elasticity of vanpooling with respect to fares to be -1.14.

Cross Elasticities

Cross-elasticity refers to the changes in demand for a good that results from a change in the price of a substitute good. This includes changes in automobile travel due to transit fare changes, changes in transit ridership due to changes in automobile operating costs, and changes in one type of transit (such as bus) in response to price changes in another type of transit (such as rail). Lago et al. (1992) found the mean cross-elasticity of auto travel demand with respect to bus fares is 0.09 (±0.07), and 0.08 (±0.03) with respect to rail fares. Hensher developed a model of elasticities and cross-elasticities between various forms of transit and car use, illustrated in Table 36.

Table 36 **Direct and Cross-Share Elasticities** (Hensher, 1997, Table 8)

	Train Single Fare	**Train** Ten Fare	**Train** Pass	**Bus** Single Fare	**Bus** Ten Fare	**Bus** Pass	**Car**
Train, single fare	-0.218	0.001	0.001	0.057	0.005	0.005	0.196
Train, ten fare	0.001	-0.093	0.001	0.001	0.001	0.006	0.092
Train, pass	0.001	0.001	-0.196	0.001	0.012	0.001	0.335
Bus, single fare	0.067	0.001	0.001	-0.357	0.001	0.001	0.116
Bus, ten fare	0.020	0.004	0.002	0.001	-0.160	0.001	0.121
Bus, pass	0.007	0.036	0.001	0.001	0.001	-0.098	0.020
Car	0.053	0.042	0.003	0.066	0.016	0.003	-0.197

This table indicates how various changes in transit fares and car operating costs affects transit and car travel demand. For example, a 10% increase in single fare train tickets will cause a 2.18 reduction in the sale of those fares, and a 0.57% increase in single fare bus tickets. This is based on a survey of residents of Newcastle, a small Australian city.

TRACE (1999) provides detailed estimates of transit ridership with respect to fuel and parking prices for various types of travel and conditions (see data in sections on fuel and parking price elasticities). It estimates that a 10% rise in fuel prices increases transit ridership 1.6% in the short run and 1.2% over the long run (this declining elasticity value is unique to fuel, due to motorists purchasing more efficient vehicles when fuel prices increase). This project made the following conclusions:

- For the cross elasticities we find more variation than for the own elasticities, partly due to the fact that the elasticities depend on the market shares of the modes in each study.
- The fuel price elasticity of public transport traveller trips (all purposes, long run) averages about 0.1. There are no clear differences between purposes and time-of-day. Short-term cross elasticities are not necessarily higher than the long-term counterparts.
- For the average fuel price elasticity of public transport traveller kilometres we find a value of around 0.1. There are no clear differences by purpose and time-of-day. Short-term elasticities are a bit higher here than long-term elasticities, indicating the long term effect of a fuel price increase on kilometres travelled with public transport includes the decline in attractiveness of destinations further away.
- The average car time elasticity of public transport traveller trips (all purposes, long run) is 0.4. There are no clear differences with respect to purpose and time-of-day.
- The car time elasticity of public transport traveller kilometres (all purposes, long run) is 0.4, which is greater than the cost sensitivity. This elasticity is higher for commuting and higher for the short term (destination choice effect, see above).

METS Transit Demand Model
(www.bized.ac.uk/virtual/vla/transport/resource_pack/notes_mets.htm)

METS (MEtropolitan Transport Simulator) is a simulation model of transport supply and demand. It uses default values that simulate transport in London, but it can be modified for any large urban region. It is updated regularly. METS was built in the early 1980s to evaluate the effects of London transit fare changes. In 1981 fares were reduced on buses and the tube by a third, and a simpler ticketing scheme was introduced. This produced an 11% increase in transit use, and a 6% reduction in car use. The policy was challenged in the courts and declared illegal, with the result that fares rose by over 90% a year later, causing a 15% reduction in transit use and 14% increase in car travel. However, after yet another court case in May 1983, the GLC was able to cut fares by 23%, and introduce further ticketing simplifications, which caused a 11% increase in transit use and a 9% reduction in car. The following table summarizes these changes:

Table 37 **Fares Fare**

	Oct 1981	Mar 1982	May 1983
Change in average Fares (%)	-31	+93	-23
Change in bus and tube use (%)	+11	-15	+11
Change in commuting to London by car (%)	-6	+14	-9

Source: Graying and Glaister 2000, page 10, from an original in Lindsay and Fairhurst (1984).

