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BEHAVIORAL RESPONSES TO ENVIRONMENTALLY-RELATED TAXES

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FOREWORD

The impact of a given change in taxation on the environment will to a large extent depend on the relevant price elasticities. The present report -- prepared in the context of the work programme of the Joint Meetings of Tax and Environment Experts, under the Committee for Fiscal Affairs and the Environment Policy Committee of the OECD -- provides an overview of available estimates of own-price elasticities regarding energy and transport. It was written by A. Ferrer-i-Carbonell, A.C. Muskens, M.J. van Leeuwen, and J.W. Velthuijsen of the Foundation for Economic Research of University of Amsterdam. A draft version of the report was presented to the 2nd Joint Meeting, held 26 November 1999.

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1. INTRODUCTION

The aim of (regulatory) environmental taxes is to reduce, through higher prices, the use of scarce resources or emissions of pollutive substances. The effectiveness of an environmental tax can be defined as its capacity to achieve these goals. If the response of consumers or producers to the introduction or increase of an environmental tax were known *a priori*, governments could set adequate environmental taxes to realize a given environmental target. Over the past years, the OECD has highlighted the importance of more research on the magnitude of behavioral responses to environmental taxes once they have been introduced, as a necessary precondition to implement correct instruments of environmental policy. For a better understanding of behavioral responses it is necessary to focus on consumer and producer behavior.

Behavioral responses to environmental taxes can be estimated *ex ante* (predicted values) or evaluated *ex post* (actual values). The latter approach concentrates on the absolute reduction in consumption (final or intermediate) caused by the introduction or increase of an environmental tax in a specific country at a specific time (see, for example, EEA, 1996; Ekins and Speck, 1998). Such studies are relevant for future modifications and adjustments of the environmental tax in the country concerned. In addition, *ex post* studies may provide useful information as input for tax impact studies focusing on other countries. The *ex ante* approach uses econometric methods to estimate price elasticities, which, with precaution, are used to predict behavioral responses to environmental taxes. The main advantage of the price elasticity estimates approach is that it does not require that a tax be implemented, merely that relative prices changed. This is important in view of the fact that environmental taxes have only a short history. Although general price elasticity estimates have been derived for many countries and for several years, empirical data on consumer responses to environmental taxes are scarce (Ekins and Speck, 1998; OECD, 1997b).

The aim of this report is to provide an overview of the estimated magnitude of behavioral responses to higher prices, including price rises as a consequence of the introduction of environmental taxes. This collected evidence will improve the understanding of the effectiveness of environmental taxes in reducing pollutive emissions and the use of environmental resources. The present report will exclusively focus on price elasticities related to energy and transport as most environmental taxes are applied to these tax bases. Another sector sometimes taxed is water (OECD, 1997a). Espey *et al.* (1997) offer a meta-analysis of water price elasticities. In the area of transport, the report focuses principally on the demand for gasoline (i.e., an energy carrier). Less attention is given to the demand for alternative modes of transport (car, public transport, or airplane).

We will not discuss the literature on *ex post* evaluation, as there is hardly any (Ekins and Speck, 1998; OECD, 1997b) As an example, the study by EEA (1996) evaluating the implementation of sixteen environmental taxes in different countries, is optimistic regarding the effectiveness of environmental taxes. Instead, this report aims to review and discuss some of the energy and transport price elasticity estimates found in the literature. Additionally, appendix I presents a list of extra references in case that more detailed information is needed.

The structure of this report is as follows. Section 2 discusses the theoretical background of consumer and producer behavior and price elasticities for energy (including transport). Section 3 provides a general classification and discussion of price elasticity studies. Section 4 presents a preliminary overview of price elasticity estimates, on the basis of a selection of criteria. Section 5 concludes.

2. ECONOMIC THEORY

2.1 Energy prices

The price paid by energy users does not reflect the marginal production and distribution costs. It is not the outcome of a competitive market process without government interference. Several energy markets have monopolistic characteristics. For example, the oil market is to some extent controlled by the OPEC. Therefore, according to economic theory, suboptimal allocations result. Deregulation policies aim to, among other things, reduce the monopoly surplus, and to lower energy prices. Furthermore, in most countries, government interventions such as taxes and subsidies affect the price of energy. Subsidies distort the optimal allocation of resources. Taxes, however, can be used as an instrument to internalize externalities. Corrected prices this can drive the market to an optimal, efficient, use of resources.

