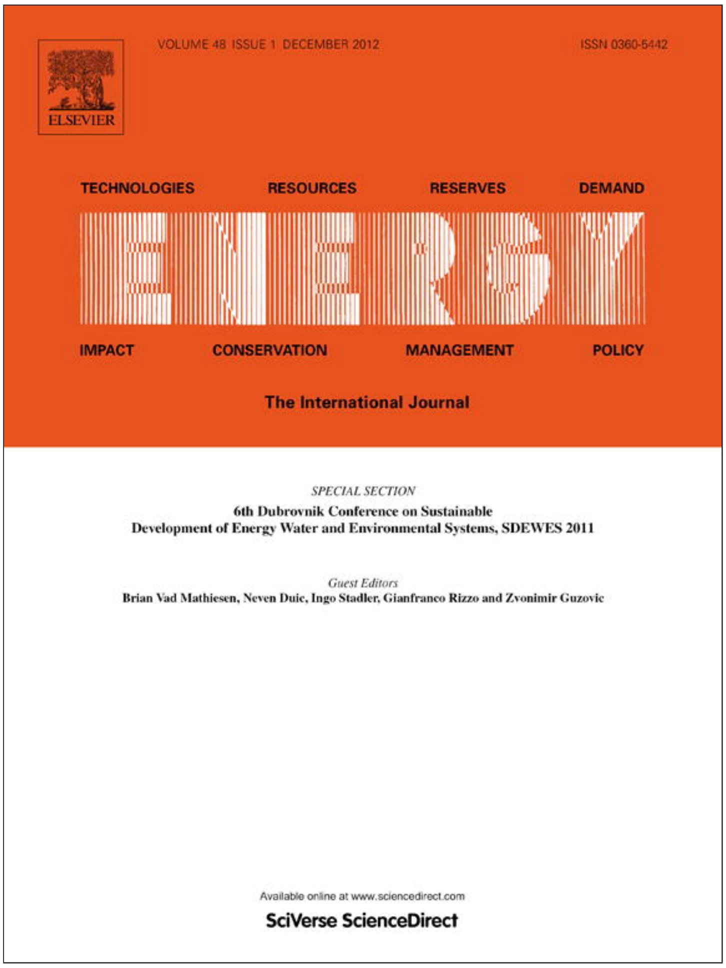
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The impact of more efficient but larger new passenger cars on energy consumption in EU-15 countries☆

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ABSTRACT

The core objective of this paper is to analyse the impact of changes in fuel intensity and car size on energy demand of passenger cars in EU-15 countries. Of special relevance in this context is how the rebound effect due to the change in car fuel intensity and car size (average engine power) affects the energy conservation effect. Lower fuel intensity reduces the cost of car travel, and may lead to further growth in vehicle kilometre driven and car size, while higher fuel prices may offset this effect to some extent.

The major conclusion is that for passenger cars policies that only strive for efficiency improvements will have very limited success. It is necessary to introduce proper additional fuel taxes (to curb the increase in vkm) and size-dependent registration taxes (to avoid excessive increases in car size) to finally harvest the full societal benefits of better car efficiency.

1. Introduction

The current problems arising from motorized individual transport lead to an urgent need for implementing efficient policy measures. Currently, in the EU standards e.g. for CO_2 emissions per km are discussed as a policy tool of priority. To get a reliable appraisal of the effects of standards we have to identify the overall impact of the corresponding parameter fuel intensity on energy consumption. This issue is addressed frequently in the scientific literature see e.g. [1,2] or [3] for some recent work.

The core objective of this paper is to analyse the impact of changes in fuel intensity and car size on energy demand of passenger cars in EU-15 countries. Of special relevance in this context is how the rebound effect due to the change in car fuel intensity and car size (average engine power) affects the energy conservation effect. Lower fuel intensity reduces the cost of car travel, and may lead to further growth in vehicle kilometre driven and car size, while higher fuel prices may offset this effect to some extent.

This is especially important given the remarkable increases in car sizes since the early 1990s. Fig. 1 depicts the average developments of power of cars (kW) for the sample of EU-countries investigated.[1] We can see that continuous increases took place in all countries until 2007 with Sweden leading followed by Germany and UK. Car power was lowest in Portugal, Italy and France. After 2007 average car power decreased or at least stagnated in all countries. It is especially of interest that the absolute increase was rather similar in most countries (except Sweden) – about 30 kW between 1990 and 2010.

It is impressive to look at the development of certain car brands. Fig. 2 shows how the share of the cars with capacities higher than 130 kW developed from 2000 to 2009 for the major European brands. We can see remarkable increase of the typical large brands like Audi, Mercedes and Volvo with peak in 2007. (Note that 2009 was the year of the financial crisis and for 2010 no data are available.) Yet, also for the other brands the share of larger cars has increased compared to the year 2000. Only for BMW this percentage is lower in 2009 than in 2000.

How the segment of four-wheel drives (4 × 4) increased is depicted in Fig. 3. We can see that in Sweden and Germany the shares virtually skyrocketed while the developments in Denmark, France and The Netherlands were very moderate. In this context it is of special interest to look at the corresponding registration taxes

☆ This paper was submitted together with Lee Schipper in spring 2011. Unfortunately, in summer 2011 Lee Schipper passed away.

