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Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review

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ABSTRACT *This paper gives the main results of a literature review of new empirical studies, published since 1990, updating work on the effects of price and income on fuel consumption, traffic levels, and where available other indicators including fuel efficiency and car ownership. The results are broadly consistent with several earlier reviews, though not always with current practice. The work was carried out as one of two parallel 'blind' literature reviews, the other being summarized in a companion paper by Graham and Glaister: the results are broadly, though not in every respect, consistent.*

Introduction

This is a companion paper to Graham and Glaister (2004). Both papers were commissioned by the UK Department of the Environment, Transport and the Regions (now called the Department for Transport), with the same project brief, but to be carried out separately and independently as a means of ensuring the robustness of the conclusions. The published versions were amended following sight of each other's draft reports, but these amendments were minor. The two projects identified an overlapping but not identical source literature, used different selection criteria when drawing from that literature, gave different weights to meta-analysis and to earlier literature reviews as source material. They had different emphases especially in relation to new evidence on freight (to which Graham and Glaister give greater attention) and to new evidence on traffic volumes and forecasting implications (to which the present paper gives greater attention). The core results are strongly consistent, but there are some interesting and illuminating differences.

Definitions

The present paper will not repeat the standard and well-rehearsed definitions and caveats relating to the estimation and use of demand elasticities, except in relation

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to the distinction made between short- and long-term effects. Dynamic methods of estimation are those—always using time series data—in which allowance is made for a progressive build-up of effects over an explicitly identified time scale. This is now standard in the fuel consumption literature and increasingly common in the traffic literature. Static (or equilibrium) methods are those—either using cross-section or time series data—in which there is no explicit allowance for any time scale of response, which their users hope relate to an end state, of indeterminate date, when all responses have been completed.

Using this definition, the distinctions between 'short term' and 'long term' are well-defined empirical results of the estimation, not assumptions based on conjectures about behaviour. Short term is defined as responses made within one period of the data used for the study, most commonly, in this context, within 1 year. Long term refers to the asymptotic end state when responses are (as close as may be estimated) completed, and might vary according to what sort of behaviour is under consideration: for much of the transport literature, periods of 5–10 years are estimated empirically, within which the greatest part of the response is in the first 3–5 years. The present authors do not support the common practice of using the phrases 'short term' and 'long term' as legitimate labels for either cross-section equilibrium models, or unlagged time series models, distinguished by whether they include big or small dimensions of behaviour, which has been common in the literature (and which was indirectly, but wrongly, applied in a previous literature review by Goodwin, 1992).

New Data

Published studies, confined to those carried out in the UK or other countries broadly comparable with the UK, were collected from academic journals, government reports, researchers and consultants (including, but not giving special attention to, studies carried out by the present authors). Although some attention was paid to old but previously unnoticed studies, these were few: the main emphasis was on papers published since the reviews carried out by Goodwin (1992) and Oum *et al.* (1992), which this exercise was intended to update, but not treating other cumulative reviews published during this period as independent source material. Altogether, 69 new empirical studies of this type were collected after filtering to ensure that the same results were not included more than once as a result of repeated publication in different forms or minor variants, or progressive updating of the same base material. (This often happens.) They were reinforced by a larger, and wider, literature adding other useful evidence, earlier reviews, etc., although these were not used as sources in their own right, and no literature review results were counted as data, since this would have double-counted the sources used. These 69 studies produced 175 different equations, containing 491 elasticities, based on data covering different periods spread over the 62 years from 1929 to 1991. Over 100 results dealt with fuel consumption, over 30 dealt with traffic levels, and others covered car sales and fuel efficiency. Nearly all were either for cars only, or for cars and lorries added together. At the aggregate level of interest to the review, there was very little evidence related to commercial traffic as a whole, and no region- and sector-specific freight studies were included.

The main properties of the database are summarized in Table 1.

