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A comparative analysis of the effects of economic policy instruments in promoting environmentally sustainable transport

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ABSTRACT

This paper presents a comparative analysis of the effects of economic policy instruments in promoting environmentally sustainable transport. Promoting environmentally sustainable transport is defined as: (1) Reducing the volume of motorised travel; (2) Transferring travel to modes generating less external effects, and (3) Modifying road user behaviour in a way that will reduce external effects of transport. External effects include accidents, congestion, traffic noise and emissions to air. Four economic policy instruments are compared: (1) Prices of motor fuel; (2) Congestion charges; (3) Toll schemes; (4) Reward systems giving incentives to reduce driving or change driver behaviour. The effects of these policy instruments are stated in terms of elasticities. All four economic policy instruments have negative elasticities, which means that they do promote environmentally sustainable transport.

Long-term elasticities tend to be larger than short term elasticities. The long-term elasticities of reward systems are unknown.

Key words: economic policy instrument; environmentally sustainable transport; elasticity; review; meta-analysis

1. INTRODUCTION

The question of how best to promote environmentally sustainable transport has attracted considerable attention from researchers and a large number of studies have been conducted, see the overview by Santos et al. (2010A, 2010B). It seems clear that a combination of policy instruments is needed to promote environmentally sustainable transport and that economic policy instruments could be an important part of a policy package. There is, however, a range of economic policy instruments, and it is not clear which of these instruments is the most effective or cost-effective. The objective of this paper is to compare the effectiveness of economic policy instruments in promoting environmentally sustainable transport. A review is made of empirical studies of the effects of economic policy instruments. The cost-effectiveness of economic policy instruments is not discussed in this paper. Before presenting the review, some key concepts are briefly discussed.

2. KEY CONCEPTS OF THE STUDY

The key concepts of this study are environmentally sustainable transport, economic policy instruments and effects of economic policy instruments. In this paper, promoting environmentally sustainable transport is defined as obtaining one or more of the following effects:

1. A reduction of the volume of travel performed by means of motor vehicles, in particular motor vehicles powered by fossil fuels.

2. A shift in the modal split of travel in favour of modes that consume less non-renewable energy and/or produce less external effects per person kilometre of travel.
3. Changes in travel behaviour, in particular road user behaviour, that reduce the external effects of transport.

External effects of transport include accidents, congestion, traffic noise and emissions to air. Emissions include both greenhouse gases and local pollutants.

While shifting from motorised travel to walking or cycling is sometimes held out as a paradigmatic example of the promotion of sustainable transport (see, for example, the papers collected in Greaves and Garrard 2012), it is clear that the external effects of road transport may vary substantially within a given mode of transport. Figure 1 shows how emissions from cars depend on speed (OECD 2006).

Figure 1 about here

A minimum is reached when speed is around 70 km/h. This means that both measures that reduce congestion, when the speed of traffic is typically around 10-30 km/h, and measures that reduce speeding, which tends to involve speeds in the high end of the range included in Figure 1, would be associated with reduced emissions. Thus, measures that influence speed may promote environmentally sustainable transport.

Economic policy instruments include all measures that influence the generalised costs of travel. The generalised costs of travel are usually defined (Santos and Bhakar 2006) as the sum of travel time, often converted to a monetary value, and direct out-of-pocket costs, such as tickets for public transport or fuel costs for cars. Other items, such as subjective risk of accident, may be included if deemed relevant. Four economic policy instruments are included in this paper:

1. The price of motor fuel.
2. Congestion charging or road pricing.
3. Toll schemes, whose main purpose is often to fund road investments, but may be regarded as a very simple form of road pricing.
4. Schemes designed to reward car drivers for reducing their driving, complying with speed limits or avoid driving in the rush hours.

The focus is on the effects of these policy instruments. Effects are stated in terms of elasticities. An elasticity shows the percentage change in demand associated with a one percent increase in the price of a commodity. A negative elasticity means that when price increases, demand is reduced. For normal goods, elasticities tend to be negative. Elasticities may differ in the short term and long term. The short term usually refers to period of a year or less. The long term usually refers to a period of 1-10 years. In the literature survey (see below), studies specifying elasticities in the short and long term were preferred to studies not specifying the period elasticities refer to. Furthermore, studies presenting elasticities were preferred to studies whose findings had to be further analysed in order to obtain elasticities. For studies that did not state elasticities, arc elasticities were estimated based on available data (see below).

3. LITERATURE SURVEY

Relevant studies were identified by searching Sciencedirect. In addition, the ancestry method was used, i.e. the list of references in relevant papers was examined and additional studies obtained. The literature is vast, in particular with respect to the demand for motor fuel. Hundreds of studies have been conductd to determine how the demand for motor fuel depends on its price. No attempt was made to obtain and review all these studies. As far as the price of motor fuel is concerned, it was decided to rely on meta-analyses of the original studies.

Three meta-analyses of fuel price elasticities were identified (Espey 1998, Brons et al. 2006, 2008). The most recent of these analyses is an update of Brons et al. (2006). Both these analyses are based on several hundred estimates of the price elasticity of motor fuel. Both analyses present summary estimates of the short-term and long-term elasticity as well as multivariate analyses of factors influencing elasticities.

As far as congestion pricing is concerned, the three most well-known schemes are those in Singapore, London and Stockholm. Several papers have been published about each of the schemes. Papers reporting demand elasticities with respect to the congestion charges were preferred. Papers containing such estimates for Singapore include Luk (1999), Menon (2000) and Olszewski and Xie (2005). For London, estimates of elasticity are presented by Santos (2004), Santos and Shaffer (2004), Prud'homme and Bocarejo (2005), Evans (2008) and Peirson and Vickerman (2008). The Stockholm congestion charging scheme is well documented by Börjesson et al. (2012). Moreover, a paper not providing elasticities reports on the effects of road pricing in Milan (Rotaris et al. 2010).