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[1] Note that all figures for 2010 used in this paper are still preliminary. Yet, to include the very interesting recent developments we have at least considered the so far existing data.

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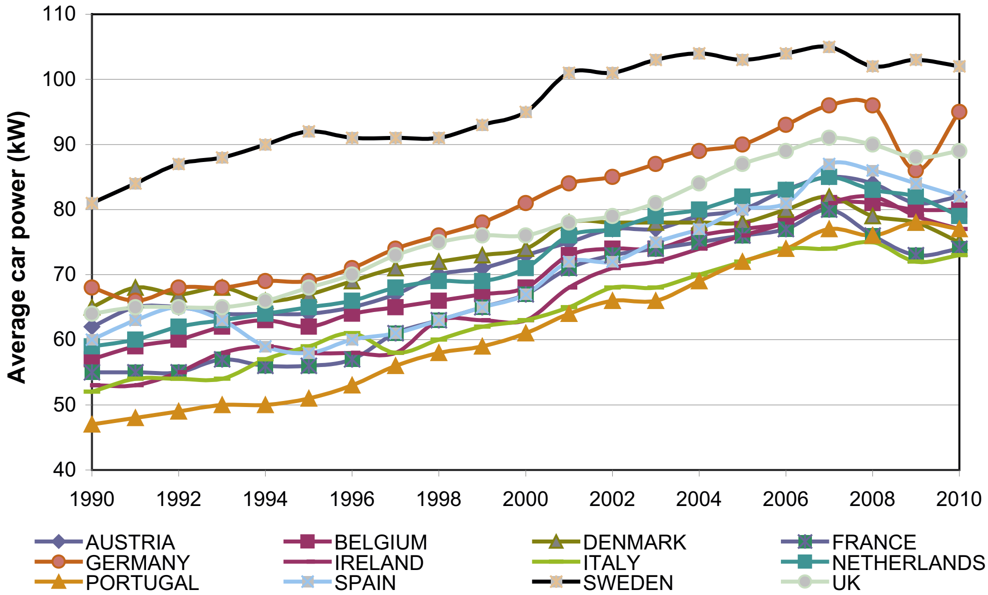

Fig. 1. Average developments of car power (kW) in various EU-15 countries from 1990 to 2010 (Source: [4,5]). Note that vertical axis does not start at zero.

in these countries. As shown in Table 1, the criteria for these taxes are quite different across the European Union. The by far highest registration tax is implemented in Denmark followed by The Netherlands. On the other hand, no registration tax exists in Germany and Sweden with the highest numbers in Figs. 1 and 3.

The phenomena of higher service demand slashing energy conservation effects due to better efficiency has been recognized for a long time in the literature. Yet, there are only very few studies that deal comprehensively with the interaction and relationships between size of cars, vehicle distances driven and fuel intensity of the cars.

Johansson and Schipper [6] try to approach this problem of interaction between fuel intensity and annual driving distance by conducting separated estimations for this parameters and finally aggregating them. Their recommendation regarding policy goes rather in the direction of pursuing various types of taxes.

Clerides and Zachariadis [7] state that “Potential fuel savings due to autonomous technical progress in the past have been counterbalanced by changes in consumer preferences towards … more comfortable cars …”. They are afraid that for social reasons further tax increases in Europe are not achievable. Ajanovic and Haas [8] discuss the effectiveness of standards versus taxes for reducing CO_2 emissions in passenger car transport Europe. They conclude that a combination of both measures brings about the highest benefit for European citizens.

Schipper [2] is one of the first to point out how the size of cars leads to setbacks on fuel efficiency improvements. He resumes that as long sizes and numbers of vehicle km driven “keep creeping up”,

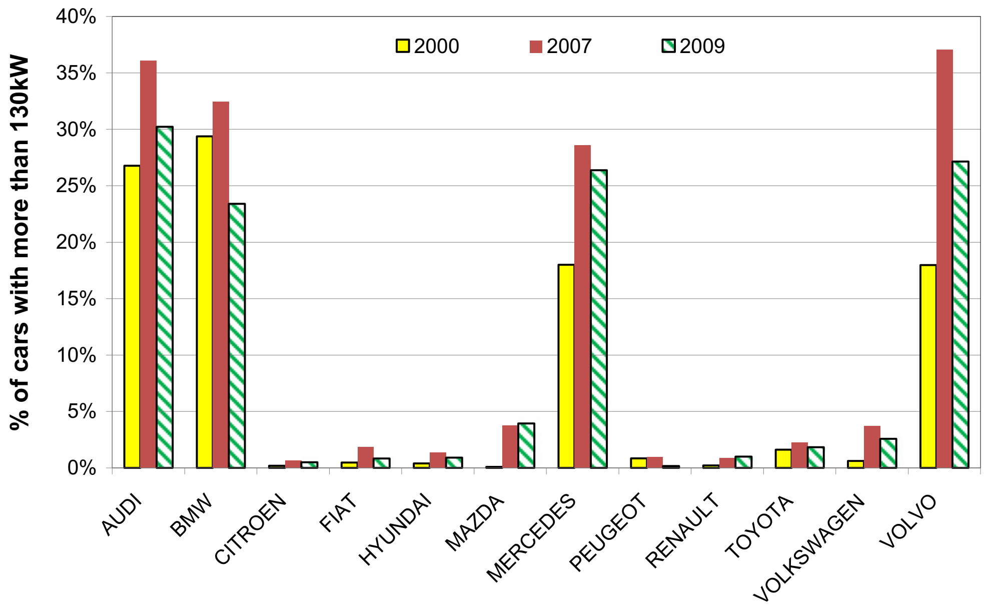

Fig. 2. Share of cars with capacities higher than 130 kW from 2000 to 2010 for some selected brands (Source: [5]).

