

Transit Price Elasticities and Cross-Elasticities 27 February 2017

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Abstract

This paper summarizes price elasticities and cross elasticities for use in public transit planning. It describes how elasticities are used, and summarizes previous research on transit elasticities. Commonly used transit elasticity values are largely based on studies of short- and medium-run impacts performed decades ago when real incomes were lower and a larger portion of the population was transit dependent. As a result, they tend to be lower than appropriate to model long-run impacts. Analysis based on these elasticity values tends to understate the potential of transit fare reductions and service improvements to reduce problems such as traffic congestion and vehicle pollution, and understate the long-term negative impacts that fare increases and service cuts will have on transit ridership, transit revenue, traffic congestion and pollution emissions.

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Introduction

Prices affect consumers' purchase decisions. For example, a particular product may seem too expensive at its regular price, but a good value when it is discounted. Similarly, a price increase may motivate consumers to use a product less or shift to another brand.

Such decisions are said to be "marginal," that is, the decision is at the margin between different alternatives and can therefore be affected by even small price changes. Although individually such decisions may be quite variable and difficult to predict (a consumer might succumb to a sale one day but ignore the same offer the next), in aggregate they tend to follow a predictable pattern: when prices decline consumption increases, and when prices increase consumption declines, all else being equal. This is called the "law of demand."

This paper summarizes research on how price changes affect transit ridership. *Price* refers to *users' perceived, marginal cost*, that is, the factors that directly affect consumers' purchase decision. This can include both monetary costs and non-market costs such as travel time and discomfort.

Price sensitivity is measured using *elasticities*, defined as the percentage change in consumption resulting from a one-percent change in price, all else held constant. A high elasticity value indicates that a good is price-sensitive, that is, a relatively small change in price causes a relatively large change in consumption. A low elasticity value means that prices have relatively little effect on consumption. The degree of price sensitivity refers to the absolute elasticity value, that is, regardless of whether it is positive or negative.

For example, if the elasticity of transit ridership with respect to (abbreviated *WRT*) transit fares is -0.5 , this means that each 1.0% increase in transit fares causes a 0.5% reduction in ridership, so a 10% fare increase will cause ridership to decline by about 5%. Similarly, if the elasticity of transit ridership with respect to transit service hours is 1.5, a 10% increase in service hours would cause a 15% increase in ridership.

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.

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, so an increase in the price of driving tends to reduce demand for parking and increase demand for transit.

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. 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.

Special care is required when calculating the impacts of large price changes, or when predicting the effects of multiple changes such as an increase in fares and a reduction in service, because each subsequent change impacts a different base. 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 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. In total a 10% price increase reduces consumption 4.9%, not a full 5% that would be calculated by simply multiplying -0.5×10 . This becomes significant when evaluating the impacts of price changes greater than 50%.

Price elasticities have many applications in transportation planning. They can be used to predict the ridership and revenue effects of changes in transit fares; they are used in modeling to predict how changes in transit service will affect vehicle traffic volumes and pollution emissions; and they can help evaluate the impacts and benefits of mobility management strategies such as new transit services, road tolls and parking fees.

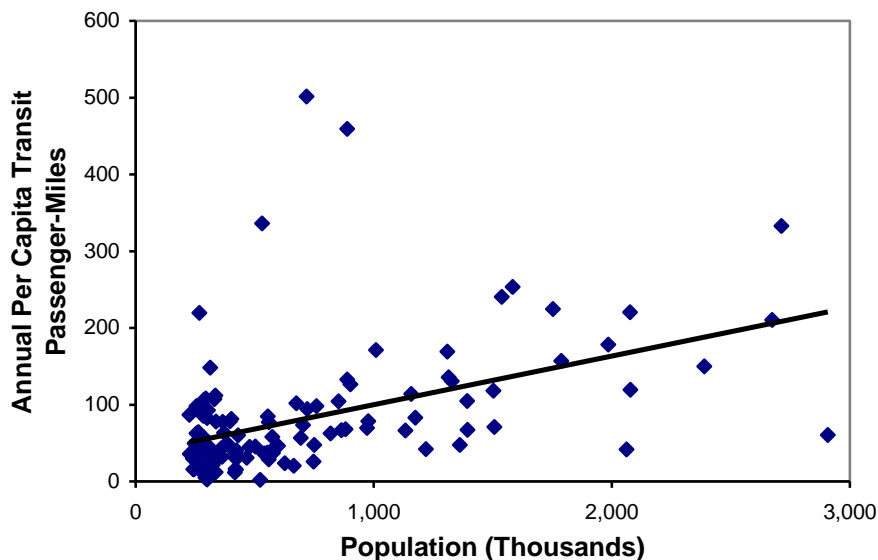
Factors Affecting Transit Elasticities

Many factors can affect how prices affect consumption decisions. They can vary depending on how elasticities are defined, the type of good or service affected, the category of customer, the quality of substitutes, and other market factors (Alam, Nixon and Zhang 2015; Chen and Naylor 2011). It is important to consider these factors in elasticity analysis.

Some factors that affect transit elasticities are summarized below.

- *User Type.* Transit dependent riders are generally less price sensitive than *choice* or *discretionary* 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 elastic transit 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, because they have a greater portion of transit-dependent users. Per capita annual transit ridership tends to increase with city size, as illustrated in Figure 1, due to increased traffic congestion and parking costs, and improved transit service due to economies of scale.

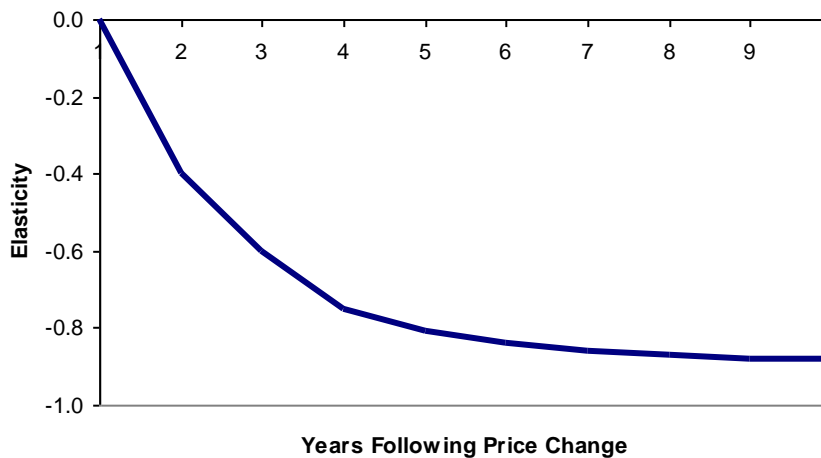
Figure 1 Transit Ridership Versus City Size (FTA 2001)



This graph illustrates the relationship between city size and annual per-capita transit travel for U.S. cities between 200,000 and 3,000,000 population. Per capita ridership tends to grow with city size, due to increasing automobile costs and transit service efficiencies.