After these court battles the federal government took away much of the local authority's power to set transit policy and required local authorities to conduct cost-benefit analyses of public transport subsidies, taking into account the benefits from lower fares and faster journeys. Only if these benefits exceed cost are subsidies allowed. The METS model was developed to equip local authorities to do this.

The METS model is quite complicated inside, but the basic ideas are simple enough. METS is a large computer program which represents London's transport system as a series of inter-related equations. There is an equation, for example, that describes the demand for bus trips as a function of the cost of the journey and the cost of alternatives, such as cars or the tube, and similar equations for the tube, overground trains, cars and taxis. The relations between cost and demand are expressed using the price elasticities you are all familiar with. Here is a table of some of the elasticities used:

Table 38 **METS cost elasticities.**

	Car	Bus	Underground
Car	-0.30	0.09	0.057
Bus	0.17	-0.64	0.13
Underground	0.056	0.20	-0.50

Source: Grayling and Glaister p.35.

Each row tells us how demand for that form of transport changes as costs (fares and travel time) change. Look at the top row. The first number indicates that the own-price elasticity of demand for car journeys is -0.3, so a 10% rise in car costs will reduce car use 3%. The second number in the first row (0.09) is the cross-price elasticity of demand for car use with respect to bus costs: a 10% increase in bus costs would cause a 0.9% increase in car use. The third number (0.057) is the cross-price elasticity of car use with respect to Underground costs: car users seem less responsive to changes in tube costs than bus costs. From the second row, second column, you can see that buses are rather more responsive to own-cost changes (an own-price elasticity of -0.64, so a 10% cost increase causes a 6% fall in use), and from the third row that the Underground elasticity, at -0.5, is somewhere in-between cars and buses. Note that all the own-cost elasticities are absolutely less than -1, which implies that total revenues should rise if fares go up. Elasticities are calculated from the National Travel Survey (an annual survey of transport use), and results from fare policy changes, such as those described earlier.

Much of the complexity in METS comes from the need to accurately measure costs. The costs of making a journey are not just the price of the bus ticket or of your car's petrol. Your time is worth something, too. Travel time is measured relative to hourly wage rates. Average hourly wage rates for people using different modes of transport can be estimated using the National Travel Survey. The length of a journey depends on waiting and boarding times for public transport, and average traffic speeds. Fares, waiting times and traffic speeds are inter-related. For example, consider a bus fare cut. This will increase demand for buses and reduce the demand for alternative modes, which should increase average speeds, since there will be less cars on the road and less traffic congestion. Consequently, you may get to your destination faster, but in some circumstances you might have longer boarding and waiting times, since the buses will be fuller and you might not be able to get on the next one.

For more information on the METS model see:

Tony Grayling and Stephen Glaister, *A New Fares Contract for London*, Institute for Public Policy Research (www.ippr.org.uk), ISBN 1 86030 100 2, 2000.

J. Lindsay and M.H. Fairhurst, *The London Transport fares experience (1980-1983)*, Economic Research Report R259, London Transport, 1984.

S. Glaister, "The Economic Assessment of Global Transport Subsidies in Large Cities," in Grayling T (ed) *Any more fares?*, Institute for Public Policy Research (www.ippr.org.uk), 2001.

Tackling Traffic Congestion: More about the METS Model, (www.bized.ac.uk/virtual/vla/transport/resource_pack/notes_mets.htm) and (www.bized.ac.uk/virtual/vla/transport/index.htm)

Parking Pricing Impacts on Transit

Several studies indicate that parking prices (and probably road tolls) tend to have a greater impact on transit ridership than other vehicle costs, such as fuel, typically by a factor of 1.5 to 2.0, because they are paid directly on a per-trip basis. Hensher and King (1998) calculate elasticities and cross-elasticities for various forms of transit fares and automobile travel in the Sydney, Australia city center.

Transit Service

Service elasticity refers to how much transit ridership increases (decreases) in response to an increase (reduction) in transit vehicle-mileage, vehicle-hours or frequency. Of course, many factors affect service elasticities, including demographic factors (i.e., the portion of the population that is transit dependent or lower-income), geographic factors (i.e., population density, employment density and pedestrian accessibility), service quality (i.e., speed, comfort and schedule information) and fare price. New transit quality of service indices that better account for these factors may be used in the future to better define transit service elasticity factors (Transit Evaluation).