Odeck and Bråthen (2008) give a comprehensive review of elasticities associated with toll schemes. A more recent Norwegian study (Meland et al. 2010) estimated elasticities based on the removal of the toll ring in the city of Trondheim.

A number of trials have been to determine the effects of offering car drivers rewards as an incentive to make them change behaviour. The trials that are of interest for this paper are those that involve driving distance (Buxbaum 2006, Reese and Pash-Brimmer 2009, Bolderdijk et al. 2011, Greaves and Fifer 2013), speeding (Mazureck and van Hattem 2006, Bolderdijk et al. 2011, Hultkrantz and Lindberg 2011, Lahrmann et al. 2012, Greaves and Fifer 2013, Stigson et al. 2014) and avoiding driving in the peak rush hour (Ben-Elia and Ettema 2011).

4. RESULTS

4.1 Price of motor fuel

Table 1 presents key results from the two most comprehensive meta-analyses that have been published concerning the price elasticity of the demand for motor fuel (Espey 1998, Brons et al. 2008). Both studies find that the mean short-term price elasticity for motor fuel is around -0.3 and the mean long-term elasticity around -0.8. The results of the two meta-analyses are highly consistent.

Table 1 about here

There is, however, large variation in estimates of price elasticity in the individual studies forming the basis for meta-analysis. The meta-analyses identified some sources of the variation in elasticities. The main focus of this paper is, however, on the mean values. Both studies present diagrams showing the distribution of estimates of short-term and long-term price elasticity. The diagrams in the paper by Espey (1998) have grouped estimates in bands of 0.25 units (0 to -0.25, -0.26 to -0.50, etc.).

The diagrams suggest that the distribution of estimates is highly skewed. Brons et al. (2008) present similar diagrams that are more detailed, and therefore lend themselves to analysis probing for the possible presence of publication bias.

Publication bias is a potential source of error in meta-analyses. It denotes a tendency not to publish findings that are not statistically significant or that contradict prior expectations and are regarded as difficult to interpret. A statistical technique for detecting and adjusting for publication bias, the trim-and-fill technique has been developed by Duval and Tweedie (Duval and Tweedie 2000A, 2000B, Duval 2005). The technique is based on funnel plots, which are scatter diagrams in which results are plotted on the abscissa and the statistical precision of each result plotted on the ordinate. The idea is that results that are more precise should display less dispersion than less precise results; hence the swarm of data points should have the contours of a funnel turned upside down. If one of the tails of the funnel plot is missing or markedly thinner populated by data points than the rest of the diagram, this is an indication of publication bias.

The information needed to develop a funnel plot is not given in the two meta-analyses quoted above. Neither of the analyses mention publication bias nor make an attempt to detect or adjust for it. The analysis reported by Brons et al. (2008) does, however, contain realtively detailed histograms of the distribution of results. Figure 2 shows the histogram of results for short-term elasticity.

Figure 2 about here

Although Figure 2 is not a funnel plot, it is analogous to a funnel plot in the sense that the distribution of estimates of elasticity ought to be symmetrical in the absence of publication bias. Figure 2 has a long tail towards negative values, but no similar tail towards positive values. There is a strong and well-supported theoretical prediction for elasticities to be negative. Should a study find a positive elasticity, it may be discounted and researchers may choose not to publish it. The trim-and-fill method has been applied to Figure 2 in order to see if it indicated a "missing tail" of positive values for the elasticity.

A total of 222 estimates are included in Figure 2. The trim-and-fill analysis added 4 missing estimates. When the mean elasticity was re-estimated, including the added data points, it was -0.25. The original estimate was -0.27. Thus, if there is publication bias it would appear to have a minor influence on the summary estimate of the elasticity.

A similar analysis was made of the estimates of long-term elasticity presented by Brons et al. (2008). That analysis gave somewhat stronger indications of publication bias, adding 9 new data points to the original 90. However, the adjusted mean elasticity (-0.69) was not very different from the un-adjusted mean elasticity (-0.77).

4.2 Congestion charges

The oldest of the congestion charging schemes that have been studied extensively is the area licensing scheme in Singapore. The original system was replaced by electronic road pricing in 1998, and only studies that have evaluated the effects of the electronic system will be quoted here. Luk (1999) reported elasticities between -0.19 and -0.58. Menon (2000) reported elasticities between -2.8 and 0.65. Menon's paper is sometimes (Santos 2005, Meland et al. 2010) quoted as giving elasticities between -

0.12 and -0.35. However, the range of elasticities provided in Table 2 of Menon's paper is considerably wider, although only the values of -0.12 and -0.35 are mentioned in the text. The most recent paper on the Singapore congestion charging system (Olszewski and Xie 2005) gives a comprehensive set of elasticities, with an overall mean value of -0.118. A formal synthesis of the estimates quoted above by means of meta-analysis is not possible, because the standard errors of the estimates are not known. The mean estimate of Olszewski and Xie is the most recent for Singapore.