Table 1. Properties of the 175 estimation equations

Property	Coverage
Geography	Countries included in the equations are the USA (*n* = 63), the UK (29), Canada (12), France (7), Germany (7), Belgium (6), OECD 12 countries (6) plus Denmark, Italy, the Netherlands, Austria, Sweden, Norway, Spain, Australia, Japan, specific US states and various multicountry groupings (1–4 each)
Data	Run from 1929 to 1998, with an average duration per study of 19 years (SD = 10 years); the mid-point of the data collected is 1974
Data type	Time series (*n* = 83), cross-section/time series (77), cross-section only (15)
Data interval	Annual (*n* = 145), quarterly (15), monthly (7) and other (15)
Dependent variable	Fuel consumption (*n* = 101), vehicle-km (34), vehicles (20), fuel efficiency (16) and other (4)
Type of vehicles/fuel	Cars (*n* = 141), cars plus trucks (29), other (5), petrol (92), petrol plus diesel (43), diesel only (1)
Equations and estimation	Static (*n* = 89), dynamic (86), constant elasticity (138), linear (26), other (8), ordinary least squares (113), full information maximum likelihood (19), generalized least squares (18) and other (19)

The full report by Hanly *et al.* (2002) from which this summary is drawn also includes new empirical statistical evidence for the UK, from which some of the findings of the literature review were checked, and a discussion of the indirect evidence in other published work, which, while not producing elasticities, nevertheless provided evidence on related responses such as induced and suppressed traffic. These results are not included here.

Methods of Analysis

It might seem unnecessary to state, but all the analysis was based on actually reading the original source studies, not summaries of them. After filtering for redundancy and repetition, all their relevant results were transferred onto a computer database. It was then used to calculate the range of results, the average and whether the results were different according to the methods, definitions and scope the original papers had used. Using a similar approach, it was then considered whether there were any definite patterns in the results, especially whether the elasticities had been changing over time, whether short-term effects were different from long-term effects, and whether differences in the elasticities found were themselves, in turn, influenced by combinations of other factors, and if so, which factors had the greatest influence. A meta-analysis was carried out, but it was not very useful. Finally, some of the patterns were checked by statistical analysis of the UK data to see if the same effects were noticed.

Main Results: An Overview

All the following figures are the average of quite a wide range of different answers. Nearly all the studies are ‘symmetrical’, i.e. they assume that the effects of a reduction are equal and opposite to the effects of an increase, both for price and income. There is some empirical evidence that this assumption might not be true, and the problem is particularly plausible if price rises induce changes in the car fleet through earlier scrappage of inefficient vehicles. Increased scrappage of fuel-inefficient vehicles for price rises would then not be balanced by an extra cheap available car stock for price falls.

Price Effects

Taking what were judged to be the best defined results, the overall picture implied is as follows. (According to the assumption of symmetry, all the statements might be reversed by replacing 'up' and 'down'.) If the real price of fuel rises by 10% and stays at that level, the result is a dynamic process of adjustment such that the following occur:

(a) Volume of traffic will fall by roundly 1% within about a year, building up to a reduction of about 3% in the longer run (about 5 years or so).
(b) 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.

The reason why fuel consumed falls by more than the volume of traffic is probably because price increases trigger a more efficient use of fuel (by a combination of technical improvements to vehicles, more fuel-conserving driving styles and driving in easier traffic conditions). A further probable differential effect is between high- and low-consumption vehicles, since with high prices, gas-guzzlers are more likely to be the vehicles left at home or scrapped.

Therefore, further consequences of the same price increase are as follows:

(c) Efficiency of the use of fuel rises by about 1.5% within a year, and around 4% in the longer run.
(d) Total number of vehicles owned falls by less than 1% in the short run, and by 2.5% in the longer run.

At face value, the 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. Attention is drawn to a strong caveat: many studies only assess the effects on car ownership, on traffic or on use per car, but not at the same time or when 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). At this stage, the authors' view is that the results *do* support the idea that the effects of prices on car ownership are important enough to take seriously, but are *not* necessarily such an overwhelmingly large part of the overall effect.

Income Effects

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.

- However, the volume of traffic does not grow in proportion: 2% within a year and about 5% in the longer run.

Taken together, these would imply that use per car declines as income increases, although (as with the price effect above) this depends on the comparison of different studies and is not yet well supported by direct evidence. (A small number of studies show a direct hint of this in the short run, but not in the long run.) It is possible that as incomes increase, successive new car owners are attracted into the car market who have less inclination to drive much. An additional effect implied is that rising income has generally been associated with a fall in the efficiency of the use of fuel, for which a possible reason might be that as incomes grow, people buy newer, but larger, vehicles. Such decisions can also raise the numbers of multiple cars per driver (e.g. 'sports' vehicles) in wealthy countries/households, while in poorer countries/households, it may be more associated with the first acquisition of cars by non-workers who typically use them less.