The demand for energy does not only depend on the price that consumers pay for energy. Demand is also closely related to the prices, usage and characteristics of machines and appliances that use energy. Therefore, the demand for energy depends strongly on the use, characteristics and price of the appliances using energy. Consumers, especially households, do not have perfect information regarding the energy use of their electrical appliances. Therefore, they are not easily aware how to save energy and notably in a cost-effective way. This complicates the estimation of the energy demand function. Related to that is the option of information as an environmental policy instrument. In other words, goals such as reducing energy use can be achieved not only by means of taxation but also by informing consumers about the energy use of some goods and appliances. For example, by making consumers aware about the energy use of cars, which depends not only on the characteristics of the car but also on the driving style.

2.2 Energy demand

Traditionally, economic theory has included capital and labor as the main, and often only, production factors. Energy often is not written in the production function as a separate input but considered as part of the ‘other inputs’. Nevertheless, energy is a very important factor in almost every production process. The share of energy costs in total production costs is between 5 and 10% in the OECD countries. Labor and capital have more substitution possibilities with energy than with any ‘other inputs’. Mainstream economic theory assumes that the demand for energy as an input in production is decided from profit maximization, taking technology as given. The use of energy is determined by the relative prices of all production factors, as well as by the technical feasibility to substitute energy.

Energy is not a homogeneous input. There are different kinds of energy carriers. They can be either complementary or substitutes. Producers choose the energy mix so as to minimize costs of production, with the result that the marginal revenues of the energy carriers equal the respective marginal costs. Therefore, each energy carrier is associated with a particular demand and price elasticity.

In the short run, substitution between energy and other production factors is technically difficult. In the longer run, however, technological changes may allow for more extensive substitution options. Since decisions on investment are made with regard to the long run, there is a significant gap between short run and long run elasticities.

Energy demand can be divided into demand for production inputs (intermediate demand) and demand for consumers (final demand). When energy prices change, so does the total volume of energy consumed. Following mainstream microeconomic theory, the total effect of an increase in the price of energy carrier *A* can be split in several partial effects:

- Energy carrier substitution effect: The demand for energy carrier *A* decreases, since energy carrier *B* becomes relatively cheaper ;
- Factor substitution effect: The demand for energy in total decreases, since other production factors become relatively cheaper;
- Intensity effect: The demand for energy decreases, since less energy-intensive production processes or products become relatively more attractive;
- Income effect: The demand for energy decreases, since the higher average energy price decreases the real income.

All these effects contribute to the overall change. The energy substitution effect is zero if all the energy carriers undergo the same price change at the same time. The intensity effect is, as already argued, limited by the technology available. In the long run, a price increase will stimulate the creation of new technology that is cleaner or uses resources more efficiently.

2.3 Price elasticity and its limitations

The overall effect of a price increase is a reduction of the demand for the products concerned. The magnitude of this reduction depends on the price elasticity of demand, defined as the relative change of demand per relative change of the price. The price elasticity of demand is closely related (though not equal) to the slope of the demand function, which reflects current preferences (consumer demand), technology (producer demand of intermediate goods), and availability of substitute goods. Theoretically, since all these basic characteristics can change, especially in the long run, the changes in prices have a larger impact in the long run than in the short run, i.e. the long term elasticity is higher than the short term one.

If the price elasticity of energy demand is known, reductions of demand due to, for example, the introduction of a tax, can be estimated. Therefore, price elasticity estimates for energy give useful insights that may help predicting the effectiveness of an environmental tax before it is implemented. The use of these estimates to predict effects of environmental taxes, however, requires precaution. Price elasticity estimates can only be used as a guide to understand consumer behavior in relation to energy and transport. It should be noted that the application of price elasticity estimates to predict consumer behavior has various limitations.