For London Santos (2004) gives eight estimates of the elasticity, ranging from -1.0 to -2.5. A simple mean of the estimates is -1.66. Santos and Shaffer (2004) present estimates of -1.32 and -2.11, suggesting that the former of these estimates (-1.32) is to be preferred. Prud'homme and Bocarejo (2005), in a controversial paper, state an elasticity of -0.83. Evans (2008) compares estimates of elasticity derived by making different assumptions about the costs that are included. Estimates based on the generalised cost of travel (defined as the sum of vehicle operating cost, the congestion charge and the value of travel time saving) range from -2.12 to -3.18 when only chargeable trips are included (i.e. trips made during the time of the day when the congestion charge is in effect) and the comparison is between no congestion charge and a charge of £ 5 or £ 8. Finally, Peirson and Vickerman (2008) give an elasticity of -0.82. All the estimates for London are considerably higher than for Singapore and suggest that the demand elasticity with respect to the congestion charge is in the range of -0.80 to -3.20.

Börjesson et al. (2012) present six estimates of demand elasticity for the Stockholm congestion charging scheme. The estimates range from -0.70 to -0.86. The authors note that the elasticity appears to have stabilised around -0.85 from 2009 and onwards and state that "It may be too early to tell if this is really the "long-term" value, although it seems likely."

The paper about the congestion charging scheme in Milan (Rotaris et al. 2010) does not state the elasticity. The information given in the paper is not sufficient to develop an estimate of the elasticity.

Estimates of the effects of congestion charging, as indicated by the elasticities, vary widely. It is clear, however, the congestion charging can be a very effective policy instrument. In the four cities that have been mentioned here (Singapore, London, Stockholm, Milan) the congestion charging schemes were associated with traffic reductions in the charged zone of 15 % (Singapore), 18 % (London), 20 % (Stockholm) and 20 % (Milan) (Li and Hensher 2012, Rotaris et al. 2010, Börjesson et al. 2012). These changes in traffic volume are remarkably similar, even if the elasticities associated with them differ widely.

4.3 Toll schemes

As far as toll schemes are concerned, the paper by Odeck and Bråthen (2008) gives a comprehensive review. The paper contains both an overview of previous studies estimating the demand elasticity for toll schemes and an analysis of 20 toll schemes in Norway. The overview of previous studies is given in Table 1 of the paper. All values listed in that table have been plotted in the stem-and-leaf plot (Tukey 1977) shown in Figure 3.

Figure 3 about here

The stem shows the first decimal of an estimate of elasticity. The leaves show the second decimal. When more than one study found the same value, a leaf is listed for each study. Thus, in the first line for international studies, the first number (2) shows an estimated elasticity of -0.02. The next two numbers show that there were two estimates of -0.03. It is seen that the majority of estimates in the international studies is in the range -0.02 to -0.29.

Twenty estimates of short-term elasticity based on Norwegian toll schemes are shown to the right of the international estimates. There is a wide range – from -0.03 to -2.26. The mean is -0.56. Five estimates of long-term elasticity are shown in the far right part of the diagram. The range is from -0.75 to -0.90 with a mean value of -0.82. Thus, although the main purpose of toll schemes is to collect money for funding road investments, the schemes do reduce travel demand. The elasticities for the Norwegian schemes are not very different from those estimated for the price of motor fuel, see section 4.1. Long-term elasticity is close to that found for the Stockholm congestion charging scheme.

4.4 Reward systems

The largest number of trials involving reward systems involve offering rewards to drivers for not speeding (Mazureck and van Hattem 2006, Bolderdijk et al. 2011, Hultkrantz and Lindberg 2011, Lahrmann et al. 2012, Greaves and Fifer 2013, Stigson et al. 2014). These trials (except Stigson et al. 2014) have been reviewed in another paper (Elvik 2013). The effects of the trials can be described in terms of a dose-response curve, in which the size of the effect is modelled as a function of the size of the reward. The trials offered drivers very different maximum rewards. The largest reward was offered in the Danish trial (Lahrmann et al. 2012), 700 Euros (about 1020 US dollars in 2008). To earn the entire reward, a driver had to avoid any speeding. In one of the experimental groups, drivers reduced speeding by close to 80 percent. If the assumption is made that the amount paid to drivers is proportional to the reduction of speeding, drivers reducing their speeding by close to 80 percent would be rewarded by about 553 Euros. Similar estimates of the effective reward paid to drivers were made for the other trials quoted above. A total of seven data points were extracted from the studies. A curve fitted to these data points is presented in Figure 4.

Figure 4 about here

There is a clear dose-response pattern. A logarithmic function fits the data quite well. The rate of speeding is stated as the percentage of distance driven above speed limits. If this percentage is reduced from 20 percent to 5 percent, the rate of speeding has been reduced by 75 percent. The arc elasticity of the function presented in Figure 4 with respect to the size of the reward was estimated as follows:

$$\text{Arc elasticity} = [(D_2 - D_1)/(0.5 \cdot (D_1 + D_2))]/[(C_2 - C_1)/(0.5 \cdot (C_1 + C_2))]$$

D is demand, in Figure 4 the "demand" for speed violations. C is cost, in Figure 4 the reward, which is, in a sense, the cost of continuing speeding. Subscript 2 denotes after a change, subscript 1 before a change. Estimates were made for increments of

15 Euro in the value of the reward; 15, 30, 45, …, 525, 540. The elasticity was found to increase from -0.20 for the first step to -0.48 for the last step. At the mean value of the reward (158 Euros), the elasticity was -0.30.

Figure 5 shows a dose-response curve for trials rewarding drivers for reducing their driving distance (Buxbaum 2006, Reese and Pash-Brimmer 2009, Bolderdijk et al. 2011, Greaves and Fifer 2013). As can be seen, the effects are considerably smaller than the effects of rewarding drivers for not speeding. The maximum reduction of driving distance is only about 10 percent, as opposed to a maximum reduction of 80 percent in the rate of speeding. There are only four data points and these show wide dispersion around the logarithmic function fitted to them.