One strong, repeated and consistent result is that studies using methods that allow explicit estimation of short- and long-run elasticities separately nearly always find that the long-run effect is substantially higher than the short-run effect, for both price and income, and for all measures of demand.

The present authors did not have sufficient information in the studies to calculate an overall freight transport effect at the aggregate level separately, but there are three pieces of relevant evidence. First, the effects of a price increase for diesel plus petrol cause a smaller reduction in the total amount of fuel bought than for petrol alone. Second, the effect of an overall fuel price increase has a smaller effect on the total traffic level (including lorries) than petrol prices have on the private car traffic. Third, as Graham and Glaister show, results of studies in particular freight sectors must also imply an aggregate effect. However, there are reasons to suppose that the influence of price on freight operators' decisions can be different from those affecting individuals, in particular because commercial vehicle operators are less likely to ignore or misperceive categories of cost such as labour, depreciation, etc., and because freight costs are part of a wider production and distribution process. These considerations mean that the direct fuel costs are likely to be a smaller proportion of (perceived) total costs for freight than for passenger transport.

Although not all goods vehicles use diesel and not all cars use petrol, these results taken together suggest that goods traffic is less sensitive to price, and private cars more sensitive. The difference is large enough to be important, but not well defined enough in the data to provide a definite figure, because the proportion of lorries and cars varies greatly, but is not recorded in most studies.

The same is not true for effects of changes in income, for which the effect on personal transport and goods transport seems to be rather similar in size.

Sources of Variation in Elasticities

Certain features are now well established and can be taken as strong results. These relate to the differences between elasticities based on traffic or fuel consumption, the effect of dynamic process, and the relative size of income and price effects:

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

Espey (1998) carried out a meta-analysis using linear regression to investigate 32 potential causes of variation in the estimated elasticity coefficients for fuel consumption, including measures of demand specification, data characteristics, geographical and other contexts, and estimation technique. These factors together explained between one-quarter and one-third of the variation found in the elasticities, which is perhaps disappointing given the number of independent variables and the fact that the estimated elasticities themselves already are highly aggregated in character. Many of the factors included in Espey's published equations had effects that were individually not statistically significant or which did not seem to relate to any particular hypothesis, or both.

A similar approach was applied to the studies in the present database, although not with exactly the same definitions as Espey. In particular, the 'static' results were we separated out from the dynamic results. (Espey included each static result in both short- and long-run dynamic results, which bypasses the need to classify them in terms of their time scale, but which will weaken the statistical association.) The resulting full equations are given in Hanly *et al.* (2002). The main results are shown qualitatively in Table 2.

The results, shown in detail in the full report, can 'explain' a high proportion of the variation, albeit remembering that the segmented form of analysis has already taken out many important sources of variation, e.g. between short- and long-run effects or between effects on fuel consumption and traffic volume. Such statistical explanatory power is at the expense of including coefficients that, taken on their own, have very poor significance, and usually fail to show a systematic pattern: it is not useful to know that, for example, maximum likelihood estimation sometimes produces significantly higher, and sometimes significantly lower, elasticities with no readily apparent reason to explain which case is which. It is possible that more detailed analysis would produce hypotheses that make sense, but this form of meta-analysis is not very revealing, and the present authors have chosen not to spend further time on it.

Implications for Practice

The full report (Hanly *et al.*, 2002) made a number of recommendations for changes in the assumptions and relationships used for forecasting, especially in the 10-year frame of interest to the Department for Transport. Particular points of interest included the following:

- Effects of price on traffic levels, although not huge, were bigger than had been assumed in earlier forecasts.
- These elasticities did not appear to decline over time as much as would be assumed when using the generalized cost framework as defined by the Department for Transport, or perhaps at all. (Income elasticities, however, have declined over time.)

