On extracting the impact of consumer behaviour and the rebound effect in passenger car transport in selected EU countries

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1. INTRODUCTION

1.1 Motivation

The current problems arising from motorized individual transport lead to an urgent need for implementing efficient policy measures. To get a reliable appraisal of the effects of different types of policies it is very important to know the impact of the corresponding addressed parameters like energy prices and fuel intensities. Of special relevance in this context is how consumer behaviour and the rebound affect the energy conservation effect especially of technical measures like standards for fuel intensity.

1.2 Core objective

The core objective of this paper is to analyze the impact of price and fuel intensity changes on overall energy demand for car passenger transport in selected European countries.

The method of approach is based on a pooled econometric cross-country-analysis of seven European countries. Differences between countries are modelled mainly by differences in population densities. We focus on analysing the demand for energy (e.g. litre of gasoline and diesel), as well as the demand for service (vehicle km driven). Rather than assuming asymmetries between rising and falling prices we focus on the effects of irreversible efficiency improvements and on corresponding simultaneous analyses of the impact of prices and efficiency improvements.

1.3 What is the rebound?

In the literature the issue of the rebound effect was first raised in 1980 by Daniel Khazzoom (Khazzom, 1980). After that it has been widely recognised and discussed in many papers (e.g. Greene, 1992; Frey et al., 1988, Hirst et al.,1985).
The rebound effect (also called a Takeback Effect) refers to the behavioral responses to the introduction of new more efficient technologies, or other measures taken to reduce energy use, e.g. increase in energy efficiency.
The direct rebound effect is the reduction in energy savings due to the increase in service demand due to cheaper service (prices) due to technical efficiency improvements, see Figure 1.

That is to say, it refers to increased energy consumption that results from actions that increase efficiency and reduce service prices. These responses tend to offset the beneficial effects of the new technology or efficiency improvement.

Figure 1 shows the basic principle of the rebound effect. Point 1 shows the initial situation (E_1 –energy consumption, η_1 –fuel efficiency, S_1 – service, in this case vehicle kilometer driven vkm_1). With the increasing energy efficiency from η_1 to η_2 theoretically energy consumption could be reduced from E_1 to E_2^{th}. Due to the higher efficiency, service price is lower, which causes increase in service demand. Due to the increase in energy efficiency from η_1 to η_2 and the rebound effect energy consumption will be reduced to E_2^{pr} instead to E_2^{th}.

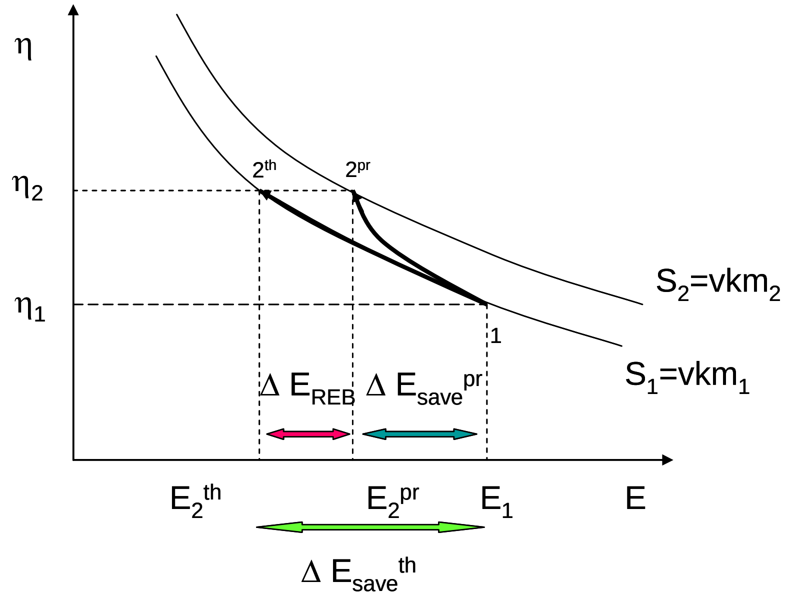

Figure 1. The rebound effect

This basic logic of the rebound effect is not seriously disputed, but there are different opinions regarding its magnitude and significance. According to some researcher (e.g. Lovins, 1988) the rebound is so insignificant that it can be neglected. On the other hand there are also opinions that it might be so large that it nearly defeats the purpose of any energy efficiency improvements.

Greene (1992) investigates the effect of fuel prices and improved fuel economy of automobiles and light tracks on vehicle miles travelled via an econometric analysis of United States statistic data from 1966-1989. The results of this work conform that the rebound effect has been quite small, about 5-15%, or less.

Greening et al (2000) provide a survey on the rebound effect. According to this paper in the period 1990-2000, aggregate studies have consistently shown a small direct rebound effect of about 10% for the short run (one year), increasing to perhaps as much as 20-30% for the ultimate long-run rebound effect.

Sorrell (2007) provides one of the so far most comprehensive and most important works on the rebound.

1.4 Types of rebounds effects

In the literature several types of the rebound effects are defined (see e.g. Greening et al 2000, Dimitropoulos and Sorrell, 2006; Sorrell, 2007):

1. Direct rebound effect: Increased fuel efficiency lowers the cost of service, and hence increases the service demand and energy consumption.

2. Indirect rebound effect: The indirect rebound effect occurs when the reduction of the effective cost of the energy services lead to changes in demands of other goods, services and productive services that also require energy for their provision.

3. Economy wide effects: New technology creates new production possibilities in and increases economic growth. This effect includes the long term effect of the increase in vehicle fuel efficiency on production and consumption possibilities throughout the economy, including any effects on economic growth rates.

In the following analysis we focus on the direct rebound effect only as defined above.