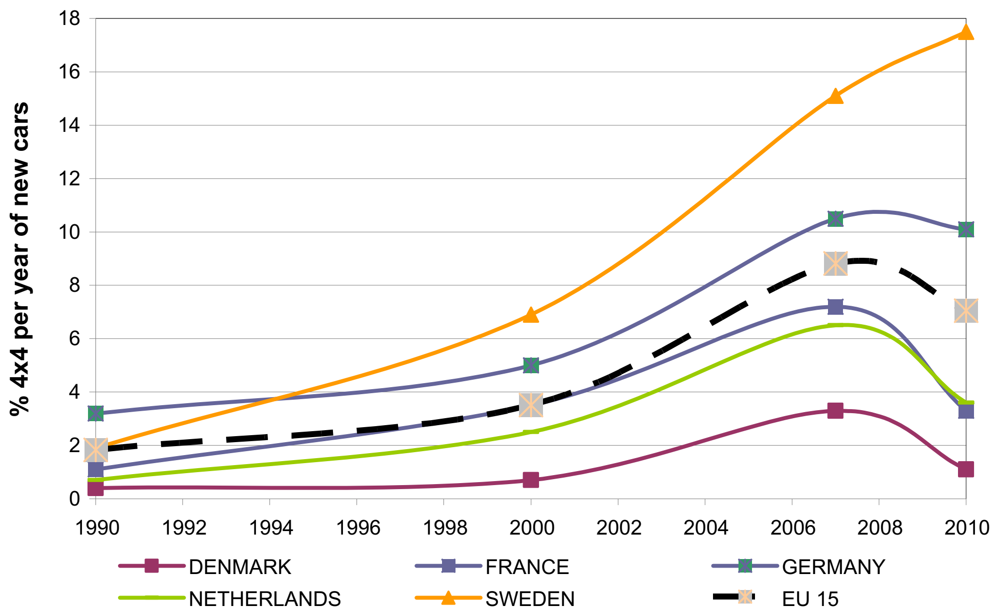

Fig. 3. Development of the segment of 4 × 4 drives in various EU-15 countries from 1990 to 2010 (Source: [4]).

technology will only contribute a minor part to energy conservation. Avelas Ferreira Pinto [9] provides a comprehensive documentation of the evolution of weight and specific fuel consumption of automobiles and its relationship.

2. Method of approach and data used

The method of approach is based on a formal framework analysis applied to passenger car transport of EU-15 countries. We focus on analysing the demand for energy (e.g. litre of gasoline and diesel) as a derived figure from the demand for service for the stock of cars. With respect to service we consider long-term service demand (average engine power of cars) as well as short-term service demand (vkm – vehicle km driven).

A specific aspect of our investigations is to find out the effects of changes in fuel intensity and car size. This is especially important in order to get an appraisal of the rebound effect due to better fuel intensity and higher fuel price. Lower fuel intensity reduces the cost of car travel, and may lead to further growth in vehicle kilometre driven and car size, while higher fuel prices may offset this effect to some extent.

This basic principle of the rebound effect is depicted in Fig. 4. Point 1 shows the initial situation (E_1 – energy consumption, η_1 – fuel efficiency, S_1 = vkm$_1$*kW$_1$). 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 to S_2 = vkm$_2$*kW$_2$.

Table 1
Taxes on acquisition (Data source: [4]).

Country	Registration tax
Germany	None
Denmark	105% up to DKK 79,000 180% on the remainder
France	Based on CO_2 emissions From € 200 (161–165 g/km) to € 2600 (above 250 g/km)
The Netherlands	Based on car price + CO_2 emissions 40% – € 1, 394(petrol) 40% + € 290 (diesel)
Sweden	None

Due to the increase in energy efficiency from η_1 to η_2 and the rebound effect energy consumption will be reduced only to E_2^{pr} instead to E_2^{th}.

The data used for these analyses are mainly taken from:

- ALTER-MOTIVE database & Country review report, see Ajanovic (2009) [10]; www.ALTER-MOTIVE.org
- Schipper (1995) [11];
- IEA, Energy prices & taxes [12];
- OECD, National accounts [13];
- ODYSSEE database [14];
- ACEA statistics [4];
- EC: Monitoring report – Access Database [5];

We use fuel prices P (from IEA [12]) and fuel intensities FI of the stock (based on [10]) to finally calculate weighted service prices Ps (of 2000) per vehicle km driven (vkm) – Ps = P*FI.