- *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. Elasticities appear to increase somewhat as fare levels increase (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.

Figure 2 Dynamic Elasticity (Dargay and Hanly 1999)

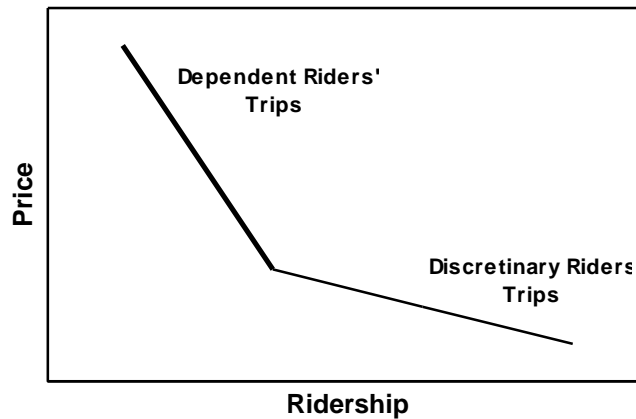


The absolute magnitude of elasticity values tend to increase over time. Long-run transit elasticities tend to be two or three times as large as short-run elasticities.

- *Time Period.* Price impacts are often categorized as short-run (less than two years), medium-run (within five years) and long-run (more than five years). Elasticities increase over time, as consumers take price changes into account in longer-term decisions, such as where to live or work, as illustrated in Figure 2. Long-run transit elasticities tend to be two or three times as large as short-run elasticities.
- *Transit Type.* Bus and rail often have different elasticities because they serve different markets, although how they differ depends on specific conditions. According to Paulley, et al. (2004), "Although car ownership has a negative impact on rail demand, it is less than for bus and, although there are quite large variations between market segments and across distance bands, the overall effect of income on rail demand is quite strongly positive. Rail income elasticities are generally found to be positive, and as high as 2 in some cases. As with the bus income elasticities, the rail elasticity can also be expected to increase over time." [as car ownership saturates]

Because there is significant difference in demand between dependent and discretionary riders we can say there is a “kink” in the demand curve (Clements 1997), as illustrated in Figure 3. As a result, elasticity values depend on what portion of the demand curve is being measured. Price changes may have relatively little impact on ridership for a basic transit system that primarily serves transit dependent users, but if the transit system wants to attract significantly more riders and reduce automobile travel, fares will need to decline and service improve to attract more price sensitive discretionary riders.

Figure 3 **A Kink In the Demand Curve**



Transit dependent riders tend to be less price sensitive than discretionary riders, so elasticity values tend to decline once their basic demand is satisfied.

Summary of Transit Elasticity Studies

Many studies have been performed on the price elasticity of public transit, and several previous publications have summarized the results of such studies, including Alam, Nixon and Zhang (2015), Pham and Linsalata (1991); Oum, Waters, and Yong (1992); Goodwin (1992); Luk and Hepburn (1993); Pratt (1999); Dargay and Hanly (1999), TRACE (1999), Booz Allen Hamilton (2003) and TRL (2004). APTA (2008) summarizes a survey of U.S. transit agencies concerning the effects of recent fuel price increase on ridership. Significant results from this research are summarized below.

General Transit Fare Elasticity Values

A frequently-used rule-of-thumb, known as the *Simpson – Curtin* rule, is that each 3% fare increase reduces ridership by 1%. Like most rules-of-thumb, this can be useful for rough analysis but it is too simplistic and outdated for detailed planning and modeling.

Table 1 shows bus 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-run (less than two years) effects of fare changes in 52 U.S. transit systems during the late 1980s. Because they reflect short-run impacts and are based on studies performed when a larger portion of the population was transit-dependent, these values probably understate the long-run impacts of current price changes.

Table 1 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 in 1991 by the APTA.

Iseki and Ali (2014) used panel data of transit ridership and gasoline prices for ten selected U.S. urbanized areas over the time period of 2002 to 2011 to analyze the effect of gasoline prices on ridership of the four transit modes—bus, light rail, heavy rail, and commuter rail. Their analysis improves upon past studies on the subject, this study accounts for endogeneity between the supply of services and ridership, and controls for a comprehensive list of factors that may potentially influence transit ridership.

The analysis found varying effects, depending on transit modes and other conditions. Strong evidence was found for positive short-term effects only for bus and the aggregate: a 0.61-0.62% ridership increase in response to a 10% increase in current gasoline prices (elasticity of 0.061 to 0.062). The long-term effects of gasoline prices, on the other hand, was significant for all modes and indicated a total ridership increase

ranging from 0.84% for bus to 1.16% for light rail, with commuter rail, heavy rail, and the aggregate transit in response to a 10% increase in gasoline prices. The effects at the higher gasoline price level of over \$3 per gallon were found to be more substantial, with a ridership increase of 1.67% for bus, 2.05% for commuter rail, and 1.80% for the aggregate for the same level of gasoline price changes. Light rail shows even a higher rate of increase of 9.34% for gasoline prices over \$4. In addition, a positive threshold boost effect at the \$3 mark of gasoline prices was found for commuter and heavy rails, resulting in a substantially higher rate of ridership increase

After a detailed review of international studies, Goodwin (1992) produced the average elasticity values summarized in Table 2. 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). Nelson, et al (2006) found similar values in their analysis of Washington DC transit demand. Nijkamp and Pepping (1998) found elasticities in the -0.4 to -0.6 range in a meta-analysis of European transit elasticity studies.

Table 2 Transportation Elasticities (Goodwin 1992)

	Short-Run	Long-Run	Not Defined
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
Petrol consumption WRT petrol price	-0.27	-0.71	-0.53
Traffic levels WRT petrol price	-0.16	-0.33	

This table summarizes international transportation elasticities. Note that long-run effects (more than one year) are typically about twice short run effects. ("WRT" = With Respect To).

Dargay and Hanly (1999) studied the effects of UK transit bus fare changes over several years to derive the elasticity values summarized in Table 3. They used a dynamic econometric model (separate short- and long-run effects) of per capita bus patronage, per capita income, bus fares and service levels. 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.

Table 3 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 major 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. Table 4 summarizes their findings.

Table 4 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 generally easiest to use and most common. Semi-log 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 they may result in exaggerated elasticity values. For typical fare changes, between 10% and 30%, log-log and semi-log functions provide similar results, so either can be used.