Table 2. Summary of meta-analysis results for sources of variation in estimated elasticities

Petrol price: Pence per litre (p/litre) Pence per km (p/km)	Few direct results, so most inferences have to be indirect. Weak evidence that short run price elasticity is higher for p/km and long run higher for p/litre. p/km gives lower income elasticity then p/litre for vehicle-km, higher for vehicle stock
Functional form: Log-linear Linear Non-linear Semilog Box–Cox	No strong consistent pattern of effect of model form. Miscellaneous hints (e.g. log-linear gives lower elasticities of car ownership with respect to income than do other non-linear forms), but the effect is not strong
Model specification: Partial adjustment Error Correction Model Inverted-v lag	Some significant differences, but with no systematic or well-supported pattern that would relate to useful hypotheses or repeatable results
Quantity measure: Per capita Aggregate Per household	Some cases indicating that per capita measures give lower price elasticities and higher income elasticities for fuel consumption. Sample sizes too small for other demand measures
Data interval: Annual Quarterly Monthly	Annual data gives lower price elasticity and higher income elasticity for fuel consumption. A number of other statistically significant but non-systematic results
Data type: Time series Cross-section Cross-section/time series	Pooled time series/cross-section analysis (usually comparisons of countries) has some tendency to give lower elasticities when using dynamic specification
Country: Europe USA OECD Australia, Canada, Japan Other	USA has lower fuel consumption elasticities than Europe with respect to both price and income. The OECD seems to have higher elasticities, although this fact is not supported by consideration of the countries within the OECD. Other results are not very consistent
Time: Data set ends before 1974 Data set ends 1974–81 Data set ends after 1981	Several results show that the middle period has higher price elasticities and lower income elasticities than early or late periods. There is no evident systematic decline except, perhaps, for long run income effect on fuel consumption
Estimation method: Ordinary least squares (two-stage least squares, three-stage least squares, maximum likelihood, error components, generalized least squares, iterative, instrumental variables, seemingly unrelated least squares)	Many significant differences, but unrevealing as in every case there was little or no consistency about whether differences were positive or negative

- Further, but less firm, evidence related to fuel efficiency that could have a big effect on how technical changes have an impact on traffic levels.

It is interesting that early results of congestion charging in London also seemed to indicate that the price elasticities were higher than expected, so that traffic reductions were greater, but revenue less, than forecast.

The results of the present review were used to inform changes to the Department for Transport forecasting procedures implemented during 2002 and contributed to substantial amendments in forecasts (Department for Transport, 2002), of which the most notable is that the level of traffic congestion is now expected to increase between 2000 and 2010 rather than decline as had previously been expected. This is prompting a reconsideration of several important policy areas, including the role of road-user charging and fuel prices. However, it should be stated that revised price elasticities were not the only new element in this change of forecasts, and a reconsideration is currently in progress for the effects of other policy instruments to which similar considerations may apply.

Table 3. Overall results: elasticities of various measures of demand with respect to fuel price per litre produced by dynamic estimation using time series data

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	–0.08	–1.1
Standard deviation	n/a	n/a
Range	–0.08, –0.08	–1.1, –1.1
Number of estimates	1	1
Vehicle-km (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-km (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

n/a = Not available

Table 4. Overall results: elasticities of various measures of demand with respect to fuel price per litre produced by static estimation

Dependent variable	Total	Of which: Cross-section data	Cross-section/time series data	Time series data
Fuel consumption (total)				
Mean elasticity	−0.43	−0.55	−0.28	−0.48
Standard deviation	0.23	0.32	0.10	0.16
Range	−0.11, −1.12	−0.23, −1.12	−0.45, −0.11	−0.77, −0.28
Number of estimates	24	7	9	8
Fuel consumption (per vehicle)				
Mean elasticity	−0.30	no observations	−0.30	no observations
Standard deviation	0.22		0.22	
Range	−0.89, −0.04		−0.89, −0.04	
Number of estimates	22		22	
Vehicle-km (total)				
Mean elasticity	−0.31	−0.38	−0.27	−0.32
Standard deviation	0.14	0.23	0.12	–
Range	−0.54, −0.13	−0.54, −0.21	−0.41, −0.13	−0.32, −0.32
Number of estimates	7	2	4	1
Vehicle-km (per vehicle)				
Mean elasticity	−0.51	no observations	−0.33	−0.69
Standard deviation	0.25		–	–
Range	−0.69, −0.33		−0.33, −0.33	−0.69, −0.69
Number of estimates	2		1	1
Vehicle stock				
Mean elasticity	−0.06	0.03	−0.11	no observations
Standard deviation	0.08	–	0.03	
Range	−0.13, 0.03	0.03, 0.03	−0.13, −0.09	
Number of estimates	3	1	2	

Appendix: Detailed Results

Using a simple classification adapted from the form that has become common in earlier reviews, results of the analysis are shown in Tables 3–7, where each cell shows the elasticities produced by different studies. Mean results, standard deviations and sample sizes (i.e. the number of estimated coefficients cited) are given to help assess the backing for the results, although each 'datum' point in this case is a statistically derived result with its own statistical properties, i.e. at least two stages away from real data, and it would not be useful to apply conventional significance tests.