2. FORMAL FRAMEWORK

In the following instead of energy efficiency energy fuel intensity FI will be used:

$$FI = \frac{1}{\eta}$$

Our analysis is based on the basic relation that energy consumption (E) is the product of total vehicle kilometres driven in a country (vkm) and average fuel intensity (FI):

$$E = vkm \cdot FI \tag{1}$$

Energy service price P_s is described by the following equation:

$$P_s = P_E \cdot FI \tag{2}$$

where P_E is energy (fuel) price.

Theoretical savings are:

$$\Delta E_{save}^{th} = vkm_1 \cdot \Delta FI \tag{3}$$

Due to the cheaper services after the improvement of fuel intensity energy saving will be reduced because of the rebound effect:

$$\Delta E_{save}^{pr} = vkm_1 \cdot \Delta FI - \Delta E_{REB} \tag{4}$$

Using the definition of the service price elasticity:

$$\alpha_{vkm,P_s} = \frac{\frac{\Delta vkm}{vkm}}{\frac{\Delta(P_E FI)}{P_E FI}} \tag{5}$$

the difference in vkm driven caused by the rebound effect is calculated as:

$$\Delta vkm_{REB} = \alpha_{vkm,P_s} vkm_1 \frac{\Delta(P_E FI)}{P_{E1} FI_1} \tag{6}$$

Where $\alpha_{vkm,Ps}$ is elasticity of vehicle kilometres driven with respect to service price P_S

Using previous equations and the fundamental definition described in Greene (1997), the elasticity of energy consumption with respect to a change in fuel intensity is derived:

$$\frac{dE}{dFI} = vkm + \frac{dvkm \cdot FI \cdot P_E}{d(FI \cdot P_E)} \tag{7}$$

$$\gamma_{E,FI} = \frac{\frac{dE}{E}}{\frac{dFI}{FI}} = \frac{FI \cdot vkm}{E} - \frac{dvkm}{d(FI \cdot P_E)} \cdot \frac{FI \cdot P_E \cdot FI}{E} = 1 + \alpha_{vkm,P_s} \tag{8}$$

From the last equation it can be seen that the elasticity of energy consumption with respect to a change in fuel intensity ($\gamma_{E,FI}$) is one plus the elasticity of energy service (in our case vkm) with respect to service price.

In case that the fuel intensity is constant in the short-term the elasticity of energy consumption with respect to a change in fuel price (P_E) is equal to the elasticity of energy service (vkm) with respect to service price (P_S):

$$\alpha_{vkm,P_s} = \alpha_{E,P_E}$$

Finally, the rebound effect will be calculated as:

$$\Delta E_{REB} = \Delta S_{REB} \cdot FI_2 \tag{9}$$

3. DATA

Our method of approach is based on a pooled econometric cross-country-analysis of seven European countries, Sweden, Denmark, Italy, France, Germany, Austria and United Kingdom.

The reason for choosing these countries is the following:

We think that it is of special interest and importance that in this analysis we also cover the period of highest volatility of energy prices and highest reduction of fuel intensity 1970-1985. Up to our current knowledge time series for the passenger data required in our analysis are only available from these seven countries.

The data set used in the paper is mainly taken from ALTER-MOTIVE database, (see Ajanovic et al., 2009) and covered the period from 1970 to 2007. Note, some of the earlier data are taken from Schipper at al (1995).

Development of service price in the analysed countries is shown in Figure 2. As can be seen, the range of service prices vary widely across analysed countries. In 2007 service price was between 6,7 and 9.2 EUR/100 km.

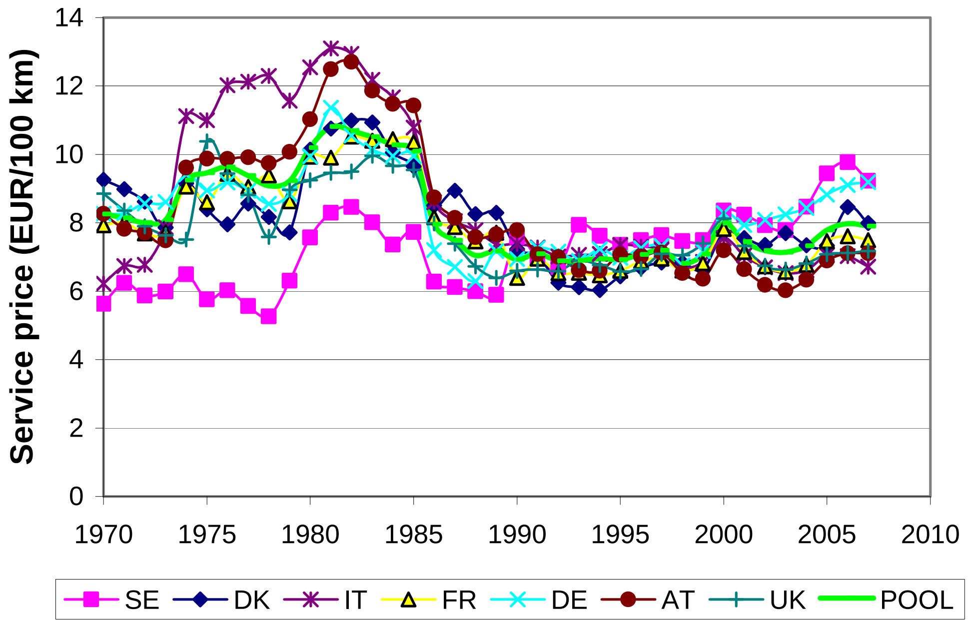

Figure 2. Development of the service price (EUR/ 100 km) for seven EU-countries and the weighted average (POOL) 1970-2007

As shown in Figure 3 since 1980 the average fuel intensity of passenger vehicles is decreasing. In 2007 fuel intensity in analysed countries was in the range from 6.5 and 8.2 litres per 100 kilometres.