Lee, Han and Lee (2009) found long-run elasticities of 0.25 for subway passenger trips and 0.32 for subway passenger kilometers with respect to fuel prices in Seoul, Korea between 2000 and 2008. Tsai, Mulley and Clifton (2014) used the Sydney Household Travel Survey data to identify public transport demand elasticities using a pseudo panel data approach. They estimate that Sydney’s public transport price elasticity is –0.22 in the short run and –0.29 in the long run.

Table 5 summarizes fare elasticities for the CityRail urban rail transit system in Sydney, Australia. These are considered short- and medium-run elasticity values. *Conditional fare elasticities* refer to a situation where all CityRail fare levels are simultaneously increased by the same proportion. Under these circumstances, there are no ‘within mode’ transfers between ticket types as relative prices remain unchanged. Accordingly, these estimates reflect transfers to/from competing private and public modes and

suppressed/generated journeys depending on the direction of the fare change. *Own-price elasticities* refers to a situation where individual fare levels change but all other CityRail fare levels remain constant so some travelers may change to alternative CityRail ticket types.

Table 5 Estimated Sydney CityRail Fare Elasticities (Booz & Co 2008)

Ticket Type	Conditional	Own Price
Single (Return)	-0.48	-0.56
Off-Peak Return	-0.23	-0.30
RailPass/FlexiPass	-0.28	-0.47
TravelPass	-0.12	-0.39
Total	-0.29	Not Applicable

Table 6 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 6 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 transit fare elasticities disaggregated by rider and trip factors, which can be very useful for many types of transit and transport planning.

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 bus riders have elasticities of -0.30 during peaks -0.46 during off-peaks, while rail riders have elasticities of -0.10 during peaks and -0.46 off-peak. Fare elasticities may be relatively high on routes where travelers have viable alternatives, such as for suburban rail systems where most riders are discretionary.

Commuter transit pass programs, in which employers subsidize transit passes, can significantly increase ridership (Commuter Check, Commuter Choice). Deep Discount passes can encourage occasional riders to increase transit use or avoid ridership losses if implemented when fares are increasing (Oram and Stark, 1996). Many campus UPass programs, which provide free or discounted transit fares to students and staff, have been quite successful, often doubling or tripling the portion of trips made by transit, because college students tend to be relatively price sensitive (Brown, Hess and Shoup 2001).

Holmgren (2007) used meta-regression to explain the wide variation in elasticity estimates obtained in previous demand studies. He calculated short-run U.S. elasticities with respect to fare price (-0.59), level of service (1.05), income (-0.62), price of petrol (0.4) and car ownership (-1.48). The analysis indicates that commonly-used elasticity estimates treat transit service quality as an exogenous variable, which reduces analysis accuracy, and recommends that demand models include car ownership, price of petrol, own price, income and some measure of service among the explanatory variables, and that the service variable be treated as endogenous.

Table 7 summarizes travel demand elasticities developed for use in Australia, based on a review of various national and international studies. These standardized values are used for various transport planning applications throughout the country, modified as appropriate to reflect specific conditions.

Table 7 Australian Travel Demand Elasticities (Luk & Hepburn 1993)

Elasticity Type	Short-Run	Long-Run
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
Petrol consumption and petrol price	-0.12	-0.58
Travel level and petrol price	-0.10	

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

Service Elasticities

Service elasticities indicate how transit ridership is affected by transit service quality factors such as convenience, frequency, speed and comfort (Kittleston & Associates, 2013; Phillips, Karachepone and Landis 2001; Greer and van Campen 2011).

Pratt (1999) finds that new bus service in a community with no previous transit service typically achieves 3 to 5 annual rides per capita, with 0.8 to 1.2 passengers per bus-mile. The elasticity of transit service expansion (routes into new parts of a community) is typically 0.6 to 1.0, meaning that each 1% of additional transit vehicle-miles or vehicle-

hours increases ridership 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, with greater effects where service is infrequent. There is a wide variation in these factors, depending on 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. On the other hand, some service increases result in little additional ridership. It usually takes 1 to 3 years for new routes to reach their full potential ridership.

Portland, Oregon's *Streamline* program includes various transit operational improvements that improved service quality on designated Frequent Service routes (Koonce, et al. 2006). Between 1999 and 2005, vehicle-hours allocated to the twelve streamlined routes increased 16.3% and ridership on those routes increased 18.2%, while the number of vehicle-hours allocated to non-Frequent Service routes decreased 2.4% and ridership on those routes decreased 0.7%. This indicates an elasticity of 1.11 for the streamlined routes, that is, ridership increased proportionately more than the amount of service added. The change in ridership on the non-Frequent Service routes corresponds to an elasticity of 0.30; that is, each 1% change in service hours caused a 0.3% change in ridership. This elasticity is typical for urban systems with routes operating at 30-minute or better headways. Brechan (2017) evaluated the long-run effects on ridership of 89 Norwegian transit projects. The results indicate that increased service frequency tends to increase transit ridership more than fare price reduction projects

Approximately 35% more bus rapid transit (BRT) service is needed compared with rail service to attract the same peak-period ridership, indicating that rail passengers accept more crowding than bus passengers (Demery and Higgins, 2002). Improved marketing, schedule information, easy-to-remember departure times, and more convenient transfers can also increase transit use, particularly in areas where service is less frequent (Turnbull and Pratt 2003). Voith (1991) found that, as with monetary price elasticities, service elasticities tend to increase over time. He concludes, "The findings suggest that reductions in public transportation subsidies that result in higher fares and lower service quality may produce higher subsidy costs per rider than would be the case with higher total subsidy. Thus, the results from this analysis support the common public perception that raising public transit fares and reducing service simply reduce ridership, requiring further fare increases and service cuts."

Multi-Modal Models

Some researchers use elasticity and cross-elasticity data to create models that predict how various combinations of changes in transit services and fares, and vehicle operating costs, would affect transit ridership and automobile travel, and therefore their ability to help achieve strategic planning objectives such as congestion and emission reductions.

The METS (MEtropolitan Transport Simulator, IFS, 2001) is an urban transport demand simulation model available on the Internet (<http://vla.ifs.org.uk/models/mets22.html>). METS was developed in the early 1980s for use by the UK Department of Transport, and updated in 2000. It allows users to predict the changes in transit and automobile travel that would result from changes in transit service quality, frequency, fares and car costs.

Hensher developed a model of cross-elasticities between various forms of transit and car use, illustrated in Table 8. This type of analysis can be used to predict the effects that transit fare changes will have on vehicle traffic, and the effect that road tolls or parking fees will have on transit ridership. Such models tend to be sensitive to specific demographic and geographic conditions and so must be calibrated for each area.

Table 8 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 changes in transit fares and car operating costs affect transit and car travel demand. For example, a 10% single fare train ticket increase 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.