Note that in all cases the range of results is quite wide, and the standard deviations are large in relation to the means. This is not surprising because the estimates come from such a wide range of different sources and contexts, whose separate influence is considered in later sections. The exclusion of some multiple results from single studies also has the effect of revealing a wider variance than if they had all been included.

The price elasticities for fuel consumption are higher than the elasticities for vehicle-km, i.e. when fuel price rises, people reduce their fuel consumption more than their mileage. The methods available to do so are (1) change driving styles (less heavy acceleration and breaking, more fuel economical speeds; (2) a shift in the pattern of journeys such that more of them are in fuel-efficient contexts (e.g. light traffic at moderate speeds as compared with very low or very high speeds); (3) changing to more fuel-efficient vehicles, e.g. newer, better maintained, smaller or more technically advanced.

To a first approximation for small quantities, the relationship is as follows:

Elasticity of fuel efficiency = –*elasticity of fuel consumption* + *elasticity of vehicle-km.*

Given the results in Tables 2 and 3, this suggests that the effect of price changes on efficiency is quite large.

The elasticity of the response of vehicle ownership to fuel price is smaller than the elasticity of vehicle-km, but not much smaller. At face value, this suggests that a larger component (perhaps 80%) of the change in traffic level is

Table 5. Overall results: elasticities of various measures of demand with respect to income using dynamic estimation

Dependent variable	Short-term	Long-term
Fuel consumption (total)		
Mean elasticity	0.39	1.08
Standard deviation	0.25	0.35
Range	0.00, 0.89	0.27, 1.71
Number of estimates	45	50
Fuel consumption (per vehicle)		
Mean elasticity	0.07	0.93
Standard deviation	n/a	n/a
Range	0.07, 0.07	0.93, 0.93
Number of estimates	1	1
Vehicle-km (total)		
Mean elasticity	0.30	0.73
Standard deviation	0.21	0.48
Range	0.05, 0.62	0.12, 1.47
Number of estimates	7	7
Vehicle-km (per vehicle)		
Mean elasticity	–0.005	0.17
Standard deviation	0.01	0.19
Range	–0.02, 0.005	0.00, 0.41
Number of estimates	3	4
Vehicle stock		
Mean elasticity	0.32	0.81
Standard deviation	0.21	0.43
Range	0.08, 0.94	0.28, 1.62
Number of estimates	15	15

n/a = Not available

Table 6. Overall results: elasticities of various measures of demand with respect to income using static estimation

Dependent variable	Total	Of which: Cross-section data	Of which: Cross-section/time series data	Of which: Time series data
Fuel consumption (total)				
Mean elasticity	0.49	0.51	0.51	0.44
Standard deviation	0.40	0.39	0.39	0.52
Range	0.02, 1.44	0.15, 1.25	0.22, 1.44	0.02, 1.34
Number of estimates	20	6	9	5
Fuel consumption (per vehicle)				
Mean elasticity	0.55	no observations	0.52	no observations
Standard deviation	0.35		0.35	
Range	0.07, 1.14		0.07, 1.14	
Number of estimates	19		19	
Vehicle-km (total)				
Mean elasticity	0.49	0.47	0.46	0.55
Standard deviation	0.42	0.02	0.51	0.40
Range	0.05, 1.44	0.46, 0.48	0.05, 1.44	0.15, 1.18
Number of estimates	15	2	8	5
Vehicle-km (per vehicle)				
Mean elasticity	0.06	0.07	no observations	0.03
Standard deviation	0.03	0.01		–
Range	0.03, 0.08	0.06, 0.08		0.03, 0.03
Number of estimates	3	2		1
Vehicle stock				
Mean elasticity	1.09	1.89	0.78	1.22
Standard deviation	0.56	–	0.40	–
Range	0.49, 1.89	1.89, 1.89	0.49, 1.23	1.22, 1.22
Number of estimates	5	1	3	1

brought about by a change in vehicle ownership. This is somewhat at odds with a widespread assumption that car ownership is relatively insensitive to fuel price, and a whole literature demonstrating that travel demand responses other than car ownership do have an importance of their own. Since the result arises from relatively few studies in this review, it should be treated as less well founded than the stronger effects noted above. Nevertheless, this is an indication that car ownership is influenced, to some extent, by fuel price, and this should not be dismissed.