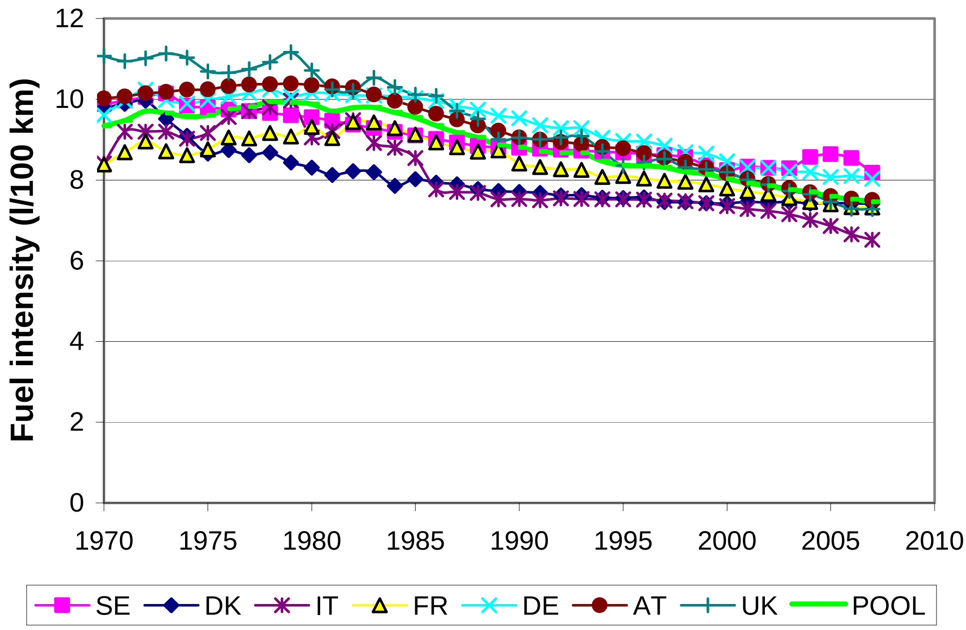

Figure 3. Development of fuel intensity, 1970-2007

Over the analysed period service demand as well as energy consumption was continuously increasing, especially in United Kingdom, France and Italy, see Figure 4 and 5.

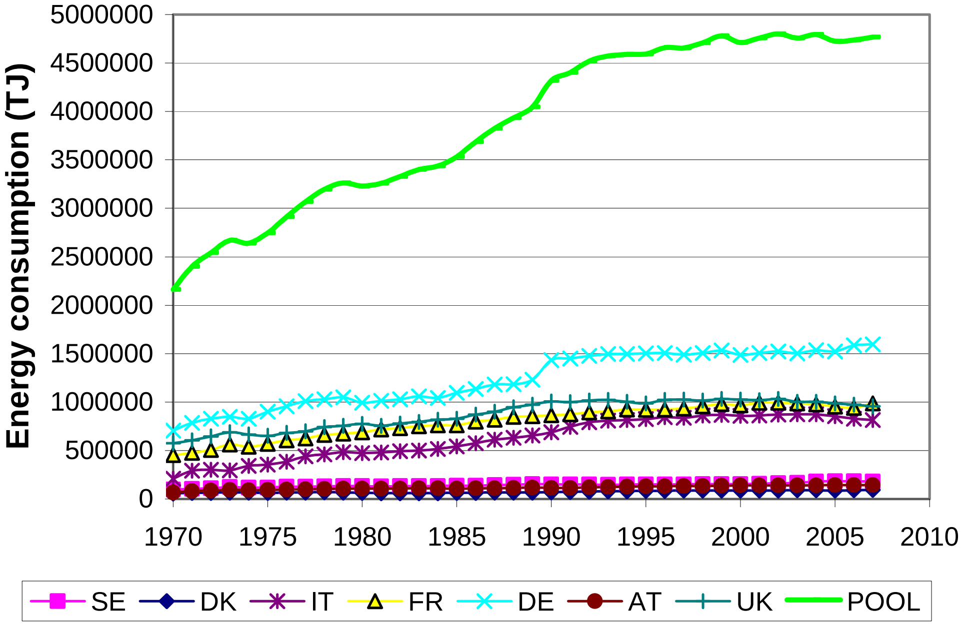

Figure 4. Development of energy consumption, 1970-2007

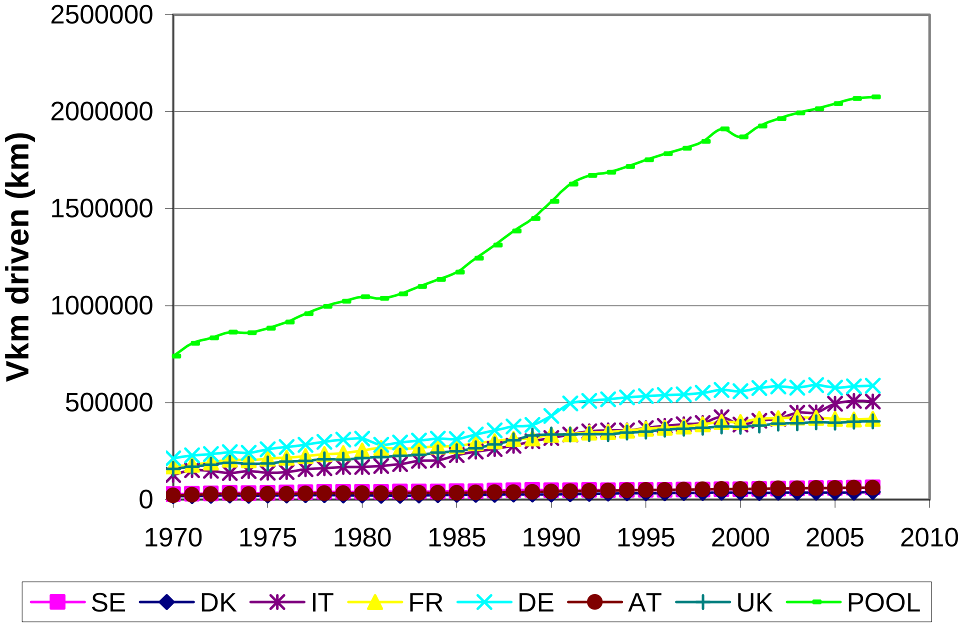

Figure 5. Development of energy consumption, 1970-2007

4. ECONOMETRIC ANALYSIS

As mentioned before, in our analyses we have focused on seven European countries. Differences between countries are modelled mainly by differences in population density. We have analysed changes of demand for energy, as well as demand for service (vehicle kilometres driven), due to the rebound effect. Change of energy price P_E – price effect – is also included in our analysis.