The Congressional Budget Office used highway traffic count data to conclude that fuel price increases can cause modal shifts (CBO 2008). They find that a 20% gasoline price increase reduces traffic volumes on highways with parallel rail transit service by 0.7% on weekdays and 0.2% on weekends, with comparable increases in transit ridership, but find no traffic reductions on highways that lack parallel rail service. Currie and Phung (2008) found that in Australia, the cross elasticity of transit ridership with respect to fuel prices are 0.22, with higher values for high quality transit (Rail/BRT) and for longer-distance travel, and lower values for basic bus service and shorter-distance trips.

TRACE (1999) provides detailed elasticity and cross elasticity estimates for various types of travel (car-trips, car-kilometers, transit travel, walking/cycling, commuting, business,

etc.) and conditions, based on numerous European studies. Comprehensive sets of elasticity values such as these can be used to model the travel impacts of various combinations of price changes, such as a reduction in transit fares combined with an increase in fuel taxes or parking fees. 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, depending on regional vehicle ownership. This declining elasticity value is unique to fuel, because fuel price increases cause motorists to purchase more fuel efficient vehicles. Table 9 summarizes elasticities of trips and kilometers with respect to fuel prices in areas with high vehicle ownership (more than 450 vehicles per 1,000 population).

Table 9 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
<i>Total</i>	<i>-0.19</i>	<i>+0.16</i>	<i>+0.13</i>	<i>+0.13</i>
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
<i>Total</i>	<i>-0.29</i>	<i>+0.15</i>	<i>+0.14</i>	<i>+0.13</i>

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.

Table 10 Parking Price Elasticities (TRACE 1999, Tables 32 & 33)

Term/Purpose	Car Driver	Car Passenger	Public Transport	Slow mode
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
<i>Total</i>	<i>-0.16</i>	<i>+0.03</i>	<i>+0.02</i>	<i>+0.03</i>
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
<i>Total</i>	<i>-0.07</i>	<i>+0.02</i>	<i>+0.01</i>	<i>+0.03</i>

Slow Modes = Walking and Cycling

WRT = With Respect To

This table indicates how parking prices affect travel by automobile, public transit and slow modes.

Frank, et al. (2008) evaluate the effects of relative travel time on mode choice. They find that, walking and biking will be used for shorter trips, such as travel to local stores and mid-day tours from worksites if services are nearby, and rates of transit use are more sensitive to changes in travel time than fare levels, with wait time much more “costly” than in-vehicle time. Their analysis suggests that a considerable growth in transit ridership could be achieved through more competitive travel times on transit.

Parking prices and 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. Table 11 shows how parking prices affects travel in a relatively automobile-oriented urban region.

Table 11 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
<i>Park & Ride</i>	<i>0.363</i>	<i>0.136</i>	<i>0.029</i>
<i>Ride Public Transit</i>	<i>0.291</i>	<i>0.104</i>	<i>0.023</i>
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.

Hensher and King (1998) calculate elasticities and cross-elasticities for various forms of transit fares and automobile travel in central Sydney, Australia, as summarized in Table 12. Fearnley and Bekken (2005) summarize elasticity research and calculate the ratio of short- to long-run effects, as summarized in Table 12.

Table 12 Transit Elasticities (Fearnley and Bekken 2005)

	Short-run Elasticity	Long-run Elasticity	Long-Run/Short-Run
Service Level, Local Public Transport	0.43	0.75	1.84
Fare Level, Local Public Transport	-0.44	-0.76	1.92
Fare Level, Train/Metro	-0.61	-0.98	1.59
<i>Average Ratio long-run/short-Run</i>			<i>1.84</i>

Fehr & Peers (2004) develop “Direct Ridership Models” for predicting the effects of various changes on transit ridership, based on regression analysis of various North American transit systems. Table 13 provides examples of their results.

Table 13 **Impacts on Transit Ridership** (Fehr & Peers 2004)

Given a 100% Increase In	Expect Ridership Increase
Population and employment within ½ mile of transit station.	23%
Population within station catchment.	2%
Number of peak period trains.	48%
Peak-period feeder buses.	29%
Parking spaces.	4%

This table shows how various transit system changes affect transit ridership.

Currie and Justin Phung (2007) calculated the aggregate cross-elasticity of US transit demand with respect to fuel price (e) to be 0.12, indicating that transit demand increases 1.2% for every 10% gas price increase. US light rail is particularly sensitive to gas prices, with values for (e) measured at 0.27 to 0.38. Bus ridership is only slightly sensitive to gas prices ($e= 0.04$) and heavy rail is higher (0.17) which is consistent with most international evidence. A longitudinal model suggests some acceleration in transit mode sensitivity.

Mattson (2008) analyzed fuel price increase impacts on transit ridership in U.S. cities. He found longer-run elasticities of transit ridership with respect to fuel price are 0.12 for large cities, 0.13 for medium-large cities, 0.16 for medium-small cities, and 0.08 for small cities. These values are similar to previous estimates from other studies. For large and medium-large cities, the response is fairly quick, mostly occurring within one or two months after the price change, while for medium and small cities, the effects take five to seven months. The quicker response in larger cities may be explained by the fact that large city residents are generally more accustomed to public transport and so are quicker to shift mode than in smaller cities where transit use is uncommon. The elasticity is lowest for the smallest cities, indicating that people in small urban or rural areas are less likely to switch to transit. Medium-small cities have the highest response.

Lane (2008) analyzed the relationships between fluctuations in gas prices and transit ridership in nine U.S. cities between June 2001 and September 2006. He found a statistically strong positive relationship, particularly in cities with rail transit systems. He developed a model which predicts how much transit demand would increase given a particular increase in fuel prices, as summarized in Table 14.

Table 14 Fuel Price Impacts on Transit Ridership (Lane 2008)

City	\$4.00		\$5.00		\$6.00	
	Fuel	Transit	Fuel	Transit	Fuel	Transit
Los Angeles	20.65%	6.21%	43.13%	14.36%	65.99%	23.97%
Chicago	22.26%	8.72%	45.03%	18.94%	68.21%	30.27%
Boston	29.11%	6.53%	53.16%	14.49%	77.63%	23.44%
San Francisco	23.82%	3.76%	46.89%	9.68%	70.36%	17.07%
Miami	26.65%	10.88%	50.24%	23.70%	74.25%	37.93%
Seattle	29.27%	10.31%	53.35%	22.66%	77.85%	36.50%
Houston	36.57%	12.24%	62.01%	26.15%	87.90%	41.31%
Denver	29.20%	17.97%	53.26%	35.70%	77.75%	53.50%
Cleveland	36.82%	18.67%	62.31%	36.83%	88.24%	54.91%

This table indicates the percentage increases in fuel prices and transit ridership that can be expected from \$4.00, \$5.00 and \$6.00 fuel prices in various U.S. cities.