First, the magnitude of the price change influences the (intermediate and final) consumer response, because the price elasticity is a marginal measure and not necessarily constant along the demand curve. This would be the case even if the slope of the demand curve is constant. Therefore, even in the latter case the magnitude of the demand response to a price change depends on the actual price of the good and on the magnitude of the price change. At a low price level the effect of a price increase will be relatively smaller than at a high price level. Note that a constant elasticity along the entire demand curve is extremely unlikely in reality. The reason is that it requires that the slope change exactly cancels out the ratio of price to quantity.

Second, the effect of an x% increase in the energy price is not equal to the equivalent effect of an x% decrease in the energy price. This is known as the asymmetry of the price elasticity (for discussion see, for example, Mork, 1989; and Gately, 1993).

Third, the source of a price increase affects consumer responses. It has been found that consumers respond differently to changes in prices if these are perceived as permanent more than temporary. Generally, consumers regard an increase of prices via taxes as more permanent than via market (demand-supply) forces (Velthuijsen, 1995).

Fourth, evaluating the impact of taxes using price elasticities ignores the indirect effects of an increase in prices. The taxation of an environmental good can have a larger indirect impact through the reduction of income or shifts in the consumption patterns. Increases of price reduce the income available for other goods, unless the price elasticity equal one (when price per quantity stays constant), in which case the demand for other goods will fall. Such impacts are better understood by using partial and general equilibrium models, which can use the estimates of price elasticity. See, for example, van Es et al. (1998).

In summary, there is not a unique price elasticity of energy but rather a range of price elasticities. In the following sections we try to asses the most likely range of price elasticities of different energy carriers, based on the existing literature.

3. APPROACHES TO ESTIMATE PRICE ELASTICITIES

Since the 1970s, a range of studies aimed to estimate price elasticities for energy and transport. The increases of oil prices between 1973 and 1979 and increasing environmental concerns may have exacerbated research on energy and transport price elasticities. Price elasticities of energy and transport have been estimated for several countries in different years, with static or dynamic models, using different demand function specifications, data and estimation techniques.

One way of analyzing the effects and importance of the assumptions, data used, and methodology underlying the estimates, is by using meta-analysis[1]. Espey offers a meta-analysis study of price elasticities of gasoline for the USA (1997) and for all countries (1998) where such estimates have been produced. Another way to observe the effects of the assumptions on the estimates is by using the same data, combined with various specifications and assumptions. Some of these studies are included in Table 1 (third column).

Table 1 shows a classification of the different characteristics of the approaches that have been employed to estimate price elasticities. First, the studies reviewed are classified according to five main characteristics, (1) the specification of the parameterization, (2) the demand function, (3) the characteristics of the data, (4) the estimation method, and (5) the energy carriers and transport. Subsequently, they are classified in greater detail. In the next section some of the categorizing criteria in this table will be used to present the estimates. Here, we discuss only some of the elements of Table 1.

The specification of the demand function determines whether an estimate will reflect the short or the long term price elasticity. Some authors include lagged prices to capture the long term effect. Dynamic models are more suitable than static models to estimate the long term elasticity. There is discussion in the literature regarding the structure of the lag (see, for example, Sterner, 1991). Another way of introducing time in the demand function is by including more explanatory variables. Demand functions with vehicle ownership (gasoline elasticity) or stock of electrical appliances (energy elasticity) can capture the difference between the long and short run effects.

In most of the studies the price elasticity is calculated by parameterizing the demand function. In a few studies, however, price elasticities are estimated using a utility function, for example in Dennerlein (1987). An important difference between studies that use demand functions, is the definition of the dependent variable. For example, electricity consumption may be measured in kilowatt hours, but it can also be deduced from the demand of household appliances. Another example is in gasoline consumption, which may be defined as gasoline per capita or per vehicle. Sterner (1991) concludes, when estimating the price elasticity of gasoline for the OECD countries, that using gasoline per capita as the dependent variable leads to higher price elasticity estimates. Similarly, the effect of a gasoline price increase may be measured using the demand for liters of petrol, the demand for vehicle kilometers, or the demand for cars (see, for example, Goodwin, 1992).