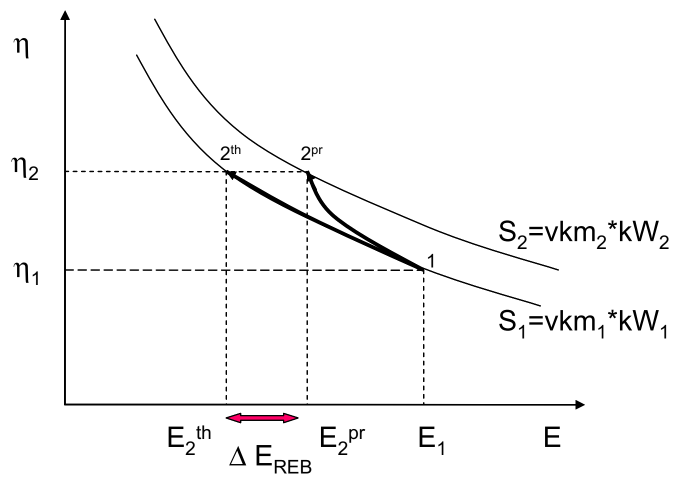

Fig. 4. The rebound effect: increase in vkm driven and car size if efficiency is improved.

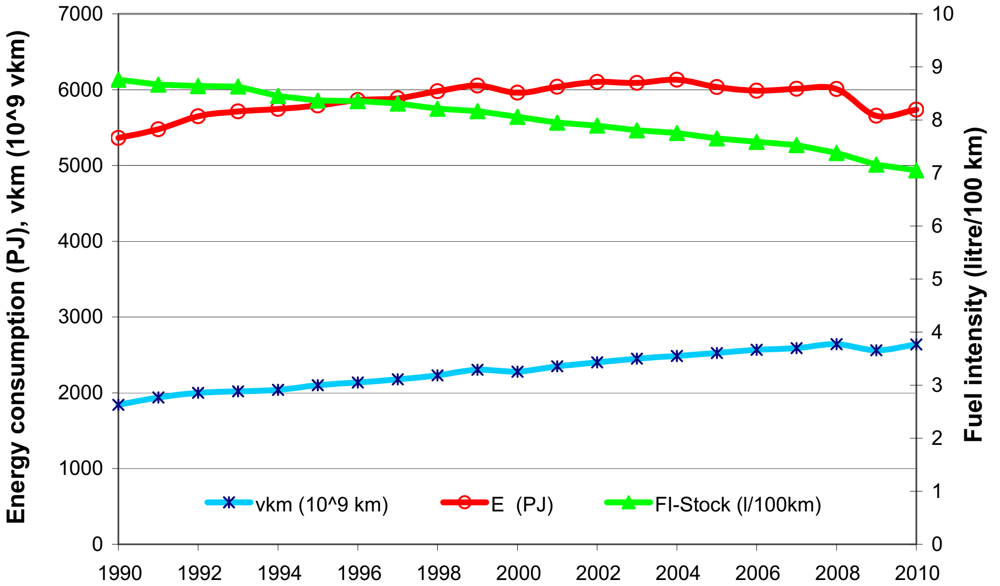

Fig. 5. Development of vehicle km driven (vkm), energy consumption and the fuel intensity of the stock of vehicles in EU-15 from 1990 to 2010.

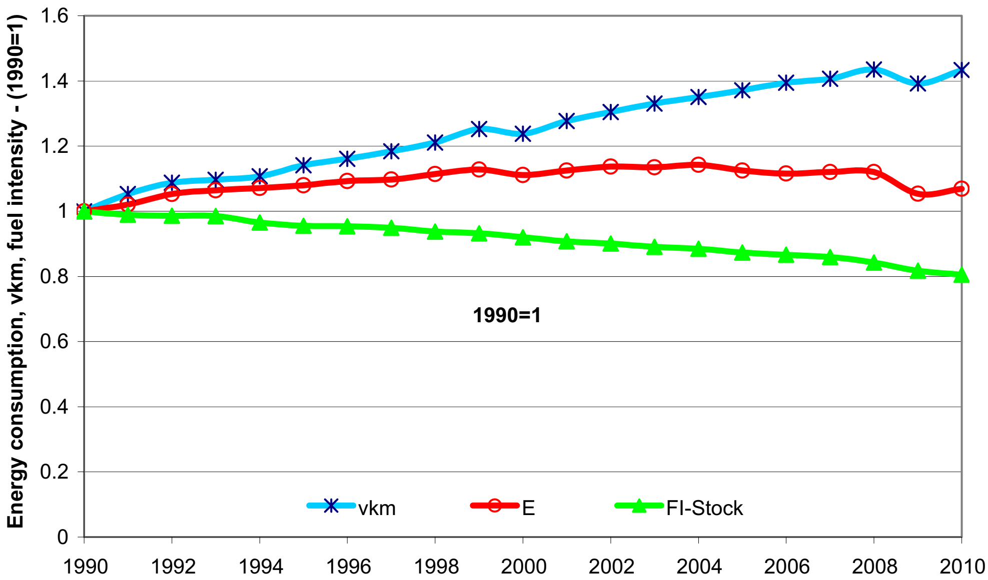

Fig. 6. Normalised development (1990 = 1) of vehicle km driven (vkm), energy consumption and the fuel intensity of the stock of vehicles in EU-15 from 1990 to 2010.