4.1 Service demand

Service demand, vkm, is estimated in five models. We have started with the conventional approach (model 1):

$$vkm = C \cdot p^{\alpha} GDP^{\beta}$$

The differences between countries are modelled mainly by differences in population density and share of diesel use in total fuel consumption (model 4):

$$vkm = C \cdot p^{\alpha} GDP^{\beta} POPA^{\gamma} SHD^{\delta}$$

The major result of this estimation is that the service price elasticity is between -0.27 and -0.32 in the models 1 to 3. This is actually a direct result for the rebound.

With respect to estimates for price elasticity in model 4 and 5 in Table 1 the following aspect is important: α is smaller when diesel share is included explicitly in the estimation because of some multicollinearity:

$$\alpha = f(\delta)$$

Note, that no difference between short-term and long-term price elasticity is expected!

So, in the models 4 and 5 part of the price elasticity is attributed to the switch to diesel cars with cheaper diesel prices.

Table 1. Estimates for service demand 1970-2007 (t-Statistics in parentheses)

Service demand, vkm (1970-2007)					
Model:	**1**	**2**	**3**	**4**	**5**
α (long-term price elasticity)	-0.293 (-7.07)	-0.316*	-0.27 (-6.40)	-0.22 (-5.29)	-0.24 (61.4)
β (long -term income elasticity)	1.06 (143)	1.062*	1.07 (113)	1.06 (112)	1.05 (140)
γ (long -term population density elasticity)			-0.0216 (1.73)	-0.019 (1.60)	
δ (long -term elasticity related to the share of diesel)				0.037 (4.97)	0.0376 (5.03)
λ (Lag)		0.20 (8.30)			
A (short -term price elasticity)		-0.253 (-6.72)			
B (short -term income elasticity)		0.85 (33)			
R^2 korr	0.987	0.989	0.987	0.988	0.98836

*) Calculated from: α=A/(1-λ) , β=B/(1-λ)

The service price elasticity is about -0.3 from model 1 and 2 of Table 1.

4.2. Energy demand

First, total energy consumption is estimated using six different models. We have started with the conventional approach (model 1):

$$E_t = C \; p_t^{\alpha} GDP_t^{\beta}$$

As mentioned before differences between countries are modelled mainly by differences in population density and share of diesel use in total fuel consumption. As shown in Figure 3 there is also a wide range of average fuel intensity across EU-countries. These impacts are considered in model 6:

$$E_t = C \ p_t^A GDP_t^B POPA_t^\Gamma SHD_t^\Delta FI_t^\Phi E_{t-1}^\lambda$$

Long-term elasticities α, β, γ, δ and φ are calculated from short-term elasticities as:

$$\alpha = \frac{A}{1-\lambda} \ , \ \beta = \frac{B}{1-\lambda}, \ \gamma = \frac{\Gamma}{1-\lambda}, \ \delta = \frac{\Delta}{1-\lambda}, \ \varphi = \frac{\Phi}{1-\lambda}$$

The results are presented in Table 2.

Table 2. Estimates for energy consumption 1970-2007 (t-Statistics in parentheses)

Energy consumption (1970-2007)						
Model:	**1**	**2**	**3**	**4**	**5**	**6**
α (long-term price elasticity)	-0.32 (-9.58)	-0.325*	-0.27 (-8.14)	-0.27 (-8.04)	-0.313 (-9.36)	-0.276*
β (long -term income elasticity)	1.04 (185)	1.046*	1.06 (156)	1.06 (147)	1.039 (178)	1.069*
γ (long -term population density elasticity)			-0.045 (-4.88)	-0.042 (-4.62)		-0.046*
δ (long -term elasticity related to the share of diesel)				0.014 (2.21)	00174 (2.66)	0.009*
φ (long -term elasticity related to the fuel intensity)	0.79 (16.0)	0.767*	0.8 (17)	0.86 (16)	0,86 (15.4)	0.83*
λ (Lag)		0.14 (6.6)				0.13 (6.21)
A (short -term price elasticity)		-0.28 (-8.78)				-0.24 (-7.55)
B (short -term income elasticity)		0.90 (40)				0.93 (42)
Γ (short -term population density elasticity)						-0.04 (-4.7)
Δ (short-term elasticity related to the share of diesel)						0.0076 (1.27)
Δ (short-term elasticity related the fuel intensity)		0.66 (13.3)				0.72 (12.96)
R^2 korr	0.992	0.993	0.993	0.993	0.9925	0.994

*) Calculated from: α=A/(1-λ) , β=B/(1-λ), γ= Γ/(1-λ), δ=Δ/(1-λ), φ=Φ/(1-λ)

The major results of Table 2 are: The direct impact of long-term elasticity related to fuel intensity φ is between 0.77 and 0.80 in the models 1 to 3 with considering change to diesel explicitly. If there would be no rebound it should be one. This implies a direct rebound of 0.20 to 0.23.

If we also consider the elasticity of the switch to diesel δ in the models 4-6 we obtain higher values for φ because part of the rebound is already captured by δ and φ=f(δ).

5. RESULTS: HISTORICAL EFFECTS

In the following we describe the results regarding the historical impact of the rebound versus the price effect. Note, that no income effects are considered.

5.1 Service demand

In analyzing service demand we consider only effects due to changes in the service price. These can be brought about by changes in energy price or in fuel intensity.