Figure 5 about here

The arc elasticity, estimated the same way as for rewards for not speeding, was -0.03. Rewards are, in other words, considerably less effective in reducing driving distance than increasing the price of motor fuel. The third type of driver behaviour targeted for rewarding was to abstain from driving in the rush hour (Ben-Elia and Ettema 2011). The results of this trial are presented in Figure 6.

Figure 6 about here

A logarithmic function once again fitted the data very well. Arc elasticity was estimated to -0.23 for an increase in effective reward from 15 to 30 Euros per driver and to -0.29 for an increase in effective reward from 60 to 75 Euros per driver. Evaluated at the mean value of the reward (45 Euros), the elasticity was -0.25. These elasticities are smaller than those found for the congestion charging schemes in London and Stockholm.

5. DISCUSSION

The four economic policy instruments reviewed in this paper have all been found to be effective in promoting environmentally sustainable transport. This means that the policy instruments serve to constrain traffic volume, reduce congestion and reduce driving at speeds associated with high emissions. However, the policy instruments differ in many respects.

Fuel prices tend to be almost uniform within a country. Taxes on fuel will therefore normally influence traffic in the whole country, whereas congestion charges and toll schemes primarily have local effects. Reward systems can be applied both locally and at a national level, but the trials made so far have all been local. The environmental problems caused by motor traffic vary substantially in time and space; there is therefore a need for policy instruments that can be targeted at local problems.

All the policy instruments reviewed in this paper have so far been used only in a technologically quite simple form. Today, as noted by Elvik (2010), an advanced system of road pricing is technologically feasible. Such a system could replace cruder policy instruments, like taxes on motor fuel or toll schemes to fund road investments. In an advanced system of road pricing, every road user would pay the marginal societal costs of road use per kilometre of travel. Each motor vehicle could be fitted with a driving computer and a geographical positioning system that could record information regarding several aspects of driver behaviour, such as speed, following distance and use of indicators. The system would, however, require a continuous and detailed monitoring of driver behaviour. The anonymity and privacy permitted in the current traffic system would be gone and many drivers would probably regard this as an unacceptable invasion of privacy. Moreover, there would be high initial costs of installing the system and drivers might react unfavourably to having to pay for something they did not pay for before (congestion, the risk of accident, etc.).

Indeed, there is evidence, supported by the review in this paper, that zero is not just another price, as standard economic theory suggests (Shampanier et al. 2007, Knetsch 2012). The short-term demand elasticity of congestion charging and toll schemes tends to be higher than for the price of motor fuel. Before congestion charges and toll schemes were introduced, you did not have to pay anything, whereas motor fuel was never for free. There is a stronger behavioural reaction when something that used to be free gets priced than when there is a corresponding increase in the price of a good that you always had to pay for. The elasticities reported by Odeck and Bråthen for Norwegian toll schemes (short-term: -0.56; long-term: -0.82) may seem high, in view of the fact the tolls were not primarily intended to deter traffic, but to fund road investments. For some road projects, however, the tolls are considerably higher than the charges paid in the London or Stockholm congestion price systems.

Reward systems are sometimes promoted as a more "positive" way of influencing behaviour than "negative" policy instruments such as taxes, tolls or congestion charges. So far, however, there are few examples of the use of reward systems to promote environmentally sustainable transport. The examples reviewed in this paper all indicate that reward systems are effective. Yet, there are several problems associated with a widespread use of reward systems.

In the first place, recruiting drivers to reward systems has been difficult, in particular in the trials rewarding drivers for not speeding. Drop-out rates from these trials have also been high (see Elvik 2013 for an overview). In the second place, the marginal effects of rewards decline rapidly; hence, rather high rewards, like several hundred Euros per driver per year, may be needed to obtain major effects. In the third place, some trials (Mazureck and van Hattem 2006, Lahrmann et al. 2012) indicate that effects decline over time; thus to maintain effects over time, it might be necessary to increase the rewards. In the fourth place, rewarding drivers for abstaining from unlawful behaviour could be viewed as ethically dubious. It is not feasible to use rewards as a general instrument of law enforcement, e.g. by rewarding people for not stealing, not committing acts of violence etc. From an ethical point of view, it may be more appropriate to introduce an advanced system of road pricing in which drivers would pay for speeding.

6. CONCLUSIONS

The main conclusions of the review presented in this paper can be summarised as follows:

1. Economic policy instruments are, in general, effective in promoting environmentally sustainable transport. Economic policy instruments can be applied to reduce traffic volume, discourage rush hour driving and discourage driving at speeds associated with high fuel consumption and high emissions.

2. The price of motor fuel, congestion charges and toll schemes are all effective instruments for controlling traffic volume.
3. Trials involving rewarding drivers for reducing their driving distance, not speeding and not driving in the rush hours have found that rewards are effective, in particular for discouraging speeding and rush-hour driving.
4. The long-term effects of reward systems are not known, but in some trials a tendency has been found for the effects of rewards to reduce over time.