Comparison with Earlier Reviews

Previous generations of literature reviews had been carried out by Oum *et al.* (1992), Sterner and Dahl (1992), Goodwin (1992), then by Lee (1998), Espey (1998), Graham and Glaister (2002), and others. These reviews substantially overlap, making use of various subsets of the same primary sources, and updated by accumulation: this naturally blurs any tendency for the estimates to change.

Table 7. Overall results: elasticities of various measures of demand with respect to car purchase cost: whole database

Dependent variable	Short-term	Long-term	Static
Fuel consumption (total)			
Mean elasticity	−0.12	−0.51	−0.45
Standard deviation	0.08	0.24	0.25
Range	−0.26, 0.00	−0.88, 0.00	−0.66, −0.15
Number of estimates	11	10	4
Fuel consumption (per vehicle)			
Mean elasticity	n/a	n/a	n/a
Standard deviation	n/a	n/a	n/a
Range	n/a	n/a	n/a
Number of estimates	n/a	n/a	n/a
Vehicle-km (total)			
Mean elasticity	−0.19	−0.42	−0.35
Standard deviation	0.12	0.21	0.42
Range	−0.33, 0.11	−0.62, −0.20	−0.65, −0.05
Number of estimates	3	3	2
Vehicle-km (per vehicle)			
Mean elasticity	n/a	n/a	n/a
Standard deviation	n/a	n/a	n/a
Range	n/a	n/a	n/a
Number of estimates	n/a	n/a	n/a
Vehicle stock			
Mean elasticity	−0.24	−0.49	−0.38
Standard deviation	0.15	0.19	0.29
Range	−0.44, −0.03	−0.78, −0.13	−0.59, −0.05
Number of estimates	11	11	3

n/a = Not available

Key results from the earlier reviews are summarized in Tables 8–10, in order of publication, and slightly rearranging the published results to fit into the format used for the present authors' results.

Espey (1998) carried out an analysis of 101 citations on fuel consumption, mostly built on earlier reviews and data collated by Sterner and Dahl (1992), published between 1966 and 1997 with data from 1929–93. Table 9 shows Espey's comparable results.

Graham and Glaister (2002) came to the general conclusions shown in Table 10, which were based substantially on the earlier reviews together with some later empirical sources.

These reviews give results that are of broadly similar general magnitude as the earlier results.

Results Related to Modelling and Forecasting

There is a widely used facility, provided by the conventions of generalized cost, for building logical extensions that go beyond the results of empirical research.

Table 8. Review results from Goodwin (1992)

	Elasticity with respect to fuel price	
Dependent variable	Short	Long
Vehicle-km	−0.16 (n = 4)	−0.32 (n = 6)
Fuel consumption	−0.27 (n = 57)	−0.73 (n = 53)

Results originally identified as 'ambiguous' or 'unspecified' are not included

Table 9. Review results from Espey (1998)

	Elasticity with respect to fuel price		Elasticity with respect to income	
Dependent variable	Short	Long	Short	Long
Fuel consumption	−0.26 (n = 277)	−0.58 (n = 363)	+ 0.47	+ 0.88
			(n = 345)	

Table 10. Review results from Graham and Glaister (2002)

	Elasticity with respect to fuel price		Elasticity with respect to income	
Dependent variable	Short	Long	Short	Long
Vehicle-km	−0.15	−0.3		
Fuel consumption	−0.2 to −0.3	−0.6 to −0.8	0.35 to 0.55	1.1 to 1.3

Using a mathematical derivation reported in Hanly *et al.* (2002), the main implications are as follows:

- Price elasticities will be positively related to price level, and will rise and fall as real price rises and falls.
- Price elasticities will be negatively related to income, and therefore would tend to fall over time.
- Price elasticities will have a definite relationship with travel time elasticities.