An important aspect in a historical analysis is to define the base year of the rebound. E.g. it makes a big difference whether we take a starting year with low service demand per GDP or one with high service demand per GDP, e.g. 1970 versus 1985.

Note, that due to equ. (4) the rebound effect depends on ΔFI. So, it is also of interest to look at the level of fuel intensity in the base year of the rebound: As can be seen from Figure 6 there will be a clear difference in the rebound depending on whether the base year is 1978 (year of highest FI), 1970 or e.g. 1993.

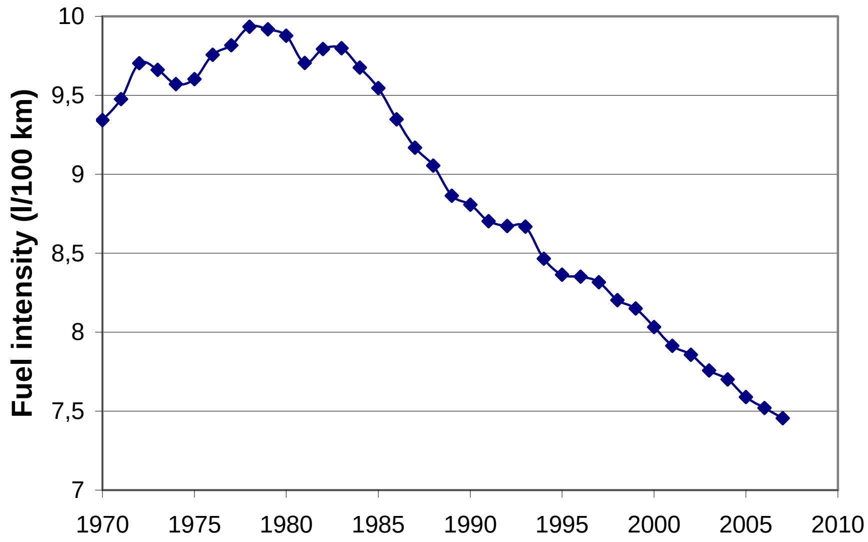

Figure 6. Development of the average weighted fuel intensity, 1970-2007
(Note: Scale started at 7!)

So, total aggregated change Δvkm_{AGG} is:

$$\Delta vkm_{AGG} = \alpha_s vkm_0 \frac{FI_t \cdot P_{Et} - FI_0 \cdot P_{E0}}{FI_0 \cdot P_{E0}} \qquad (10)$$

And it consists of the rebound and the price effect:

$$\Delta vkm = \alpha_s vkm_0 \frac{(FI_t \cdot P_{Et} - FI_0 \cdot P_{Et}) + (FI_0 \cdot P_{Et} - FI_0 \cdot P_{E0})}{FI_0 \cdot P_{E0}} =$$

$$= \alpha_s vkm_0 \frac{P_{Et}(FI_t - FI_0) + FI_0(P_{Et} - P_{E0})}{FI_0 P_{E0}} \qquad (11)$$

With :

$P_{Et}(FI_t - FI_0)$ …. Rebound effect

$FI_0(P_{Et} - P_{E0})$ …. Price effect

Figure 7 depicts the change of vkm due to rebound and price effect. It can be seen that for the base year 1970 in the period 1970-1985 rebound effect and price effect were even negative.

Then until 1999 both effects were positive while after 1999 the signs changed: rebound effect remained positive while price effect led to a reduction in service demand, as well as in energy consumption.

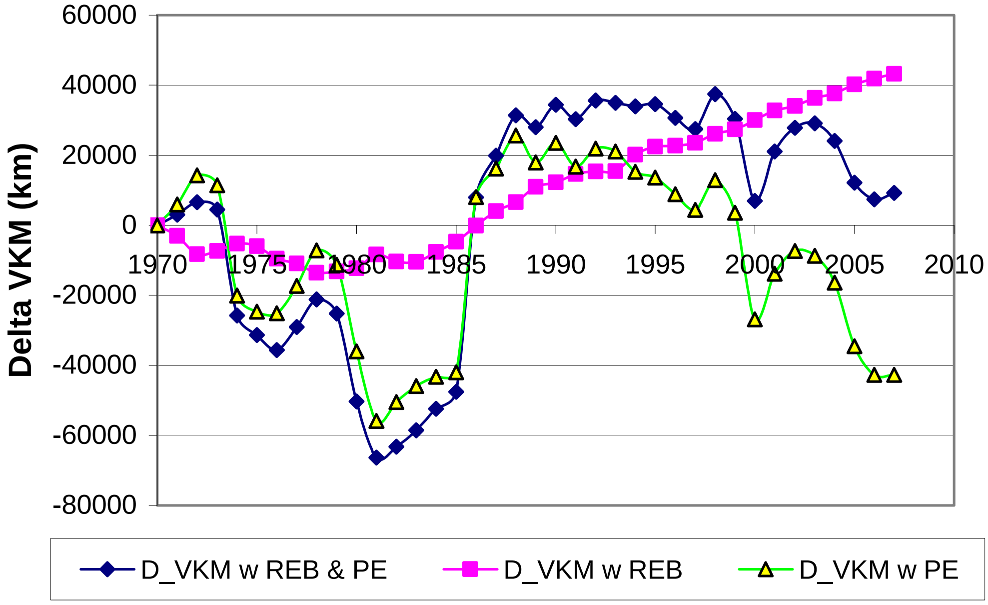

Figure 7. The change of vkm due to rebound and price effect, base 1970

However with maximum impact of +5% for the rebound and about (-)8% for the price effect over a period of 37 years we consider these effects as moderate, see also Figure 8.