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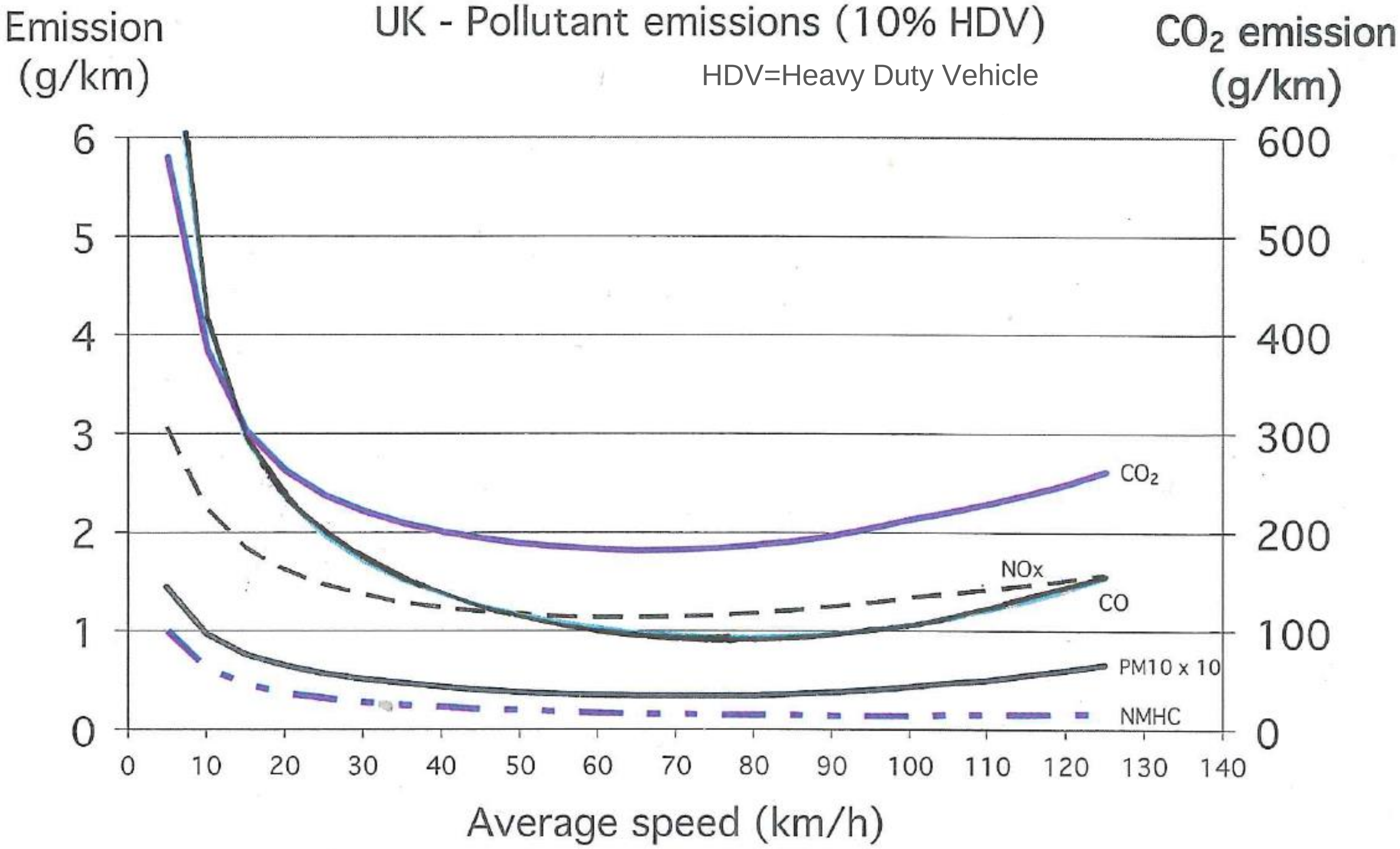
LIST OF FIGURES AND TABLES

Figure 1:



UK - Pollutant emissions (10% HDV)
HDV=Heavy Duty Vehicle
Emission
(g/km)
CO2 emission
(g/km)
6
5
4
3
2
1
0
600
500
400
300
200
100
0
CO2
NOx
CO
PM10 x 10
NMHC
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Average speed (km/h)

Figure 2:

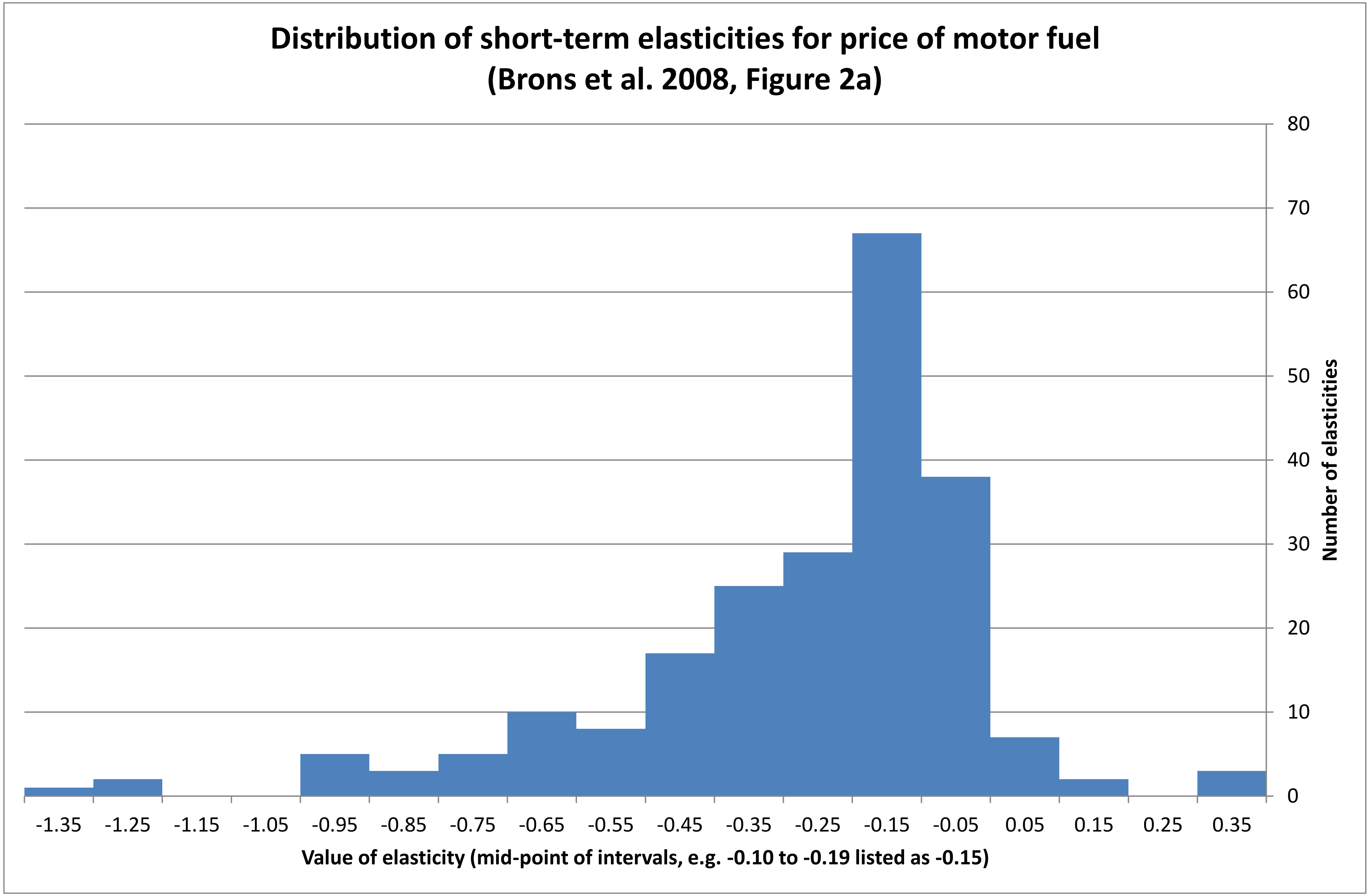
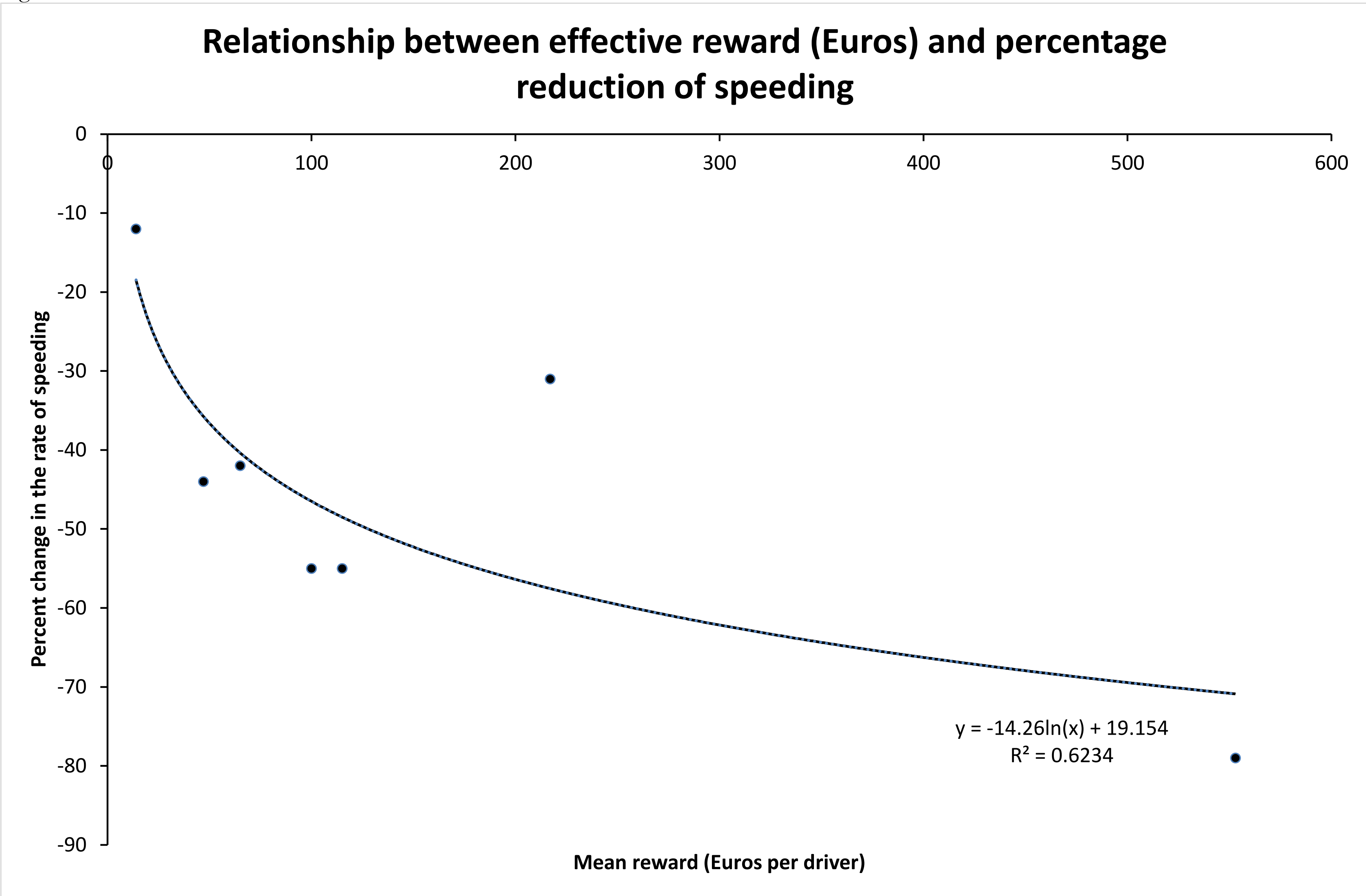