Evans (2004) provides information on the effects of various types of service improvements on transit ridership. The elasticity of transit use to service expansion (e.g. routes into new parts of a community) is typically in the range of 0.6 to 1.0, meaning that each 1% of additional service (measured in vehicle-miles or vehicle-hours of service) increases ridership by 0.6-1.0%, although much lower and higher response rates are also found (from less than 0.3 to more than 1.0). The elasticity of transit use with respect to transit service frequency (called a *headway elasticity*) averages 0.5. There is a wide variation in these factors, depending on the type of service, demographic and geographic factors. Higher service elasticities often occur with new express transit service, in university towns, and in suburbs with rail transit stations to feed. It usually takes 1 to 3 years for ridership on new routes to reach its full potential.

Pratt (1999) finds that completely new bus service in a community that previously had no public transit service typically achieves 3 to 5 annual rides per capita, with 0.8 to 1.2 passengers per bus mile.

Improved schedule information, easy-to-remember departure times (for example, every hour or half-hour), and more convenient transfers can also increase transit use, particularly in areas where service is less frequent.

Mackett (2000 and 2001) identifies a number of positive incentives that could reduce short (under 5 mile) car trips, including improved transit service, improved security, reduced transit fares, pedestrian and cycling improvements. Of those, transit improvements are predicted to have the greatest potential travel impacts.

Transit ridership tends to be more responsive to service improvements than to fare reductions (Pratt concludes that “ridership tends to be one-third to two-thirds as responsive to a fare change as it is to an equivalent percentage change in service”), and most responsive to combinations of service improvements and fare reductions.

Transit Elasticities Summary

No single transit elasticity value applies in all situations: various factors affect price sensitivities including type of user and trip, geographic conditions and time period. Transit dependent people are generally less price sensitive and discretionary riders more price sensitive. As per capita wealth, drivers, vehicles and transport options increase, transit elasticities are likely to increase.

Commonly used transit elasticity values are based on studies performed 10-30 years ago, when real incomes where lower and a greater portion of the population was transit dependent. These studies primarily reflect short-term impacts. The resulting elasticity values are probably lower than what would accurately predict medium and long-term changes under current conditions in most North American urban areas. Although residents of Canadian cities are somewhat more transit dependent than residents of comparable size U.S. cities, virtually all other factors identified in this research tend to increase transit elasticities relative to the standard values.

Available evidence suggests that the elasticity of transit ridership with respect to fares is about –0.3 to –0.5 in the short run (first year) and increases to about –0.6 to –0.9 over the long run (five to ten years). Table 39 summarizes transit elasticity values.

Table 39 **Transit Elasticity Values**

	Market Segment	Short Term	Long Term
Transit ridership WRT transit fares	Overall	–0.2 to –0.5	–0.6 to –0.9
Transit ridership WRT transit fares	Peak	–0.15 to –0.3	–0.4 to –0.6
Transit ridership WRT transit fares	Off-peak	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit fares	Suburban Commuters	–0.3 to –0.6	–0.8 to –1.0
Transit ridership WRT transit service	Overall	0.50 to 0.7	0.7 to 1.1
Transit ridership WRT auto operating costs	Overall	0.05 to 0.15	0.2 to 0.4
Automobile travel WRT transit costs	Overall	0.03 to 0.1	0.15 to 0.3

This table summarizes estimates of transit elasticities. These values can be used to predict how various types of changes in prices and service are likely to affect transit ridership and travel behavior.

These are affected by the following factors:

- Transit price elasticities are lower for existing (transit dependent) riders than for new (discretionary) riders, and lower in urban areas than for suburban commuters.
- Elasticities are about twice as high for off-peak and leisure travel as for peak-period and commute travel.
- Transit price elasticities are relatively high for efforts to shift automobile travel to transit as a demand management strategy (i.e., a relatively large fare reduction is needed to attract motorists), although improved transit services or increased automobile operating costs through road or parking pricing are likely to increase the impacts of fare reductions.
- Discretionary ridership is often more responsive to service quality (speed, frequency and comfort) than fares.

- Packages of transit ridership incentives that include fare reduction or discounted passes, increases service and improved marketing can be particularly effective at increasing ridership.
- Cross-elasticities between transit and automobile travel are relatively low in the short run (0.05), but increase over the long run (probably to 0.3 and perhaps as high as 0.4).
- Due to variability and uncertainty it is preferable to use a range rather than single point values for elasticity analysis as much as possible.