In the Figs. 5 and 6 we describe features of the stock of vehicles. Fig. 5 depicts the development of vehicle km driven (10^9 vkm), energy consumption (PJ) and the fuel intensity (litre/100 km)[2] of the stock of vehicles in EU-15 from 1990 to 2010. It can clearly be seen that energy consumption is stagnating since about 1998. Yet, vkm has still increased almost continuously. Fig. 6 depicts the same development for normalized figures, setting the values of 1990 equal to 1.

In the next Figs. 7 and 8 we show features of new vehicles. It is important to note that in this paper some analyses – e.g. regarding vkm – a based on data of the stock and some other analyses – e.g. the size of vehicles – are based on data of new vehicles. The major reason is that for the stock no kW-related data are available and for new vehicles no data for vkm are available.

Regarding power in this paper we first look at new vehicles. Fig. 7 shows the development of fuel intensity, power-specific fuel intensity and power (kW) of new vehicles in EU-15 from 1990 to 2010. Fuel intensity (FI) in Figs. 7 and 8 does not reflect the real efficiency improvement because it is distorted by the switch to larger cars. To correct for this we define a power-specific fuel intensity (FIP), see also Schipper [2]:

$$\mathrm{FIP} = \frac{\mathrm{FI}}{\mathrm{kW}}(\mathrm{litre}/(\mathrm{km\ kW})) \tag{1}$$

kW…vehicle power.

It can clearly be seen from Figs. 7 and 8 that the decrease in FIP from 1990 to 2009 was virtually twice as high as the decrease of FI.

[2] Note, that litre refers to litre gasoline equivalent throughout the reminder of the paper.

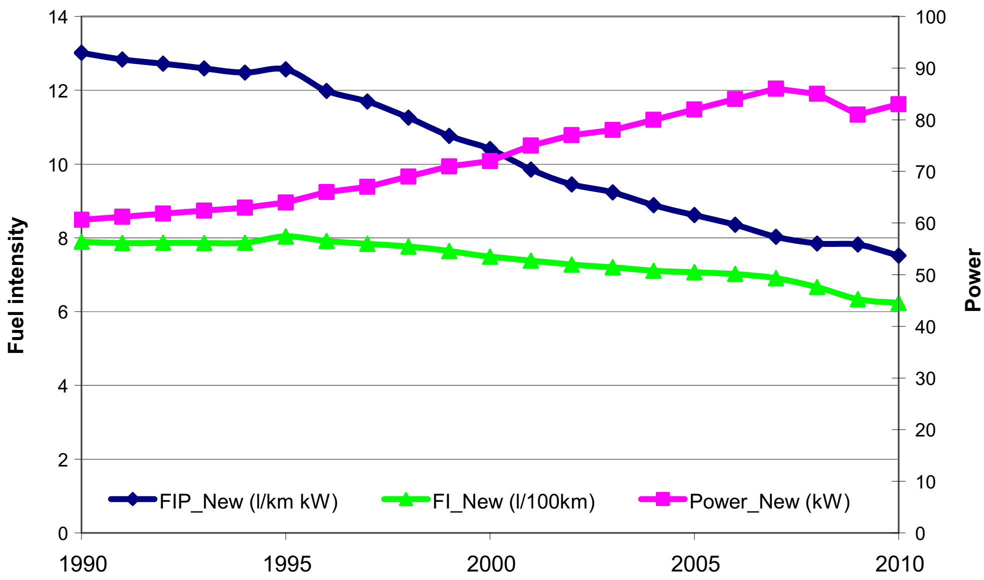

Fig. 7. Development of fuel intensity, power-specific fuel intensity and power (kW) of new vehicles in EU-15 from 1990 to 2010.

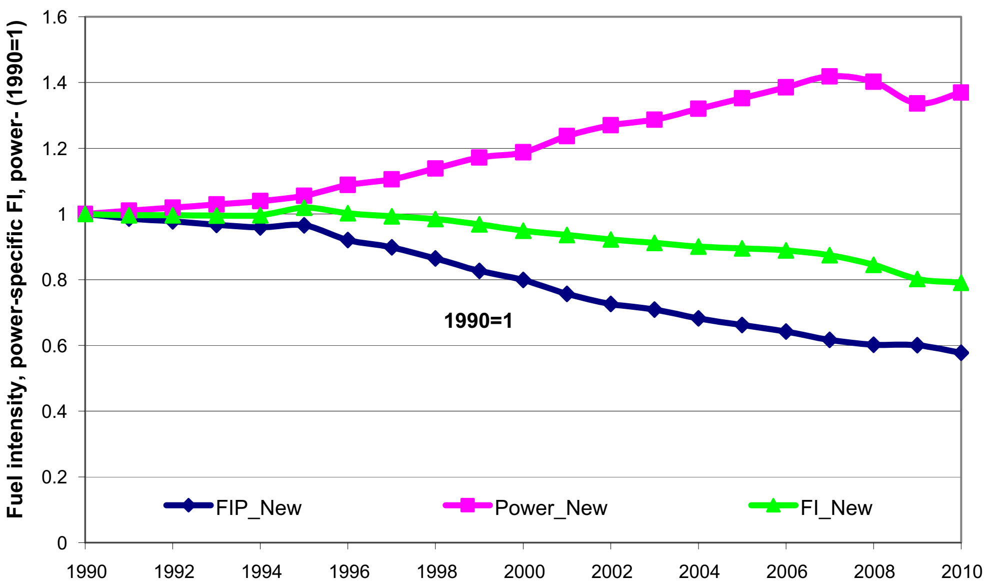

Fig. 8. Normalised development (1990 = 1) of fuel intensity, power-specific fuel intensity and power (kW) of new vehicles in EU-15 from 1990 to 2010.