Distribution of short-term elasticities for price of motor fuel
(Brons et al. 2008, Figure 2a)
80
70
60
50
40
30
20
10
0
Number of elasticities
-1.35 -1.25 -1.15 -1.05 -0.95 -0.85 -0.75 -0.65 -0.55 -0.45 -0.35 -0.25 -0.15 -0.05 0.05 0.15 0.25 0.35
Value of elasticity (mid-point of intervals, e.g. -0.10 to -0.19 listed as -0.15)

Figure 3:

	International studies							Norwegian short-term					Norwegian long-term	
Stem	***Leaf***													
-0.0	2	3	3	5	9			3						
-0.1	0	0	4	5	5	5	5	1	4					
-0.2	0	1	2	2	5	9		1	4	6				
-0.3	1	1	5	5	6			6						
-0.4	0	5	5	8				0	3	6	8	9		
-0.5	0	0						0	2					
-0.6								1						
-0.7								5	8				5	9
-0.8	0	3											0	8
-0.9													0	
-1.0	0							8						
-1.1								9						
-1.2														
-1.3														
-1.4														
-1.5														
-1.6														
-1.7														
-1.8														
-1.9														
-2.0														
-2.1														
-2.2								6						

Figure 4:



Relationship between effective reward (Euros) and percentage reduction of speeding
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
100
200
300
400
500
600
Percent change in the rate of speeding
Mean reward (Euros per driver)
y = -14.26ln(x) + 19.154
R² = 0.6234

Figure 5:

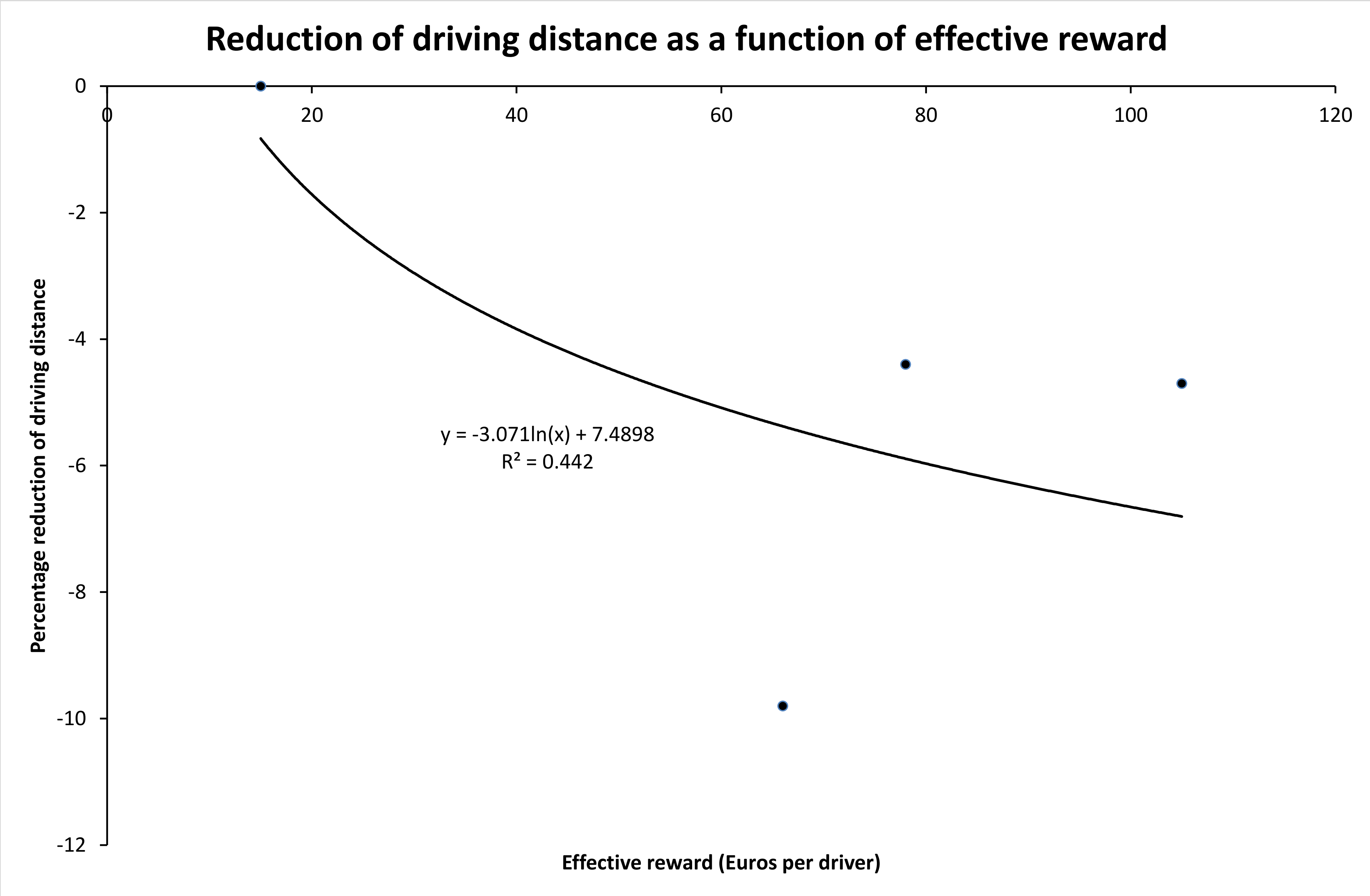

Reduction of driving distance as a function of effective reward
0
-2
-4
-6
-8
-10
-12
0
20
40
60
80
100
120
y = -3.071ln(x) + 7.4898
R² = 0.442
Percentage reduction of driving distance
Effective reward (Euros per driver)