APTA (2011) used data from previous studies and recent experience by U.S. transit agencies to evaluate how transit ridership would grow in response to increased fuel prices. Regular gasoline prices increased 35% from \$3.053 per gallon on 31 December 2007 to a peak of \$4.114 on 7 July 2008, then declined 61% to \$1.613 on 27 December 2008. Transit ridership increased during this period, with a 3.42% increase during the first quarter, 5.19%, and 6.52% during the third quarter, indicating a lag between fuel price and transit ridership changes. Based on this research they developed a model that predicts how annual transit ridership is expected to increased using low, average, and high elasticity values.

Haire and Machemehl (2007) found similar results. Analyzing ridership in five U.S. cities they found statistically significant correlation between ridership and fuel prices, suggesting that rising fuel prices increased transit use in historically auto-oriented American cities. They estimate that, on average, a one percent fuel price rise increases transit demand approximately 0.24 percent, or approximately 0.09 percent ridership gain for each additional cent of fuel price. Maley and Weinberger (2009) found that in Philadelphia, fuel price increases had a larger effect on regional rail ridership (0.27 to 0.38 elasticities) than on local bus ridership (0.15 to 0.23 elasticities), probably due to a larger portion of rail riders being discretionary transit users who have the option of driving, and so are more likely to do so when fuel prices decline.

Blanchard (2009) used regional gasoline prices, transit ridership and supply data from 218 US cities from 2002 to 2008 to estimate the cross elasticity of demand for four transit modes with respect to gasoline price. The results indicate that the cross-price elasticity of transit demand with respect to gasoline price ranges from -0.012 to 0.213 for commuter rail, -0.377 to 0.137 for heavy rail, -0.103 to 0.507 for light rail, and 0.047 to 0.121 for bus. The values vary significantly between cities, but are not highly correlated with urban population size, and the cross-price elasticity increased over this time period for commuter rail, light rail, and motorbus transit.

Jung, et al. (2016) used a data set of debit and credit card transactions in Korea to examine the effect of gasoline prices on individual choices between private vehicle and public transit travel. The study found significant heterogeneity, with some people being much more price sensitive than others.

Brand (2009) found that the 20% 2007 to 2008 U.S. fuel price increase caused a 3.5% VMT reduction, indicating a short-run price elasticity ranging from -0.12 to -0.17. Accounting for base trends (between 1983 and 2004 VMT increased about 2.9% annually and gasoline consumption increased about 1.2% annually, reflecting population, income and GDP growth) the short-run VMT fuel price elasticity ranged from -0.21 to -0.30. During this period, transit ridership increased about 4%. This increase was widespread, with 86% of transit agencies reporting ridership increases. Comparing the transit ridership increase to VMT decline indicates that only about 5% of the reduced vehicle travel shifted to transit, although this shift was much greater in major cities with high quality public transit services. For example, in New York City traffic declined 6.3% through the Lincoln and Holland Tunnels, and more than 7% on four major bridges. Greer and van Campen (2011) found that each 1% reduction in cars per household increases public transit ridership about 0.763% in Auckland, New Zealand.

The Puget Sound *Traffic Choices Study* measured how the travel behavior of 275 volunteer motorists responded to road pricing (PSRC 2005). Each participant was given a \$1,016 debit account. A meter similar to those used in taxis was installed in their car and which tracked where and when they drive and subtracted tolls that varied depending on time and location. Participants made numerous travel changes in response to this price incentive, including changes in trip time, route, frequency and distance. Overall, total vehicle travel declined about -0.12, although impacts varied due to various factors. The elasticity of Home-to-Work travel averaged approximately -0.04 overall, but was four times higher (-0.16) for workers with the best public transit service, indicating that the cross-elasticity of vehicle travel with respect to price is affected by transit service quality.

Conclusions and Recommendations

An important conclusion of this research is that 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.

Available evidence suggests that the elasticity of transit ridership with respect to fares is usually in the -0.2 to -0.5 range in the short run (first year), and increases to -0.6 to -0.9 over the long run (five to ten years). These are affected by the following factors:

- Transit price elasticities are lower for transit dependent riders than for discretionary (“choice”) riders.
- Elasticities are about twice as high for off-peak and leisure travel as for peak and commute travel.
- 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).
- A relatively large fare reduction is generally needed to attract motorists to transit, since they are discretionary riders. Such travelers may be more responsive to service quality (speed, frequency and comfort), and higher automobile operating costs through road or parking pricing.
- Due to variability and uncertainty it is preferable to use ranges rather than point values for elasticity analysis.

Commonly used transit elasticity values primarily reflect short- and medium-run impacts and are based on studies performed 10-40 years ago, when real incomes were lower and a greater portion of the population was transit dependent. The resulting elasticity values may be appropriate for predicting how a change in transit fares or service will affect next year’s ridership and revenue, but long-run elasticity values are more appropriate for strategic planning. Conventional traffic models that use standard elasticity values based on short-run price effects tend to understate the potential of transit fare reductions and service improvements to reduce problems such as traffic congestion and vehicle pollution. Conversely, these models will understate the long-term negative impacts that fare increases and service cuts can have on transit ridership, transit revenue, traffic congestion and pollution emissions.

In most communities (particularly outside of large cities) transit dependent people are a relatively small portion of the total population, while discretionary riders (people who have the option of driving) are a potentially large but more price sensitive market segment. As a result, increasing transit ridership requires pricing and incentives that attract travelers out of their car. Combinations of fare reductions and discounted passes, higher vehicle user fees (such as priced parking or road tolls), improved transit

service, and better transit marketing can be particularly effective at increasing transit ridership and reducing automobile use (Brechan 2017).

Transit planners generally assume that transit is price inelastic (elasticity values are less than 1.0), so fare increases and service reductions increase net revenue. This tends to be true in the short-run (less than two years), but long-run elasticities approach 1.0, so financial gains decline over time.

Not all of the increased transit ridership that results from fare reductions and service improvements represents a reduction in automobile travel. Much of this additional ridership may substitute for walking, cycling or rideshare trips, or consist of absolute increases in total personal mobility. In typical situations, a quarter to half of increased transit ridership represents a reduction in automobile travel, but this varies considerably depending on specific conditions.

Table 15 summarizes recommended generic values based on this research. These values reflect the results of numerous studies, presented in a format to facilitate their application in typical transport planning situations. High and low values are presented to allow sensitivity analysis, or a midpoint value can be used. Actual elasticities vary depending on circumstances, so additional review and research is recommended to improve and validate these values, and modify them to specific situations.