However, for our analysis the impact of the average power of the stock (kW) is of interest. Using kind of a Weibull distribution for the remaining vehicles of the last years in the stock we have calculated average kW of the stock from 1990 to 2010. The result is documented in Fig. 9.

3. Estimating elasticities of service demand

The basic relationship for the following analyses is that energy consumption is the product of demand for services and fuel intensity (see e.g. [15–17]).

$$E = S \cdot \mathrm{FI} \tag{2}$$

The analysis in this paper builds on Ajanovic and Haas [8,18]. They have analysed the rebound effect due to improvements in fuel intensity FI (l/100 km driven). Fuel intensity was used as a proxy for the reverse of efficiency.

The first step in this analysis is to estimate the price elasticity of service demand. It is important to note, that due to the definition of service price – $P_s = P^*\mathrm{FI}$ – this elasticity covers both, the impact of fuel price[3] and the impact of fuel intensity.

The level of service demand S of e.g. a household with respect to km driven depends on available income Y and the price of energy service P_S:

$$S = f(P_S, Y) = f(P \cdot \mathrm{FI}, Y) = C(P \cdot \mathrm{FI})^{\alpha} Y^{\beta} \tag{3}$$

[3] The fuel price P is the weighted average of the price of gasoline and diesel weighted per kWh fuel.

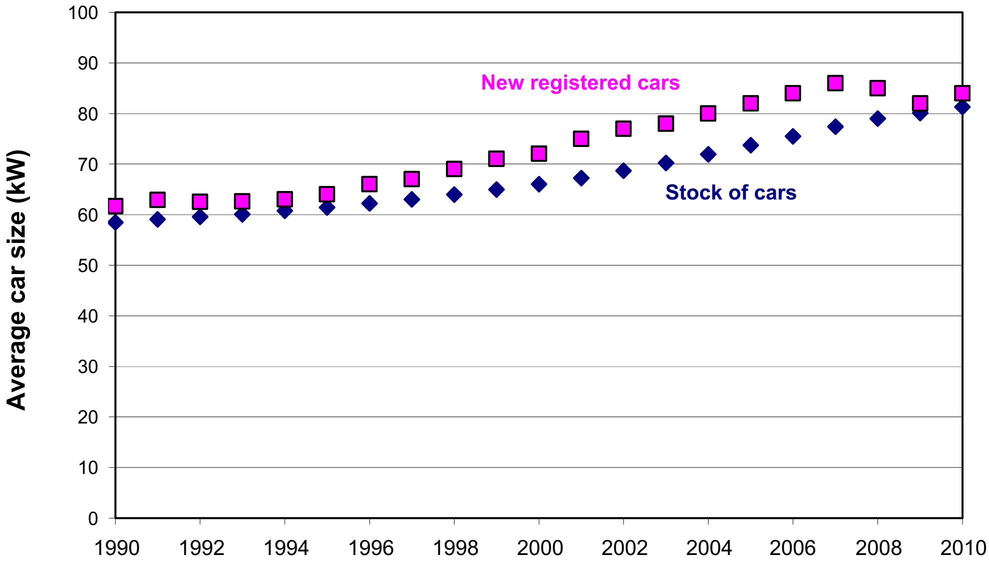

Fig. 9. Development of average power of new cars versus average power of total car stock (Source: [4,5]).

We estimate the impacts on vkm driven by using a cointegration approach:

$$\ln S_t = C + \alpha \ln P_{S_t} + \beta \ln Y_t \tag{4}$$

where C: Intercept, S_t: Demand for service, vehicle km driven in year t in a country, P_{S_t}: Weighted average price of service vkm driven (calculated by means of weighted fuel prices), Y_t: Real private final consumption expenditures.

The most interesting numbers of this analysis are the service price elasticities because they contain information for both – price and efficiency impact.

The results of cointegration are shown in Tables 2 and 3.

For the econometric analysis in this paper we used only 10 EU-countries from which we had sound data for vkm, price and fuel intensity. Because for 2008–2010 some data are still preliminary these were not used in the econometric analysis.

Table 2
Estimates for long-term overall service demand for period 1980–2007 (t-statistics in parentheses).

	Model
C (intercept long-term)	6.71 (13.3)
α (long-term service price elast.)	−0.42 (−8.41)
β (long-term income elasticity)	0.97 (21.1)

Table 3
Estimates of ECM for overall service demand for period 1980–2007 (t-statistics in parentheses).