Taxi Service Elasticities

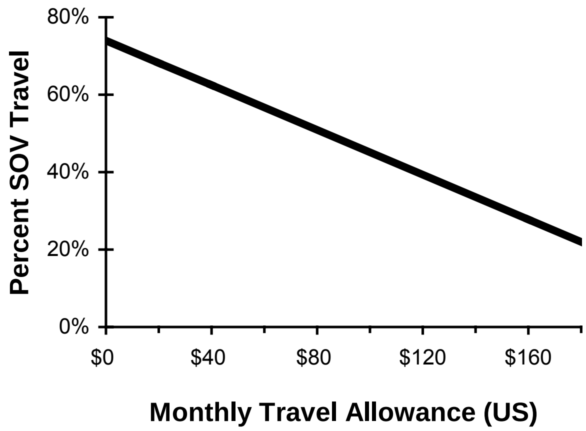
Schaller (1999) finds that in New York City, the elasticity of taxi demand with respect to fares is –0.22, the elasticity of service availability with respect to fares is 0.28, and the elasticity of service availability with respect to total supply of service is 1.0. Based on these values he concludes that fare increases tend to increase total industry revenues and service availability, and that the number of taxi licenses can often be expanded without reducing the revenue of existing operators.

Commute Trip Reduction Programs

Models are now available which can predict the travel impacts of a specific Commute Trip Reduction program, taking into account the type of program and worksite. These include the *CUTR_AVR Model* (www.cutr.usf.edu/tdm/download.htm), the *Business Benefits Calculator* (BBC) (www.commuterchoice.gov) and the *Commuter Choice Decision Support Tool* (www.ops.fhwa.dot.gov/PrimerDSS/index.htm).

The figure below illustrates the effect such economic incentives typically have on single occupant vehicle (SOV) commuting.

Figure 5 **Effect of Economic Incentives on SOV Rates** (Rutherford, 1995)



SOV travel decline as economic incentives for other modes increase.

The VTPI Trip Reduction Tables provide more information on the impacts that financial incentives can have on commute travel under various circumstances. Table 38 is an example. It shows the effects of a transit subsidy on commute trips for various worksite settings, taking into account location (suburban, activity center, central business district [CBD]), and whether carpooling or transit are favored as alternative modes. For example, a $1 (in 1993 U.S. dollars) per day transit subsidy provided to employees at a transit-oriented activity center is likely to reduce commute trips by 10.9%, while in a rideshare-oriented Central Business District, the same subsidy only causes a 4.7% trip reduction.

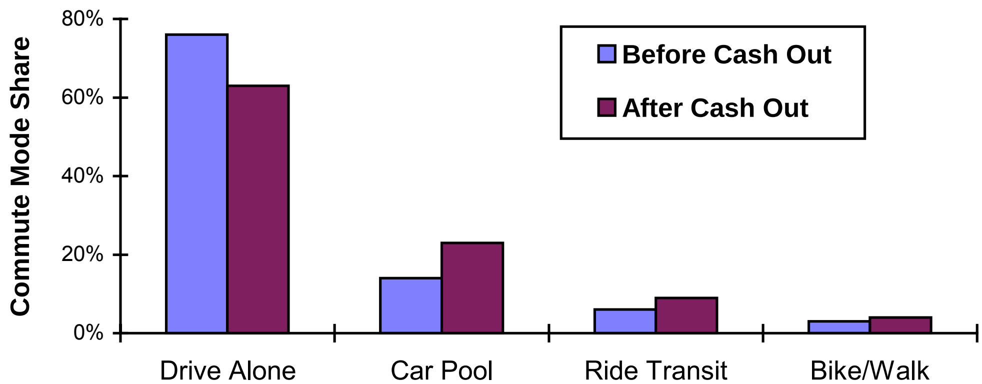
Table 40 **Percent Vehicle Trips Reduced by Daily Transit Subsidy** ("Trip Reduction Tables," VTPI, 2005, based on Comsis Corporation, 1993)

Worksite Setting	$0.50	$1	$2	$4
Low density suburb, rideshare oriented	0.1	0.2	0.6	1.9
Low density suburb, mode neutral	1.5	3.3	7.9	21.7
Low density suburb, transit oriented	2.0	4.2	9.9	23.2
Activity center, rideshare oriented	1.1	2.4	5.8	16.5
Activity center, mode neutral	3.4	7.3	16.4	38.7
Activity center, transit oriented	5.2	10.9	23.5	49.7
Regional CBD/Corridor, rideshare oriented	2.2	4.7	10.9	28.3
Regional CBD/Corridor, mode neutral	6.2	12.9	26.9	54.3
Regional CBD/Corridor, transit oriented	9.1	18.1	35.5	64.0

This table can be used to predict how transit subsidies are likely to affect automobile commute trips. See Trip Reduction Tables for more information.