[1] Meta-analysis can be defined as eliciting relevant information by a formal analysis of earlier studies, or more specifically, as the formal synthesis of results and findings of scientific studies, possibly including summarizing, assessing, comparing, averaging, evaluating, and apprehending common elements in impact studies (van den Bergh and Button, 1999).

The type of data used is another relevant characteristic of the price elasticity estimates. First, the data can be time-series, cross-section or time-series cross-section. The type of data use has an impact on the estimates (see, for example, Espey, 1998; Sterner 1991). Also important is whether the data is aggregated macro or desegregated micro. It could be that macro data captures the general responses, whereas micro data only captures the partial responses to changes in prices.

An approach to estimate price elasticity that is not mentioned in Table 1 is the approach used by the Netherlands Bureau for Economic Policy Analysis (CPB). The CPB makes us of the ICARUS database (de Beer et al., 1994), which lists technical possibilities for, and costs of, energy saving in each economic (sub)sector for the Netherlands. The information in the ICARUS ('bottom-up' information) generates different results than the 'top-down' models. NEMO, an energy model developed by the CPB, attempts to bridge the gap between the two approaches with a top-down structure, and parameters estimated from bottom-up information. In Koopmans et al. (1999) some results of the parameter estimation are presented.

The approaches discussed in Table 1 lead to different estimates of price elasticity. It is difficult to decide which approach provides the most reliable estimates. Ideally, information is needed on the whole demand curve. This is, however, impossible. The best one can do is to consider all the estimates provided by different approaches and link them to concrete methods, data and assumptions used. Subsequently, one can assume that the 'real' price elasticity will fall somewhere inside the range of estimates. Experiments with artificial data sets could perhaps provide additional information. The most reliable test, however, is to compare *ex ante* with *ex post* estimates.

Table 1. Approaches to estimate price elasticities

	Theoretical Approaches:	Selected empirical studies offering a comparison:
Parameterization	□ Utility function □ Demand function	
Specification of the demand function	□ Energy as an isolated commodity versus energy as a part of a complete demand system	□ We have not found any. Using complete demand system: Jorgenson and Wilcoxen, 1990, Rothman et al., 1994, Seale et al., 1991
	□ Functional form: linear, double-log, log-linear, or determined by the sample	□ Chang and Hsing, 1991(electricity), Hsing, 1990 (gasoline)
	□ Static versus dynamic	□
	□ Structure of the lag: polynomial distributed, geometrically declining, inverted-v , lagged endogenous model, and lagged dependent variable	□ Of the lag structure see Sterner, 1991 (gasoline)
	□ Explanatory variables included in the model: inclusion of stocks and use of vehicles or appliances, demographic variables, etc.	□ Rouwendal, 1997 (transport)
	□ Definition of the dependent variable	□ Sterner, 1991, Jorgenson, 1976, Schipper et al., 1993 (all gasoline)
Data	□ Countries and regions included	□ Sterner, 1991 (gasoline), Brenton, 1995 (energy), Hsing, 1992 (natural gas)
	□ Period covered	□ Sterner, 1991 (gasoline), Rouwendal, 1997 (transport)
	□ Type and amount of data: cross-section, time-series, or pooled cross-section time-series	□ Sterner, 1991 (gasoline), Sterner, 1990 (gasoline), Goodwin, 1992 (transport), Halvorsen and Larsen, 1999 (electricity), Dahl and Sterner, 1991b (gasoline)
	□ Macro or micro data	□
	□ Time span: yearly, quarterly, monthly	□ Dahl and Sterner, 1991a (gasoline)
Estimation Method	□ OLS, Cointegration, GLS, iterative 3SLS, error correction, pooled with or without dummies, random effects or fix effects, etc.	□ Sterner, 1991 (gasoline), Baltagi and Griffin, 1983 (gasoline), Puller and Greening, 1999 (gasoline), Maddala et al., 1997 (electricity and natural gas), Rouwendal, 1997 (transport), Silk and Joutz, 1997 (electricity)
	□ Logit choice models (discrete models for transport)	□ Oum et al., 1992 (transport) for a discussion
Energy carriers and transport	□ Energy aggregated, electricity, gasoline, natural gas, or crude oil	□ Rothman et al., 1994 (energy as a whole and electricity compared to other energy), Maddala et al., 1997 (electricity and natural gas)
	□ Transport aggregated, per mode of transport, passengers versus freight, per fare and mode, or individual firms.	□