Figure 6:

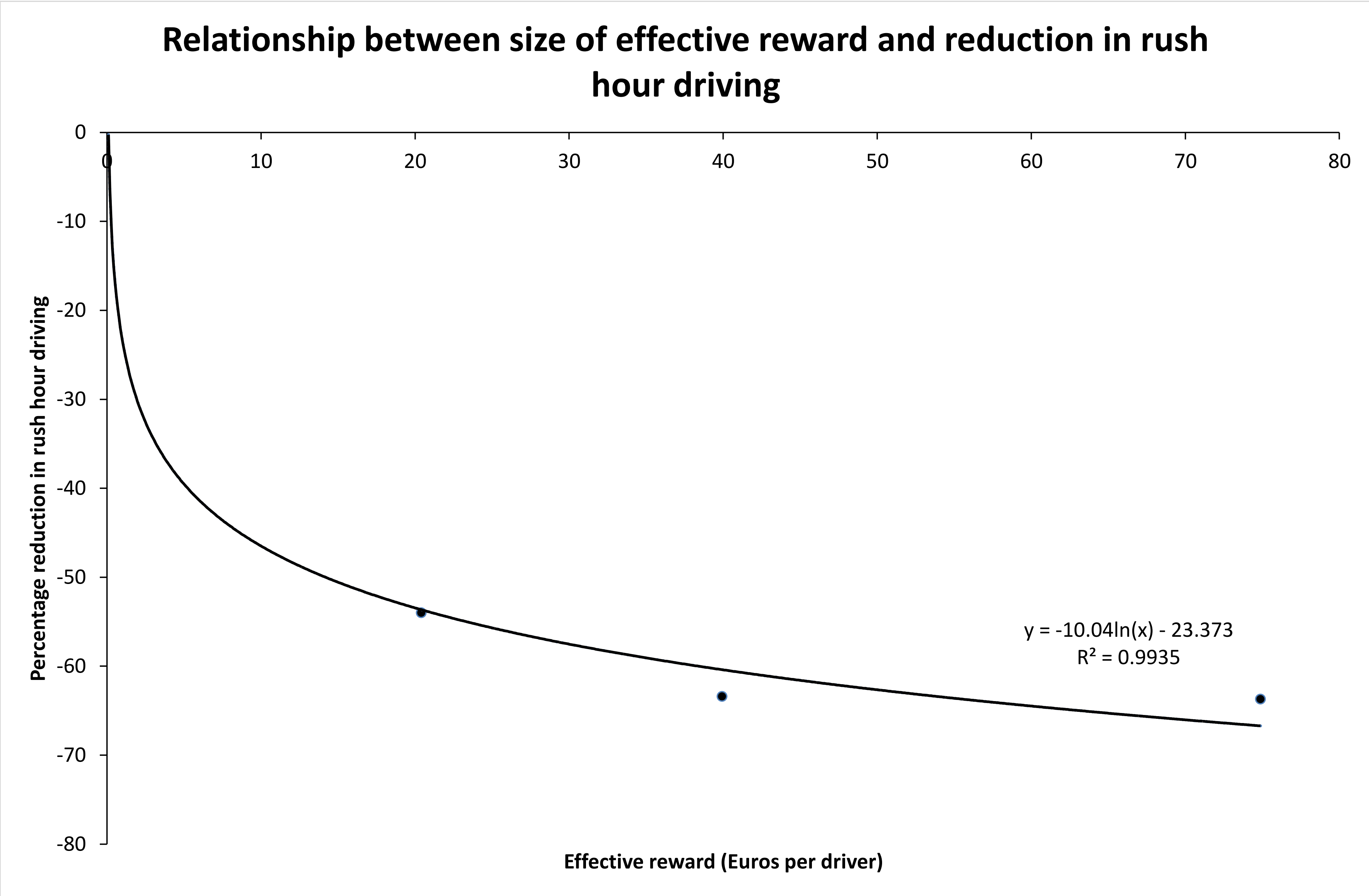

Relationship between size of effective reward and reduction in rush hour driving
Percentage reduction in rush hour driving
Effective reward (Euros per driver)
y = -10.04ln(x) - 23.373
R² = 0.9935
0
-10
-20
-30
-40
-50
-60
-70
-80
0
10
20
30
40
50
60
70
80

Table 1:

Study	Term	Number of estimates	Statistical measure	Value of elasticity
Espey 1998	Short	363	Crude mean	–0.26
			Range	0.00 to –1.36
			Base model mean	–0.16
	Long	277	Crude mean	–0.58
			Range	0.00 to –2.72
			Base model mean	–0.81
Brons et al. 2008	Short	222	Crude mean	–0.27
			Range	0.37 to –1.36
			Fixed effects model mean	–0.36
			SUR model mean	–0.34
	Long	90	Crude mean	–0.77
			Range	–0.12 to –2.04
			Fixed effects model mean	–0.81
			SUR model mean	–0.84