Solo driving declined 17% after parking was *cashed out* (employees could choose cash instead of subsidized parking), as illustrated in Figure 6. Travel impacts tend to increase over time: one employer that solo commuting continued to decline each year for three years after cashing out was introduced, as more employees found opportunities to reduce their driving (Shoup, 1997). Transit vouchers tend to have similar effects (Oram Associates, 1995; Schwenk, 1995).

Figure 6 **Cashing Out Impacts on Commute Mode** (Shoup, 1997)



This figure illustrates the effects Parking Cash Out had on commute mode choice.

Travel impacts are affected by the magnitude of the benefit and the quality of travel choices. Mode shifts tend to be greatest if current transit use is low. In New York City, where transit commute rates are already high, transit benefits only increased transit use by 16% to 23%, while in Philadelphia, transit commuting increased 32% among recipients (Schwenk, 1995). Similarly, only 30% of employees who received transit benefits who work in San Francisco increased their transit use, while 44% of those in other parts of the region commuted by transit more (Oram Associates, 1995). These probably represent the lower range of mode shifts since they are marketed primarily as an employee benefit and are therefore most attractive to firms with high current levels of transit commuting.

Mode Shifts

Increases in vehicle operating charges (fuel, parking, tolls, etc.) tend to reduce vehicle use, as described in the previous sections of this report. Some of this travel simply disappears, due to fewer and shorter trips, and more use of mobility alternatives such as telework and delivery services. A portion of reduced automobile use consists of shifts to other travel modes.

Which changes occur depends on specific conditions, such as the type of trip, the travel route, the quality of travel alternatives, the type of traveler, etc. In general, a larger share of shorter distance, non-work trips shift to walking and cycling, while a larger share of longer distance trips shift to transit (particularly for urban destinations) and ridesharing (particularly for suburban commutes). A disincentive to driving (say, higher parking fees or a road toll in urban areas) generally causes 20-60% of automobile trips to shift to transit, while other trips will shift to nonmotorized modes, ridesharing, or be avoided altogether when travelers consolidate errands or shift destinations. Conversely, when bus service is improved, typically 10-50% of the added trips will substitute for automobile trips, with higher shifts for longer-distance trips. For example, if improved regional bus service attracts 1,000 additional riders, perhaps 500 of them will substitute for car passenger-trips, resulting in 333 fewer automobile vehicle-trips (assuming 1.5 passengers per automobile). Other new bus passengers will consist of people who would have gone to a different destination, or not traveled at all.

Pratt (1999) and Kuzmyak, Weinberger and Levinson (2003) provide information on the mode shifts that result from various incentives, such as transit service improvements. They find that commercial center parking supply has a major impact on transit ridership: each 1% increase in downtown parking supply reduces transit ridership by 0.77% (Kuzmyak, Weinberger and Levinson, 2003, p. 18-18), although this probably reflects confounding factors, such as walkability and transit service quality, not just parking supply. Table 41 provides one example. Also see Pratt, Table 10-22 and Kuzmyak, Weinberger and Levinson, Table 18-34.

Table 41 **Mode Shifts By New Transit Users** (Pratt, 1999, Table 9-10)

Riders Attracted By Increased Bus Frequency		**Riders Attracted By Increased Commuter Rail Frequency**	
Prior Mode	Percentage	Prior Mode	Percentage
Own Car	18-67%	Own Car	64%
Carpool	11-29%	Carpool	17%
Train	0-11%	Bus	19%
Taxi	0-7%		
Walking	0-11%		

The Transit Performance Monitoring System (TPMS) surveys provide a variety of information on transit ridership (FTA, 2002). More than half (56%) of transit passengers report that if transit service were unavailable they would have traveled by automobile, either as a driver or passenger. Below is what survey respondents would do if transit service were unavailable:

Drive	23%
Ride with someone	22%
Taxi/Train	12%
Not make trip	21%
Walk	18%
Bicycle	4%

Below are results of an on-board survey that asked transit riders what they would do if transit was unavailable. In this case, between 25% and 58% of total transit trips displace a motor vehicle trip (depending on the portion of "Ride with someone" responses would involve an additional vehicle trip). Other surveys find similar results. The amount of substitution is likely to be higher in more automobile dependent areas, and lower in multi-modal areas where travelers have a greater variety of mobility options, including walking and cycling.