4. A SURVEY OF EMPIRICAL ESTIMATES OF PRICE ELASTICITIES

4.1 Introduction

This section presents a survey of empirical estimates of price elasticities reported in the literature. We divide the section into discussions of price elasticity estimates for energy and transport. The first type includes estimates for energy as a whole, and also at a more desegregated level for electricity, natural gas, and crude oil. Price elasticities for gasoline are discussed in section 4.3, which also reports on elasticity estimates for the use of modes of transport. A very limited number of studies exist that estimate elasticities for the level of fares. As there are insufficient estimates for a robust comparison, we omit discussion of these (see, for example, Hensher, 1998). Another relevant distinction not discussed in the current paper is price elasticities per type of gasoline. For a study in the Netherlands see MuConsult (1993).

The price elasticity estimates are classified below according to the type of data and econometric technique used. The aim of the discussion is to offer an overview to be useful for future energy policy planning. As a consequence of changes in technology and preferences, elasticities have changed significantly over the last few decades. Therefore, the focus is mainly, but not exclusively, on results published since the early 1980s. The relatively most recent price elasticity estimates can better predict consumer reactions to change in prices and technological substitution options. For older studies that offer estimates of price elasticities we refer to Appendix I, which includes a more extensive list of relevant studies.

There is a large amount of estimates of price elasticity for energy and transport. In this section we only offer a limited selection. As discussed above, we limit the survey to the most recent studies. Furthermore, we focus on OECD countries. In addition, studies have been included that cover OECD in addition to other countries. We also refer to surveys and meta-analysis studies. These are based on much larger sets of estimated results. By including them, we offer a more complete overview.

4.2 Price elasticities of energy

This section presents extremes of the range of estimates that are found in the elasticity studies concerned. First, this section offers some estimates for energy consumption in the aggregate. Most studies estimating elasticities distinguish between various energy carriers.

The price elasticity for energy consumption in the aggregate is, not surprisingly, generally lower than the isolated price elasticity for electricity. Rothman *et al*. (1994) estimate the price elasticity in 1985 for 53 countries for energy and electricity. Their reported price elasticity of energy is between -0.69 and -0.78, whereas the price elasticity for electricity is between -1.35 and -1.42. A Danish study (Bentzen and Engsted, 1993) estimates, using time series, a fairly low price elasticity for energy. According to this study the price elasticity of energy between 1948 and 1990 was -0.135 in the short run, and -0.465 in the long run. Prosser (1985) estimates the price elasticity for energy for seven OECD countries[2] between 1971 and 1982. This estimates are -0.26 for the short run, and -0.37 for the long run. Prosser (1985) shows a decreasing elasticity between 1963 and 1982. For the Netherlands, Koopmans *et al.* (1999) estimate an energy elasticity of -0.29.

[2] The countries included in the study are USA, Canada, Germany, France, UK, Italy, and Japan

Maddala *et al.* (1997) offer a comparison between price elasticities for electricity and natural gas. For both energy carriers price elasticities are estimated using the same data set and methodology. Natural gas price elasticity estimates tend to be lower than electricity. Rothman *et al.* (1994) find similar results when comparing electricity with other energy carriers (oil, gas, and solid fuels). The IEA (1997) survey comes up with a short run price elasticity for crude oil for OECD countries between -0.07 and -0.11. The estimates are, once more, showing a fairly inelastic demand.

The price elasticity estimates for energy show that, in most cases, demand for energy is rather inelastic (i.e. elasticity is, in absolute terms, smaller than 1). This means that an increase of prices equal to x% would reduce the demand for energy in less than x%[3]. Nevertheless, if the price elasticity is significantly different from zero, which is undoubtedly the case, increases in prices can substantially reduce the demand for energy. Similarly, the reduction of energy prices in the last decade has led to an increase in the energy demand. Therefore, environmental taxes could have a significant impact on reducing energy demand. This impact would tend be larger in the long run, when elasticities are, in general, larger (Laroui, and van Leeuwen, 1996).