Table 15 Recommended 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 recommended values resulting from this study. These values should be modified as appropriate to reflect specific conditions. (WRT = With Respect To)

References

Bhuiyan Alam, Hilary Nixon and Qiong Zhang (2015), *Investigating The Determining Factors For Transit Travel Demand By Bus Mode In Us Metropolitan Statistical Areas*, Mineta Transportation Institute (<http://transweb.sjsu.edu>); at <http://transweb.sjsu.edu/PDFs/research/1101-transit-bus-demand-factors-in-US-metro-areas.pdf>.

APTA (2008), *Rising Fuel Costs: Impacts on Transit Ridership and Agency Operations: Survey Results*, American Public Transportation Association (www.apta.com); at www.apta.com/resources/reportsandpublications/Documents/fuel_survey_0809.pdf.

APTA (2011), *Potential Impact of Gasoline Price Increases on U.S. Public Transportation Ridership, 2011 -2012*, American Public Transportation Association (www.apta.com); at <http://tinyurl.com/cuy2hl7>.

Christopher Blanchard (2009), *The Impact of Rising Gasoline Prices on US Public Transit Ridership*, Masters Thesis, Duke University; at <http://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/1379/Blanchard,%20Christopher.pdf;jsessionid=CFD50E95C8DC8F6F35783C67FEF302BE?sequence=1>.

Booz Allen Hamilton (2003), *ACT Transport Demand Elasticities Study*, Canberra Department of Urban Services (www.actpla.act.gov.au/plandev/transport/ACTElasticityStudy_FinalReport.pdf).

Booz Allen Hamilton (2008), *CityRail Fare Elasticities*, Independent Pricing and Regulatory Tribunal (www.ipart.nsw.gov.au); at www.ipart.nsw.gov.au/files/CityRail%20fare%20elasticities%20-%20Booz%20-%20website%20final%20document%20%20June%202008.PDF.

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

Inge Brechan (2017), "Effect of Price Reduction and Increased Service Frequency on Public Transport Travel," *Journal of Public Transportation*, Vol. 20, No. 1 (<http://scholarcommons.usf.edu/jpt>); at <http://scholarcommons.usf.edu/jpt/vol20/iss1/8>.

Jeffrey Brown, Daniel Hess and Donald Shoup (2001), "Unlimited Access," *Transportation*, Volume 28, number 3, 2001, pp. 233-267; at UCLA Institute of Transportation Studies website: www.spsr.ucla.edu/res_ctrs/its/UA/UA.pdf.

BTE, *Transport Elasticities Database Online*, Bureau of Transportation Economics (www.dynamic.dotrs.gov.au/bte/tedb/index.cfm). This website contains approximately 200 separate bibliographic references and 400 table entries, from international literature on transportation elasticities.

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

Cynthia Chen, Don Varley and Jason Chen (2011), "What Affects Transit Ridership? A Dynamic Analysis Involving Multiple Factors, Lags and Asymmetric Behavior," *Urban Studies*, Vol. 48, No. 9, July, pp. 1893-1908.

Chun-Hung Peter Chen and George A. Naylor (2011), "Development of a Mode Choice Model for Bus Rapid Transit in Santa Clara County, California," *Journal of Public Transportation*, Vol. 14, No. 4 (www.nctr.usf.edu); at www.nctr.usf.edu/wp-content/uploads/2011/12/JPT14.4.pdf.

Harry Clements (1997), "A New Way to Predict Transit Demand," *Mass Transit*. July, pp. 49-52.

Graham Currie and Justin Phung (2007), *Transit Ridership, Auto Gas Prices and World Events – New Drivers of Change?*, Transportation Research Board Annual Meeting (www.trb.org).

Graham Currie and Justin Phung (2008), *Understanding Links Between Transit Ridership and Automobile Gas Prices: U.S. and Australian Evidence*, Transportation Research Board 87th Annual Meeting (www.trb.org).

Joyce Dargay and Mark Hanly (1999), *Bus Fare Elasticities*. ESRC Transport Studies Unit, University College London, (www.ucl.ac.uk).

Joyce Dargay, Mark Hanly, G. Bresson, M. Boulahbal, J.L. Madre and A. Pirotte (2002), *The Main Determinants of the Demand for Public Transit: A Comparative Analysis of Great Britain and France*, ESRC Transport Studies Unit, University College London (www.ucl.ac.uk).

Gerard de Jong and Hugh Gunn (2001), "Recent Evidence on Car Cost and Time Elasticities of Travel Demand in Europe," *Journal of Transport Economics and Policy*. Vol. 35/2, May, pp. 137-160.

Leroy W. Demery and J. Wallace Higgins (2002), *Rapid Bus and Rapid Rail: Peak Period Service Supply vs. Observed Passenger Utilization*, PublicTransit.Us (www.publictransit.us).

DFT (2006), *Transport Analysis Guidance*, Integrated Transport Economics and Appraisal, Department for Transport (www.webtag.org.uk/index.htm).

Nils Fearnley and Jon-Terje Bekken (2005), *and Long-Run Demand Effects in Transport: A Literature Review*, Institute of Transport Economics (TØI) of the Norwegian Centre for Transport Research (www.toi.no/attach/a1274456r371471/Summary_802_05.pdf).

Fehr & Peers (2004), *Direct Ridership Forecasting: Out of the Black Box*, Fehr & Peers (www.fehrandpeers.com).

Lawrence Frank, et al. (2008), "Urban Form, Travel Time, And Cost Relationships With Tour Complexity And Mode Choice," *Transportation*, Vol. 35, No. 1, January, pp. 37-54; at www.springerlink.com/content/9228326786t53047.

FTA (2001), *National Transit Summaries and Trends*, Federal Transit Administration (www.fta.gov); at [www.ntdprogram.com/NTD/NTST.nsf/NTST/2001/\\$File/01NTST.pdf](http://www.ntdprogram.com/NTD/NTST.nsf/NTST/2001/$File/01NTST.pdf).

David Gillen (1994), "Peak Pricing Strategies in Transportation, Utilities, and Telecommunications: Lessons for Road Pricing." *Curbing Gridlock*. TRB (www.trb.org), pp. 115-151.

Phil Goodwin (1992), "Review of New Demand Elasticities With Special Reference to Short and Long Run Effects of Price Changes," *Journal of Transport Economics*, Vol. 26, No. 2, May, pp. 155-171.

Mark R. Greer and Bart van Campen (2011), "Influences on Public Transport Utilization: The Case of Auckland," *Journal of Public Transportation*, Vol. 14, No. 2, pp. 51-68; at www.nctr.usf.edu/wp-content/uploads/2011/07/JPT14.2.pdf.