Table 42 **Alternatives To Transit Travel** (Volusia County Public Transit, 1999)

How would you make this trip if not by bus?	**Frequency**
Ride with someone*	626 (33%)
Walk	369 (19%)
Wouldn't make trip	262 (14%)
Taxi*	245 (13%)
Drive*	147 (8%)
Bicycle	161 (8%)
Paratransit service*	57 (3%)
Other	56 (3%)
Total	*1,923 (100%)*

* Increases automobile trips.

In a survey of 2000 motorists driving to a Haifa, Israel commercial district, Shiftan (1999) found that parking demand would be reduced 29% by a US$1.00 per hour fee, and 50% by a US$1.50 per hour fee. Of those who change, 40% would change mode (to walking, taxi or public transportation), 31% would change destination, about 8% would change how long they park, and 8% would cancel the trip. For commuters, nearly all of the reduction results from mode shifting. For non-work trips, about a third of the reduction results from mode shifting, half results from changing time (and therefore reducing the amount of time they are charged to park), and there are small shifts in destination or trip generation.

Shoup (1997) found that the Parking Cash Out programs he studied caused a 13-point reduction in drive alone, a 9-point increase in carpooling, a 9-point increase in transit use, and a 1-point increase in walk/bike commuting. In another example, after Canadian fuel prices increased about 15% in 2001, a survey by the federal Competition Bureau found that about a quarter of motorists reported shifting some travel from driving to alternative modes. Of those, 46% took transit, 36% walked, 24% bicycled, and 20% used ridesharing.

The TravelSmart program in the city of Perth, Australia used TDM Marketing and a variety of incentives to encourage residents to use alternative travel modes. The goal of the program is to encourage residents to increase the portion of total trips made by environmentally friendly modes (walking, cycling and public transit) from 10% to 25% of trips by 2029. This goal is considered feasible, based on detailed market research and transportation surveys. Before-and-after surveys of pilot projects found the following results (Transport WA, 2001):

Trips By	Change
Car-as-driver	Down 14%
Public transit	Up 17%
Cycling	Up 61%
Walking	Up 35%
Car mileage	Down 17%

A survey by Mackett (2001) of UK residents evaluated the potential of shifting short trips (less than 8 kms) from driving to alternative modes. Survey respondents indicated that 31% to short vehicle trips could be shifted to bus, 31% to walking, 7% to bicycle and 3% to taxi; respondents often indicated more than one possible alternative mode for particular trips.

Freight Elasticities

The price elasticity of freight transport (measured in ton-miles) in Denmark is calculated to be –0.47, while the elasticity of freight traffic (measured in truck-kilometers) is –0.81, and the elasticity of freight energy consumption is only about –0.1 according to a study by Thomas Bue Bjørner (1999). A 10% increase in shipping costs reduces truck traffic by 8%, but total shipping volume by only 5%. Some freight is shifted to rail, while other freight is shipped using existing truck capacity more efficiently.

Hagler Bailly (1999) estimate the long-run price elasticity of rail and truck freight transport at –0.4, with a wide range depending on the type of freight. Small and Winston summarize various estimates of freight elasticities, as summarized in the table below.

Table 43 **Freight Transport Elasticities** (Small & Winston, 1999, Table 2-2)

	Rail	Truck
Aggregate Mode Split Model, Price	-0.25 to –0.35	-0.25 to –0.35
Aggregate Mode Split Model, Transit Time	-0.3 to –0.7	-0.3 to –0.7
Aggregate Model from Tanslog Cost Function, Price	-0.37 to –1.16	-0.58 to –1.81
Disaggragate Mode Choice Model, Price	-0.08 to -2.68	-0.04 to –2.97
Disaggragate Mode Choice Model, Transit Time	-0.07 to –2.33	-0.15 to –0.69

These elasticities vary depending on commodity group.

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