	Model
ARDL order	(1,0,0)
C (intercept short-term)	2.59 (8.61)
A (short-term service price elast.)	−0.16 (−7.92)
B (short-term income elasticity)	0.37 (5.08)
ECM(−1)	−0.38 (−6.26)
R^2 ADVANCE \l 12 ADVANCE \u 14 _ ADVANCE \d 14	0.75
RESS	0.00187
F-Stat	27.65
AIC	86.9
SBC	84.3
DW	1.96

*ARDL (AutoRegressive Distributed Lag); AIC (Akaike Information Criteria); ECM (Error-Correction-Model); DW (Durbin-Watson statistic).

4. The impact of fuel intensity

Ajanovic and Haas [14] have shown how to conduct an estimation of the effect of changes in fuel intensity including a saving effect and a rebound effect because of increases in service demand (S) and the price effect.[4] In the following S is equal to vehicle km driven (vkm).

Using derivations of Eq. (3) the change in service demand (dS) can be split up into the fuel price, the efficiency and the income effects:

$$\mathrm{d}S = \frac{\partial f}{\partial P}\mathrm{d}P + \frac{\partial f}{\partial \mathrm{FI}}\mathrm{dFI} + \frac{\partial f}{\partial Y}\mathrm{d}Y \tag{5}$$

In this paper we are further on interested in the change of service demand due to a change in the fuel price and the fuel intensity. We do not look at the income effect.

We proceed further using this equation and we obtain for the change in energy consumption:

$$\mathrm{d}E = S\mathrm{dFI} + \mathrm{FI}\mathrm{d}S \tag{6}$$

Next the effect of an exogenous aggregated fuel intensity change is analysed. Note that this FI also encompasses the switch to larger cars.

With the definition of service price elasticity:

$$\mathrm{d}S = \alpha \cdot S \frac{\mathrm{dFI}}{\mathrm{FI}} \tag{7}$$

we obtain for the total energy change from a change in FI:

$$\mathrm{d}E(\mathrm{dFI}) = S(1+\alpha)\mathrm{dFI} = S\mathrm{dFI} + \alpha S\mathrm{dFI} \tag{8}$$

Fig. 10 shows the two effects due to changes in fuel intensity from Eq. (8). The first effect is change in demand from driving more fuel efficient vehicles the same number of miles (SdFI). In Fig. 10 we see that in 2010 the total change in FI led to total energy savings dE(dFI) of about 970 PJ. The second effect is the energy change from driving more kilometres, (α S dFI) called the rebound effect due to

[4] For better reading and following the arguments we repeat part of this formal analysis here.

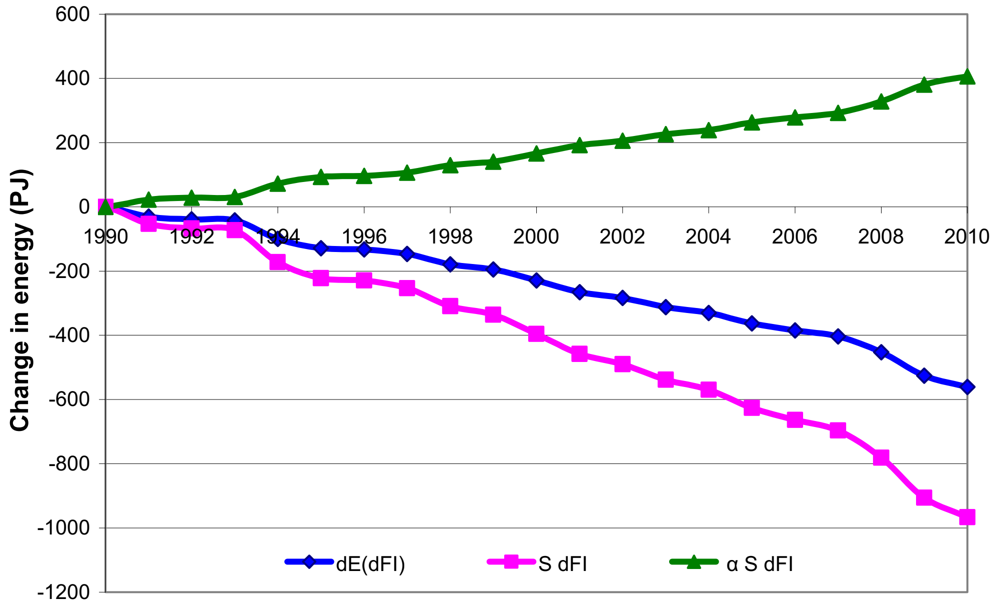

Fig. 10. The change of energy consumption due to changes in fuel intensity for EU-15, base 1990.