The studies cited above show that the price elasticity of electricity is, on average, higher than for other energy carriers. Table 2 presents some of the estimates of the elasticity of demand for residential electricity. In this area, few estimates distinguish between households and firms (see Greening *et al*., 1998, for a survey). Koopmans *et al.* (1999) and Tishler (1998) offer estimates of price elasticity of firms' demand for electricity in the Netherlands and Israel, respectively. In these studies, elasticities for households are found to be larger than elasticities for firms.

Table 2. Selected estimates of price elasticity of residential electricity

		Short Run	Long Run	Ambiguous
Pooled time-series/ cross-section	Micro	-0.433 (Norway) -0.2 (US)	-0.442 (Norway)	
	Macro	-0.158 to -0.184 (USA)	-0.263 to -0.329 (USA)	
Cross-section	Micro	0.4 to -1.1 (Norway)	0.3 to -1.1 (Norway)	
	Macro			-1.42 (53 Countries)
Time-series	Macro	-0.25 (USA) -0.62 (USA)	-0.5 (USA) -0.6 (USA)	
Meta-Analyses and Surveys		-0.05 to -0.9	-0.2 to -4.6	-0.05 to -0.12 (4 studies)

Sources: Branch, 1993; Chang and Hsing, 1991; Greening et al., 1998; Halvorsen and Larsen, 1999; Maddala et al., 1997; Rothman et al., 1994; Silk and Joutz, 1997.

The table shows that the demand for electricity is rather inelastic**.** The long run estimates are somewhat higher. Exceptions are the highest estimates of -1.1 and -0.9 for the short run, and -4.6 for the long run. Nevertheless, these high estimates should be taken with precaution. This come from Maddala *et al.* (1997) and Halvorsen and Larsen (1999). The first article gives a range of estimates from various studies between -0.05 and -0.9 for the short term, and -0.2 to -4.6 for the long term. Information about whether -0.9 and -4.6 are outliers of all the studies that were reviewed is not available. However, this seems probable, given the variance between the lowest and highest values, and given the other estimates in

[3] More precisely, if the elasticity is equal to *e* then a x% increase would give rise to a *e**x% demand reduction.

the literature. The second article provides estimates of the price elasticity for Norway. A price elasticity estimate of around -1.1 is found only for a few years. Notably, between 1984-1992, the price elasticity estimate is between -0.4 and -0.6. In 1993, the last year of the estimation period, the price elasticity increases to -0.9.

Another relevant conclusion from the Halvorsen and Larsen (1999) study is that there is hardly any difference between the short and long run elasticities. Generally, long run elasticities are found to be somewhat higher than short run elasticities. There are, however, some other few exceptions. In addition to Halvorsen and Larsen (1999), Silk and Joutz (1997) detected only small differences between long and short run price elasticities. They found non-significant differences between long and short run elasticity estimates for the USA between 1949 and 1993, when using an error correction model.

According to Chang and Hsing (1991) the elasticities for electricity in the USA have declined between 1950 and 1987. The study by Halvorsen and Larsen (1999) does not sustain the same hypothesis for the Norwegian case.

4.3 Price elasticities of transport

In the literature there are few meta-analyses (Espey, 1997 and 1998) and qualitative studies (for example, Dahl and Sterner, 1991a; Dahl and Sterner, 1991b; Sterner, 1991) that have compared the different estimates of price elasticities for gasoline. The studies of Dahl and Sterner cover more than one hundred estimates of price elasticity for gasoline. They argue that differences reported in the literature can be fairly well explained by different assumptions, data characteristics, functional demands, and estimation methods used. It is, therefore, argued that estimates are fairly robust. Table 3 presents some of the estimates.