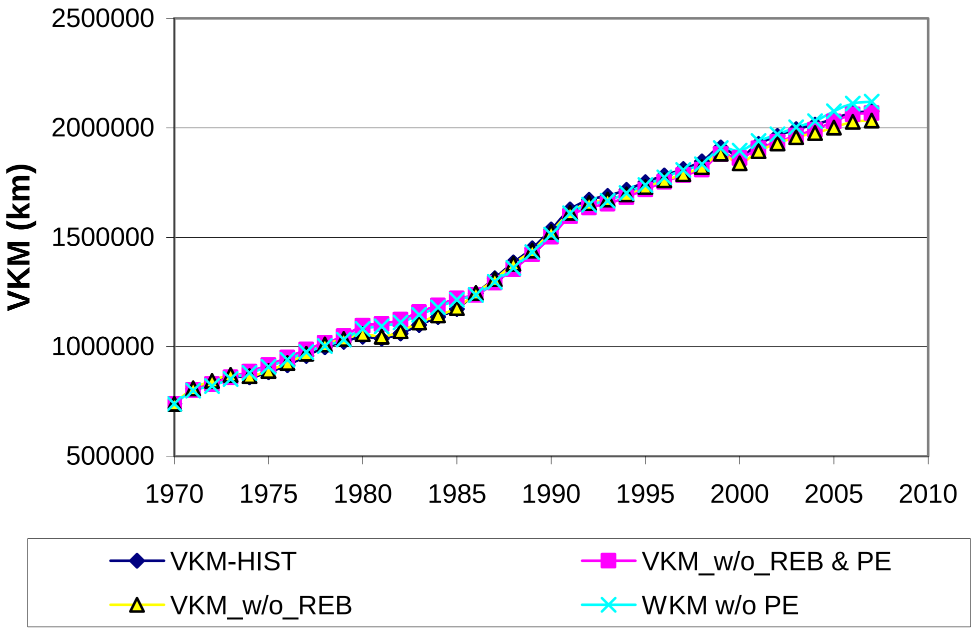

Figure 8. Historic development of vkm in comparison to the impact of rebound effect (REB) and price effect (PE), base 1970

5.2 Energy demand

The changes in energy demand are straightforward obtained from change in service demend by using equ. (1):

$$\Delta E_{CH} = \Delta E_{REB} + \Delta E_{pr-eff}$$

Figure 9 splits up the change of energy consumption due to rebound and price effect.

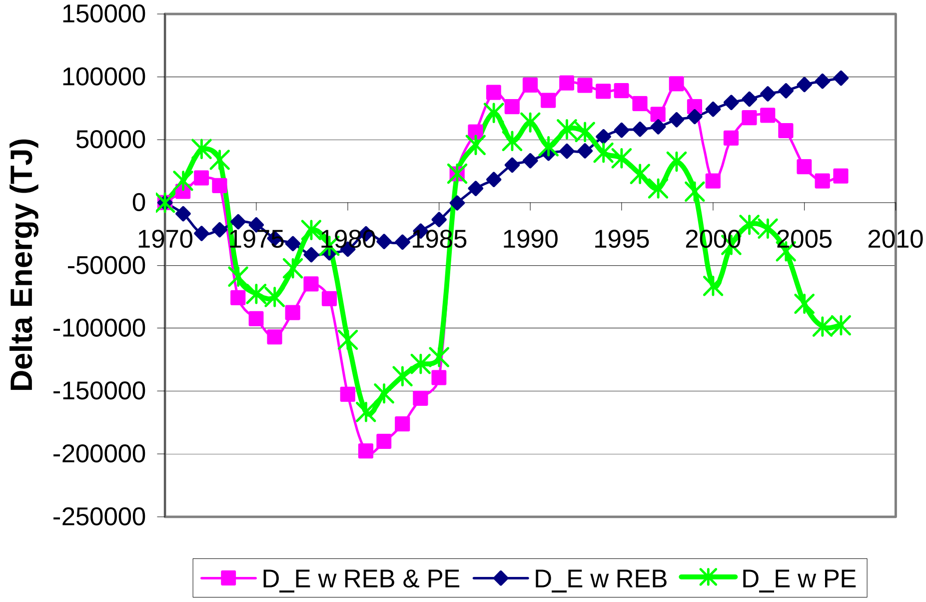

Figure 9. The change of energy consumption due to rebound and price effect, base 1970

Figure 10 depicts the historic development of total energy consumption in comparison to the impact of rebound effect and price effect. We see a similar small overall effect as shown in Figure 8.

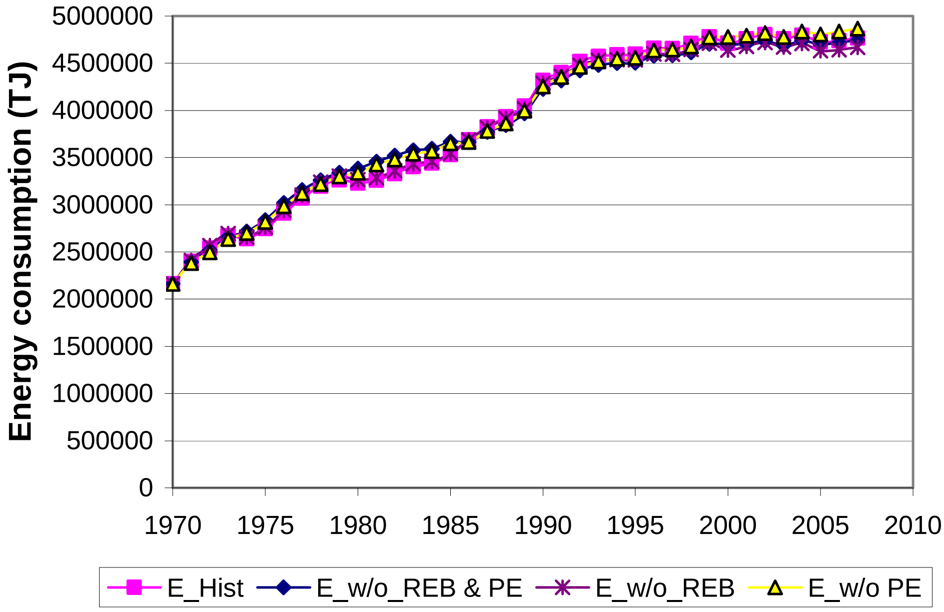

Figure 10. Historic development of total energy consumption in comparison to the impact of rebound effect (REB) and price effect (PE), base 1970

6. FUTURE PERSPECTIVES / SCENARIOS

The core question of interest is, of course, what can be learned from the past for future energy policies. We discuss this aspect in four scenarios using the following assumptions:

In Business as usual scenario (BAU) it is assumed that fuel price is increasing 2% per year, and GDP 2.5%. We have also assumed reduction of fuel intensity of 1.5% per year.