Not derived directly from the generalized cost argument, but nevertheless overlapping with its results, is the expectation from ideas of saturating car ownership that elasticities of demand for cars should come down as income increases, and therefore over time, with a consequent, possibly weaker, effect for traffic volume.

Table 11. Elasticities of fuel consumption with respect to fuel price and income

Period	Average elasticity with respect to fuel price			Average elasticity with respect to income		
	Short	Long	Static	Short	Long	Static
Pre-1974	–0.29	–0.45	–0.56	0.52	1.28	0.63
1974–81	–0.35	–0.93	–0.36	0.37	1.08	0.43
Post-1981	–0.16	–0.43	–0.28	0.38	1.04	0.14

Table 12. Elasticity of vehicle-km with respect to fuel price and income

Period	Average elasticity with respect to fuel price			Average elasticity with respect to income		
	Short	Long	Static	Short	Long	Static
Pre-1974	n/a	n/a	–0.54	n/a	n/a	0.30
1974–81	n/a	n/a	–0.32	n/a	0.21	0.57
Post–1981	–0.10	–0.29	–0.24	0.30	0.73	0.49

n/a = Not available

The literature database contains several sources of variation for incomes and prices, primarily variation between places, and over time. Some results are shown in Tables 11 and 12. Only the short-run fuel consumption price elasticity behaves in a way fully in accordance with both hypotheses. The long-run elasticity is supportive of the expectation that price elasticity is related to price level, but not the overall trend of income. The static results appear to demonstrate the opposite. In general, the expectation of a decline in income elasticities over time is mildly supported.

The empty cells in Table 11 arise because the new dynamic studies included in the present review mostly update the data series, therefore there are no new studies only relating to the earlier period. However, it is notable that the dynamic results for fuel price, at –0.1 for short-run and at –0.29 for long-run effects on traffic volume, show a slightly lower short-run elasticity but virtually the same long-term elasticity as reported 10 years ago in, for example, Goodwin (1992), whose own results seemed similar to comparable results 10 years earlier. If one were only to look at the static results, there is an appearance of a downward movement, although this is based on only seven studies. The most important figure for forecasting, –0.29 for the price elasticity in the latest period, is as high as has ever been estimated. There is no obvious trend effect for income elasticities.

Similar analyses were carried out for effects on the vehicle stock and fuel efficiency not reported here.

Collating these results, one finds that quite a number of indications that demand elasticities with respect to income have declined over the period of the studies, but there is a much more mixed picture about price elasticities. Some analyses suggest they have declined (notably for short-term effects) and others that they have increased (notably for long-term effects). Perhaps the most intriguing feature here is the *absence* of strong, clear evidence of a systematic decline, since the effect, if price elasticities are indeed inversely related to income, would be a large one over such a long period of continued income growth.

These results are supported by other studies, and some new empirical analysis of UK data from 1960 to 2000, for different functional forms, model specifications and periods. The results are shown in Hanly *et al.* (2002). These strongly supported a declining income elasticity for both fuel consumption and vehicle-km. Specifications using (1) a constant price elasticity and (2) a declining price elasticity as demand increases are indistinguishable on statistical grounds. In addition, there is no evidence that price elasticity is related to price level. However, dividing the period into three indicates that price elasticity has *increased* over time, not reduced as the generalized cost hypothesis would suggest.

Thus, the area of current practice that seems least consistent with the results is the assumption that price elasticities will come down as income increases. This in turn puts pressure either on the presumption that generalized cost behaves in the way assumed, or on the presumption that values of time increase as income increases.

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Main source reference: Hanly, M., Dargay, J. & Goodwin, P. (2002). *Review of Income and Price Elasticities in the Demand for Road Traffic*. Report 2002/13 (London: ESRC Transport Studies Unit, University College London) (available in full in pdf format at: http://www.cts.ucl.ac.uk/tsu/elasfinweb.pdf). Attention is also drawn to a web-based compilation of elasticity references maintained by Todd Litman as part of an online travel demand management encyclopaedia (available at: http://www.vtpi.org/tdm/) and to an earlier literature review by TRACE (1998) (also as Jong and Gunn, 2001), which was not used as separate source evidence itself, but whose sources overlap those used here.

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