Table 2 shows that most price elasticity estimates of electricity were higher for the long term. A few exception were, however, found. From Table 3 we can see that this is also the case for estimates of gasoline price elasticity. Remarkably, Pueller and Greening (1999) have estimated a short term elasticity higher than the long term. These estimates were found when using panel data for the US between 1980 and 1990.

The table offers no comparison between time periods. Sterner (1991) maintains that the elasticity of gasoline has increased over time in the OECD countries. From his estimates it can be concluded that this is especially true for the long run elasticity. Espey (1998) arrives at the same conclusion based on meta-analysis study.

When looking at specific regions or countries, the estimates used in Table 3 do not always confirm Brenton's (1995) findings that poor countries have a higher elasticity of energy. For example, the estimates by Sterner (1991) give a price elasticity of gasoline higher for Northern Europe (-0.2 for the short run, and -1.28 for the long run) than for Europe as a whole (-0.15 for the short run, and -1.24 for the long run). The meta-analysis of Espey (1998) generates significant differences in the short run price elasticities for different countries. The study indicates that the short run price elasticity of gasoline for USA is lower than for other western countries.

Table 3. Selected estimates of price elasticity of gasoline

		Short Run	Long Run	Ambiguous
Pooled time-series/ cross-section	Micro	-0.77 to -0.83 (USA)	-0.30 to -0.39 (USA)	
	Macro	-0.15 to -0.38 (OECD*) -0.15 (Europe) -0.6 (Mexico)	-1.05 to -1.4 (OECD*) -1.24 (Europe) -0.55 to -0.9 (18 countries of the OECD**) -1.25 to -1.13 (Mexico)	
Cross-Section	Micro	-0.51 (USA) 0 to -0.67 (USA)		
	Macro	Mean -1.07 (-0.77 to -1.34) (OECD*)		
Time-Series	Micro			
	Macro	-0.12 to -0.17 (USA)	-0.23 to -0.35 (USA)	
Meta-Analyses and Surveys		Avg. -0.26 (0 to -1.36) (International) Mean -0.27 (Time-series) Mean -0.28 (Cross-sect.) -0.26	Avg. -0.58 (0 to -2.72) (International) Mean -0.71 (Time-series) Mean -0.84 (Cross-sect.) -0.86	Avg. -0.53 (-0.02 to -1.59) (USA) Mean -0.53 (Time-series) Mean -0.18 (Cross-sect.) -0.53 (panel data) -0.1 to -0.3 (22 estimates)

Sources: Baltagi and Griffin, 1983; Dahl and Sterner, 1991b; Eskeland and Feyziouglu, 1997; Espey, 1998; Espey, 1996; Goodwin, 1992; Greening et al., 1995; Greening and Greene, 1998; Haughton and Soumodip, 1996; Puller and Greening, 1999; Sterner, 1990; Sterner, 1991; Walls et al., 1993.

* OECD except Luxembourg, Iceland, and New Zealand.

** OECD 18 countries include: Canada, US, Japan, Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, and UK.

Espey's (1998) results from the meta-analysis study comparing international estimates of price elasticity of gasoline offer other very useful insights. According to this study, the major behavioural responses to changes in gasoline prices occur "within the time frame of the static models" (ibid., page 289). Another conclusion is that the data type makes no difference for the long run estimates. In the short run, however, cross-section studies estimate higher elasticities than time-series and pooled time-series/ cross-section; time-series estimate the lowest elasticities. The differences between using micro and macro data have also been found to be significant; micro panel data give higher elasticity estimates than macro-national data.

There are two main surveys of price elasticities for modes of transport, these are Goodwin (1992) and Oum *et al*. (1992). These papers, which are in the same issue of the *Journal of Transport Economics and Policy*, both cover a lot of ground, starting in the beginning of the 1980s until 1991. Since then, little has been added to the literature. Therefore, we present their results here. Rouwendal (1997) offers recent estimates for the Netherlands.

Oum *et al*. (1992) also carry a survey of elasticities for rail and truck freight classified for commodities and functional form. These estimates will not be discussed here.