Ashley R. Haire and Randy B. Machemehl (2007), "Impact of Rising Fuel Prices on US Transit Ridership," *Transportation Research Record 1992*, TRB (www.trb.org), pp. 11-19; at <http://pubsindex.trb.org/view.aspx?id=802405>.

Hagler Bailly (1999), *Potential for Fuel Taxes to Reduce Greenhouse Gas Emissions from Transport*, Transportation Table of the Canadian National Climate Change Process (www.tc.gc.ca/Envaffairs/subgroups1/fuel_tax/study1/final_Report/Final_Report.htm).

Lawrence Harrell (1990), *The Effect of Intangible Product Attributes on Rail Passenger Demand with Special Reference to Ride Quality*, PhD Thesis, Centre For Transport Studies; Cranfield Institute Of Technology, BNR Consulting (www.demandanalysis.co.uk).

David A. Hensher (1997), *Establishing a Fare Elasticity Regime for Urban Passenger Transport: Non-Concession Commuters*, Working Paper, ITS-WP-97-6, Institute of Transport Studies, University of Sydney (www.itls.usyd.edu.au).

David A. Hensher (2008), "Assessing Systematic Sources of Variation in Public Transport Elasticities: Some Comparative Warnings," *Transportation Research A*, Vol. 42, Issue 7 (www.elsevier.com/locate/tra), pp. 1031-1042.

David A. Hensher and Jenny King (1998), "Establishing a Fare Elasticity Regime for Urban Passenger Transport: Time-Based Fares for Concession and Non-Concession Market Segments by Trip Length," *Journal of Transportation And Statistics*, Vol. 1, No. 1, Bureau of Transportation Statistics (www.bts.gov), January 1998, pp. 43-61.

David A. Hensher and Jenny King (2001), "Parking Demand and Responsiveness to Supply, Price and Location in Sydney Central Business District," *Transportation Research A*, Vol. 35, No. 3 (www.elsevier.com/locate/tra), March 2001, pp. 177-196.

Johan Holmgren (2007), "Meta-analysis of Public Transit Demand," *Transportation Research Part A: Policy and Practice*, Volume 41, Issue 10, Dec. 2007, pp. 1021-1035.

IFS, *Virtual Learning Arcade – London Transport*, Institute for Fiscal Studies (www.ifs.org.uk), 2001; at <http://vla.ifs.org.uk/models/mets22.html>. For technical information see Tony Grayling and Stephen Glaister, *Tackling Traffic Congestion: More about the METS Model* (www.bized.ac.uk/virtual/vla/transport/index.htm). *A New Fares Contract for London*. Institute for Public Policy Research (www.ippr.org.uk), ISBN 1 86030 100 2, 2000.

Hiroyuki Iseki and Rubaba Ali (2014), *Net Effects Of Gasoline Price Changes On Transit Ridership In U.S. Urban Areas*, Report 12-19, Mineta Transportation Institute (<http://transweb.sjsu.edu>); at <http://transweb.sjsu.edu/PDFs/research/1106-gas-price-changes-and-transit-ridership.pdf>.

Hojin Jung, et al. (2016), "Investigating the Effect of Gasoline Prices on Transit Ridership and Unobserved Heterogeneity," *Journal of Public Transportation*, Vol. 19, No. 4, pp. 56-74 (DOI: <http://dx.doi.org/10.5038/2375-0901.19.4.4>); at: <http://scholarcommons.usf.edu/jpt/vol19/iss4/4>.

Kittleson & Associates (2013), *Transit Capacity and Quality of Service Manual – Third Edition*, TCRP Web Document 165, Transit Cooperative Research Program, TRB (www.trb.org); at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_165fm.pdf.

Peter Koonce, Paul Ryus, David Zagel, Young Park and Jamie Parks (2006), "An Evaluation of Comprehensive Transit Improvements—TriMet's Streamline Program," *Journal of Public Transportation*, Vol. 9, No. 3, (www.nctr.usf.edu/jpt), pp. 103-115; at www.nctr.usf.edu/jpt/pdf/JPT%209-3S%20Koonce.pdf.

Richard J. Kuzmyak, Rachel Weinberger and Herbert S. Levinson (2003), *Parking Management and Supply: Traveler Response to Transport System Changes, Chapter 18*, Report 95, Transit Cooperative Research Program; Transportation Research Board (www.trb.org).

Sarah J. LaBelle and Daniel Fleishman (1995), *Common Issues In Fare Structure Design*, Federal Transit Administration (www.fta.dot.gov/library/technology/symops/LABELLE.htm).

Armando Lago, Patrick Mayworm and Jonathan McEnroe (1992), "Transit Ridership Responsiveness to Fare Changes," *Traffic Quarterly*. Vol. 35, No. 1, January 1992.

Bradley W. Lane (2008), *Gasoline Costs, Public Transit, And Sustainability*, Peer Reviewed Conference Paper, Berkeley Electronic Press (<http://works.bepress.com>); at <http://works.bepress.com/bradleywane/8>.

Bradley W. Lane (2012), "A Time-Series Analysis of Gasoline Prices and Public Transportation in U.S. Metropolitan Areas," *Journal of Transport Geography*, Vol. 22, May, pp. 221–235; summary at www.sciencedirect.com/science/article/pii/S0966692311001578.

Bradley W. Lane (2012), *Modeling Urban Transit Ridership in Repeated Cross Sections: What is the Role of Gasoline Prices in Transit Demand?*, Working Paper 05-2012, University of Texas at El Paso (<http://academics.utep.edu>); at <http://academics.utep.edu/Portals/1890/Lane%20wp5-2012%20modeling%20transit%20ridership.pdf>.

Jaimin Lee, Sangyong Han and Chang-Woon Lee (2009), *Oil Price and Travel Demand*, Korea Transport Institute (<http://english.koti.re.kr>).

Todd Litman (2006), *Transportation Elasticities: How Prices and Other Factors Affect Travel Behavior*, Victoria Transport Policy Institute (www.vtppi.org); at www.vtppi.org/elasticities.pdf.

Todd Litman (2012), "Changing North American Vehicle-Travel Price Sensitivities: Implications For Transport and Energy Policy" *Transport Policy*

(<http://dx.doi.org/10.1016/j.tranpol.2012.06.010>); full report at www.vtppi.org/VMT_Elasticities.pdf.

James Luk and Stephen Hepburn (1993), *New Review of Australian Travel Demand Elasticities*, Australian Road Research Board (www.arrb.org.au).

Donald W. Maley and Rachel Weinberger (2009), "Rising Gas Price and Transit Ridership: Case Study of Philadelphia, Pennsylvania," *Transportation Research Record 2139*, Transportation Research Board (www.trb.org), pp. 183-188.