In Tax-Scenario we have assumed additionally to the assumptions in the BAU scenario an increase of fuel tax of 3% per year.

In Standard-Scenario we have assumed additionally to the assumptions in the BAU scenario that fuel intensity has to be reduced also due to the standards for additional 1.1% per year.

The Tax & Standard Scenario is a combination of increasing fuel taxis and improving fuel efficiency due to the standards.

The future development of vkm driven in above described scenarios is shown in following figures.

Figure 11 depict scenarios for the future development of vkm driven for a BAU- and Tax-Scenario with and without rebound up to 2030. It can be seen that due to the rebound vkm driven are slightly higher. As shown with the increasing fuel tax, travel activity could be significantly reduced.

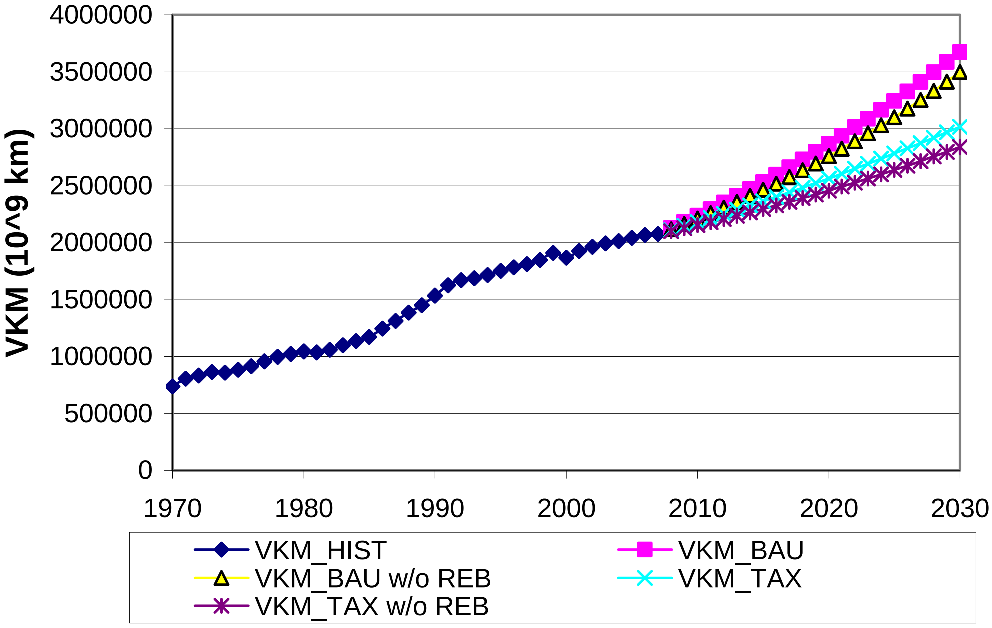

Figure 11: Scenarios for the future development of vkm driven for a BAU and Tax Scenario with and without rebound up to 2030

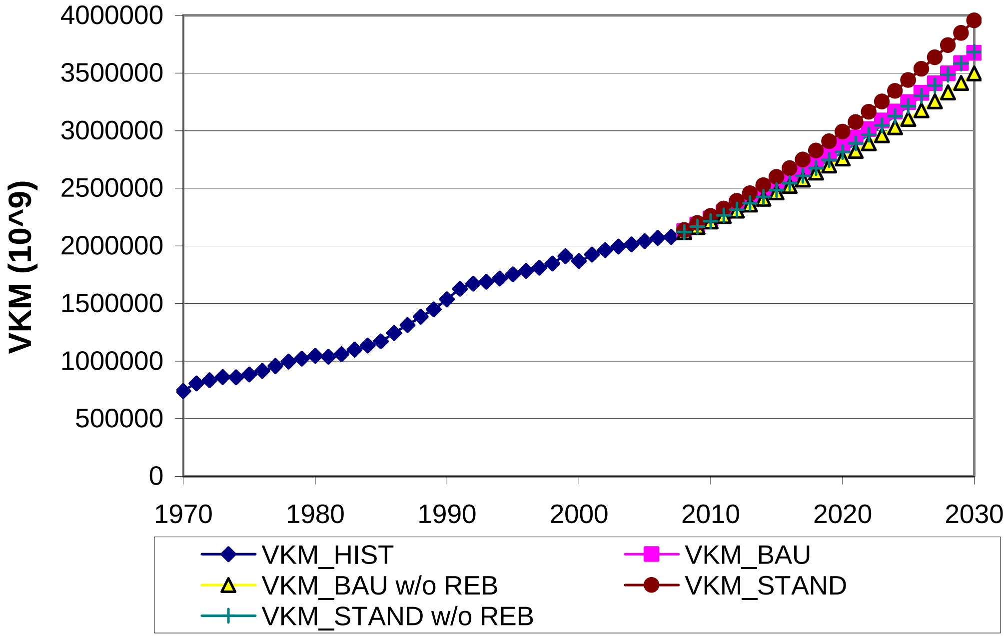

Figure 12. Scenarios for the future development of vkm driven for a BAU and Standard Scenario with and without rebound up to 2030

It can be seen from Figure 12 that due to the rebound the demand for vkm driven increases strongest in the standard improvement scenario higher than in BAU with and without rebound.