Table 4 summarizes some of the estimates from the survey by Oum *et al*. (1992). The table shows that the demand for urban transit is inelastic. Oum et al. (1992) argue that it would be more adequate to separate the estimates according to peak or off-peak hours. The few evidence available shows that off-peak elasticities are higher than peak elasticities. Regarding the mode of transport, we conclude that empirical evidence seems to agree that rail elasticities are higher than bus elasticities (Goodwin, 1992).

Table 4. Elasticity for modes of transport

	Short run	Long run	Ambiguous
Elasticity for Automobile			
	-0.09 to -0.24	-0.22 to -0.31	-0.13 to -0.52
Elasticity for Urban Transit			
Time-series			-0.01 to -1.32 *
Cross-section			-0.05 to -0.34
Pooled data			-0.06 to -0.44

	Time-series	Cross-section
Elasticity for Air Travel		
Leisure	-0.4 to -1.98	-1.52
Business	-0.65	-1.15
Mixed or Unknown	-0.36 to -1.81	-0.76 to -4.51
Elasticity for Intercity Rail		
Leisure	-0.67 to -1.00	-0.7
Mixed or Unknown	-0.37 to -1.54	-1.4

Source: Oum et al., 1992
* Most values fall between -0.1 and -0.6

The demand for cars is fairly inelastic. Goodwin (1992) surveys studies that have estimated the elasticity of traffic levels with respect to the petrol price. The mean values reported by Goodwin are -0.16 for the short run and -0.29 (cross-section) to -0.33 (time-series) for the long run. Furthermore, Goodwin provides a survey of studies that have estimated the elasticity of the car stock with respect to increases in the petrol price. These estimates are around -0.4.

The elasticity estimates for air travel reflect a higher elasticity of demand than for the other modes of transport, especially regarding the leisure trips. Oum *et al*. (1992) point at the large variance of the estimates, especially when compared with other modes of transport. According to the authors the greater variability may come from the large differences between fares and distances. Probably, the difference of price elasticity per fares for bus or rail trips are much lower than for air trips. This highlights the importance of estimating the elasticity for air travel according to fare.

5. CONCLUSIONS

This report gives an overview of the range of price elasticity estimates for energy and transport found in the literature. Price elasticity estimates may be used to understand behavioral responses to changes in prices due to environmental taxes. Predictability on the basis of price elasticities has its limitations, though. Demand for energy and for transport services are generally found to be fairly inelastic (price elasticity is, in absolute terms, smaller than 1). This means that an x% increase of prices would lead to a less than x% reduction of demand. Price elasticity estimates for both energy and transport are, however, significantly different from zero. In other words, an increase of prices via an environmental tax would lead to a reduction of energy and transport demand. This reduction would be, as estimated in the majority of the cases, larger in the long than in the short run. In the long run, economic agents have a wider range of options available for responding, such as new techniques, reorganization, shifts to other goods and services, relocation, etc. From the elasticity estimates presented in the survey, it can be concluded that environmental taxes can create a significant reduction of energy and transport demand. This, in turn, would lead to a more optimal allocation of resources taking external effects into account.

The literature on price elasticity estimates for energy carriers is quite extensive. It shows a large variance of price elasticity estimates. This variance can be partly explained by the use of different methods and data. Sterner (1991, page 91) argues that price elasticity estimates for gasoline “become more homogeneous” when taking into account the differences in approach used to estimate the price elasticity. Therefore, it is of special interest to use different methods to estimate the price elasticity for a specific (set of) country (countries) and time period. In doing so, researchers can offer a range of price elasticity estimates that take into account the differences in assumptions and methods. This range of price elasticities gives more information than a unique estimate. In fact, one can assume that the ‘real’ price elasticity will usually fall inside the range of estimates. It is difficult to conclude deciding about a best method or approach. We argued that experiments (using fake but complete demand functions) and comparing *ex ante* with *ex post* estimates is useful. Furthermore, in using price elasticity estimates to evaluate the implementation of an environmental tax in the OECD countries, attention has to be given to the countries and time period included in the estimations. Ideally, we would want to have information on the entire demand curve for each country. This is, however, impossible.

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APPENDIX I: A CLASSIFIED BIBLIOGRAPHY OF STUDIES

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