Donald W. Maley and Rachel Weinberger (2009), *Does Gas Price Fuel Transit Ridership?* PANORAMA, University of Pennsylvania; at www.design.upenn.edu/files/Panorama09_06_GasTransit_MaleyWeinberger.pdf.

Praveen Maghelal (2011), "Investigating The Relationships Among Rising Fuel Prices, Increased Transit Ridership, And CO2 Emissions," *Transportation Research Part D: Transport and Environment*, Vol. 16, (3), pp. 232-235; at www.worldtransitresearch.info/research/3712.

Jeremy Mattson (2008), *Effects of Rising Gas Prices on Bus Ridership for Small Urban and Rural Transit Systems*, Upper Great Plains Transportation Institute (www.ugpti.org); at www.ugpti.org/pubs/pdf/DP201.pdf; summarized in *Community Transportation*, Spring, pp. 38-41; at http://web1.ctaa.org/webmodules/webarticles/articlefiles/Effects_Rising_Gas_Prices_Transit_Ridership.pdf.

Brian E. McCollom and Richard Pratt (2004), *Transit Pricing and Fares*, Chapter 12, TCRP Report 95, Transit Cooperative Research Program, Transportation Research Board, Federal Transit Administration (www.trb.org/publications/tcrp/tcrp_rpt_95c12.pdf).

Gerrit R. Moore (2002), "Transit Rider Efficiency as a Function of Fares," *Journal of Public Transportation*, Vol. 5, No. 1, Spring 2002.

Multisystems (1997), *Coordinating Intermodal Transportation Pricing and Funding Strategies*, Research Results Digest, Transit Cooperative Research Program (www4.nationalacademies.org/trb/crp.nsf/All+Projects), TRB (www.trb.org).

Peter Nelson, Andrew Baglino, Winston Harrington, Elena Safirova and Abram Lipman (2006), *Transit in Washington, D.C.: Current Benefits and Optimal Level of Provision*, Resources for the Future (www.rff.org/rff/Documents/RFF-DP-06-21.pdf).

Peter Nijkamp and Gerard Pepping (1998), "Meta-Analysis for Explaining the Variance in Public Transport Demand Elasticities in Europe," *Journal of Transportation Statistics*, Vol. 1, No. 1, Jan., pp.1-14; at <http://ntl.bts.gov/lib/7000/7100/7104/nijkamp.pdf>.

Richard Oram and Stephen Stark (1996), "Infrequent Riders: One Key to New Transit Ridership and Revenue," *Transportation Research Record 1521*, TRB (www.trb.org), pp. 37-41.

Tae Hoon Oum, W.G. Waters II, and Jong-Say Yong (1992), "Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates," *Journal of Transport Economics*, May, pp. 139-154.

Neil Paulley, et al (2004), *Factors Affecting the Demand for Public Transport*, Association for European Transport; at www.etcproceedings.org/paper/download/1179.

Neil Paulley, et al (2006), "The Demand For Public Transport: The Effects of Fares, Quality Of Service, Income and Car Ownership," *Transport Policy*, Vol. 13, No. 4 (www.elsevier.com/locate/tranpol), July 2006, pp. 295-306.

Larry Pham and Jim Linsalata (1991), *Effects of Fare Changes on Bus Ridership*, American Public Transit Association (www.apta.com).

Rhonda Phillips, John Karachepone and Bruce Landis (2001), *Multi-Modal Quality of Service Project*, Florida Department of Transportation, Contract BC205; (www.dot.state.fl.us); at www.dot.state.fl.us/Planning/systems/sm/los/FinalMultiModal.pdf.

Richard H. Pratt (2004), *Traveler Response to Transportation System Changes*, TCRP Report B12-A, TRB (www.trb.org); at <http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1034>.

Richard Pratt and John Evans (2004), *Bus Routing and Coverage: Traveler Response to Transport System Changes*, Chapter 10; Report 95, Transit Cooperative Research Program; Transportation Research Board (www.trb.org); at http://gulliver.trb.org/publications/tcrp/tcrp_rpt_95c11.pdf.

PSRC (2005), *Traffic Choices Study*, Puget Sound Regional Council (<http://psrc.org>); at <http://psrc.org/assets/37/summaryreport.pdf>.

Brian D. Taylor, et al. (2004), *Analyzing the Determinants of Transit Ridership Using A Two-Stage Least Squares Regression On A National Sample Of Urbanized Areas*, Transportation Research Board Annual Meeting; at www.uctc.net/papers/682.pdf.

Brian D. Taylor and Camille Fink (2009), *The Factors Influencing Transit Ridership: A Review and Analysis of the Ridership Literature*, UCLA Department of Urban Planning, University of California Transportation Systems Center (www.uctc.net); at www.uctc.net/papers/681.pdf.

TRACE (1999), *Elasticity Handbook: Elasticities for Prototypical Contexts*, Prepared for the European Commission, Directorate-General for Transport, Contract No: RO-97-SC.2035, (www.hcg.nl/projects/trace/trace1.htm).

TRL (2004), *The Demand for Public Transit: A Practical Guide*, Transportation Research Laboratory, Report TRL 593 (www.trl.co.uk); at www.demandforpublictransport.co.uk and http://eprints.ucl.ac.uk/1349/1/2004_42.pdf.

Chi-Hong (Patrick) Tsai, Corinne Mulley and Geoffrey Clifton (2014), "A Review of Pseudo Panel Data Approach in Estimating Short-run and Long-run Public Transport Demand Elasticities," *Transport Reviews: A Transnational Transdisciplinary Journal*, Vol. 34, No. 1, pp. 102-121; www.tandfonline.com/doi/abs/10.1080/01441647.2013.875079#.UzxhGfldVqU.

Katherine F. Turnbull and Richard H. Pratt (2003), *Transit Information and Promotion: Traveler Response to Transport System Changes*, Chapter 11, Transit Cooperative Research Program Report 95; Transportation Research Board (www.trb.org).

Richard Voith (1991), "the Long-Run Elasticity of Demand for Commuter Rail Transportation, *Journal of Urban Economics*, Vol. 30, pp. 360-72.

Ian Wallis (2004), *Review of Passenger Transport Demand Elasticities*, Report 248, New Zealand Transport Agency (www.nzta.govt.nz); at www.nzta.govt.nz/resources/research/reports/248.

Judith Wang (2011), *Appraisal of Factors Influencing Public Transport Patronage*, Research Report 434, NZ Transport Agency (www.nzta.govt.nz); at www.nzta.govt.nz/resources/research/reports/434/docs/434.pdf.

Mark Wardman and Jeremy Shires (2003), *Review Of Fares Elasticities in Great Britain*, ITS Working Paper 573, Institute for Transport Studies, University of Leeds (www.its.leeds.ac.uk/working/downloads/WP573.pdf).

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