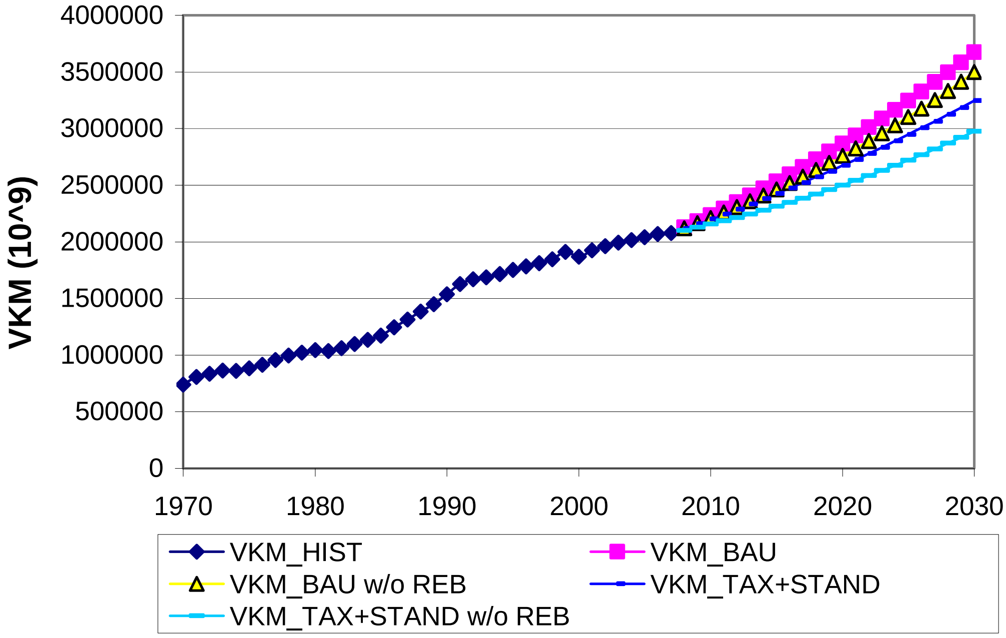

Figure 13. Scenarios for the future development of vkm driven for a BAU and Tax & Standard Scenario with and without rebound up to 2030

To cope with the problem observed due to standards in Figure 12 we introduce in addition to the standard a tax as in Figure 11. So a lower increase in vkm driven could be reached, as shown in Tax & Standard Scenario, see Figure 13.

The future development of energy consumption in four scenarios described above with and without rebound up to 2030 is shown in Figure 14.

Due to the efficiency improvements increases in energy consumption are not as steep as for service, see Figure 14. The pure standard scenario shows lower energy than BAU – on contrary to the effect in Figure 12 and the Tax & Standard Scenario leads to lowest energy consumption, see Figure 14.

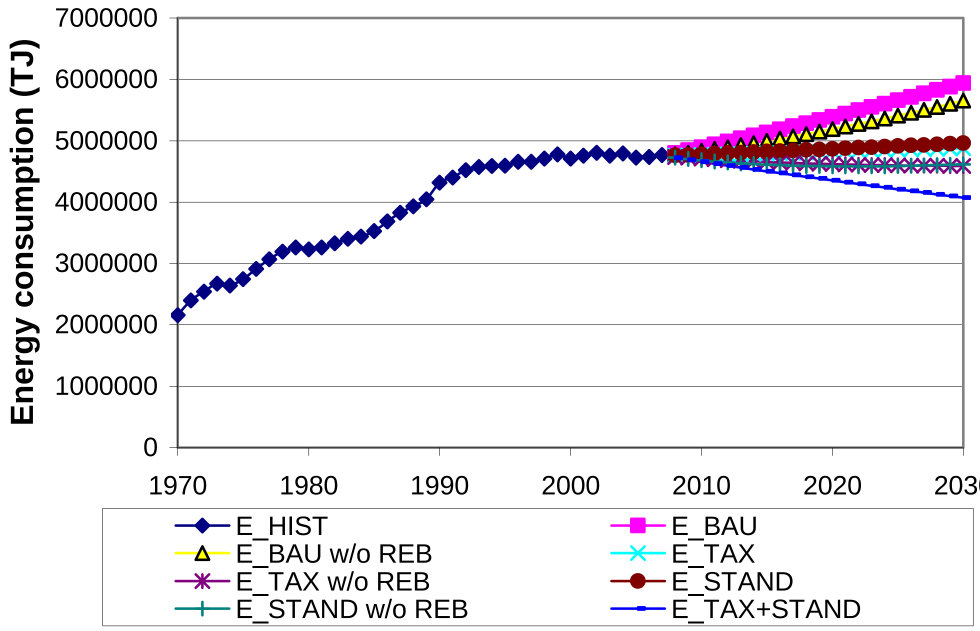

Figure 14. Scenarios for the future development of energy consumption driven four scenarios with and without rebound up to 2030

7. CONCLUSIONS

The major results of this investigation are: The reversible share (=the short term service price elasticity) reflects the rebound effect which turns out to be very stable (about -0.3 for the aggregate of investigated countries). The effect of energy efficiency improvements is about 0.7. This is a very nice result indicating that: (i) price increases e.g. due to taxes (of 1%) lead to energy demand reductions of 0.3% in the short term; (ii) pure efficiency increases (of 1%), e.g. by standards trigger savings of 0.7% (either due to standards or due to lasting price increases).

This leads to the final conclusions that indicate a rebound effect due to consumers short-term behaviour of 0.3% which is in “perfect harmony” with a short-term service price elasticity of 0.3%.

Regarding future policies it is important to note that a rigorous standard policy in addition to the BAU efficiency increases should be accompanied by a fuel tax policy leading to about the same percentage in price increases and compensates by and large for the rebound due to the technical efficiency improvements. .

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