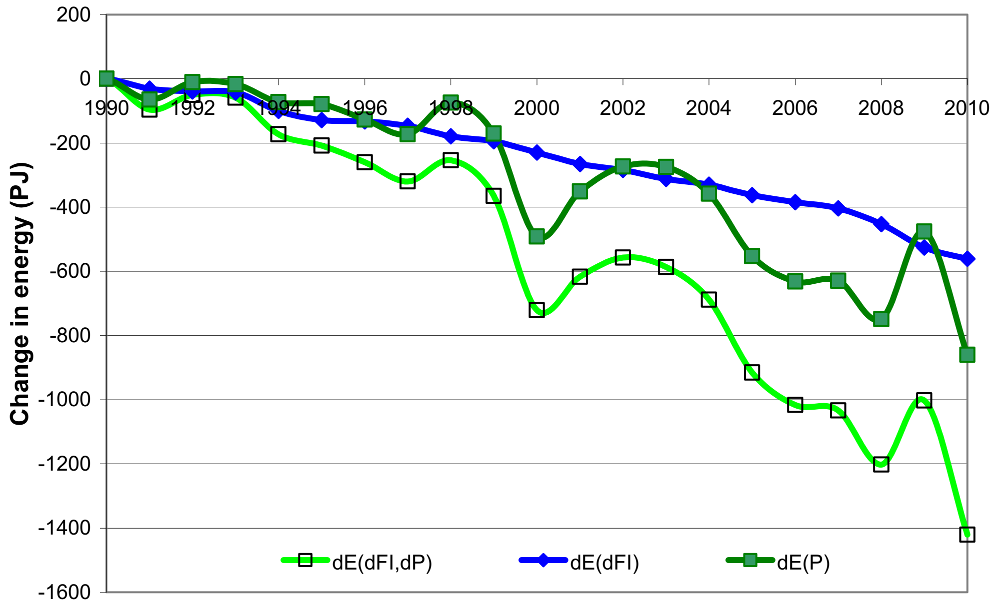

Fig. 11. The change of energy consumption due to changes in fuel intensity and fuel price for EU-15, base 1990.

more driving. An example to explain the rebound effect in detail see also [8]:

Assume FI of old car is 60 kWh/100 km and service price elasticity is −0.4. If it is improved by 10% and we have 10,000 km driven, we calculate theoretical savings of (60/100) 0.1·10,000 = 600 kWh. Yet due to the rebound we currently drive 240 km more because we use FI and not FIP. This is 10,240 km – we now save only 360 kWh. Note that this rebound is too small because it is curtailed by the switch to larger cars. This rebound effect led already to an additional energy consumption of about 410 PJ, and only about 560 PJ savings remained.

5. The impact of fuel price

Next we calculate the effect of the energy price on energy consumption.

The change with respect to price is:

$$\frac{dE}{dP} = \frac{SdFI}{dP} + \frac{FIdS}{dP} \tag{9}$$

The change in energy demand (if $dFI/dP = 0$)[5] due to the direct price effect is:

$$\frac{dE}{dP} = \frac{FIdS}{dP} \tag{10}$$

We can identify the change in S using the equation for the definition of the price elasticity and we obtain for dvkm:

5 In the long run, lasting price changes will have an impact see e.g. Walker/Wirl (1993) [16].

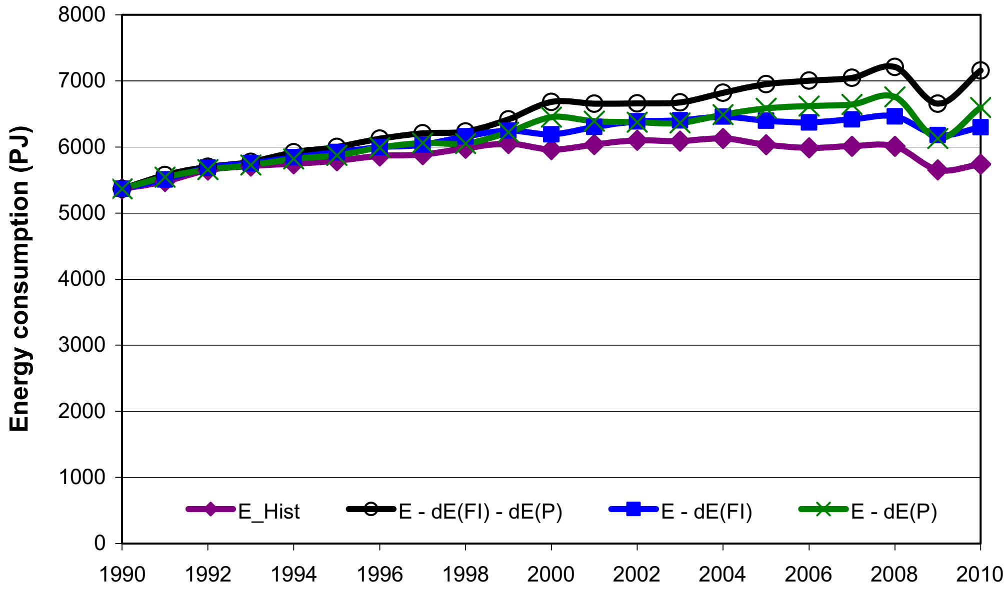

Fig. 12. Historic development of total energy consumption in comparison to the impact of fuel intensity and the fuel price for EU-15, base 1990.

$$dS = \alpha \cdot S\frac{dP}{P} \tag{11}$$

and the total energy change from a price change is

$$dE(dP) = FI\alpha S\frac{dP}{P} \tag{12}$$

Fig. 11 shows the price effect of a change in energy consumption. At the end of the investigated period in 2010, there was a price effect of about 860 PJ energy savings compared to 1990. As shown in Fig. 11, due to the volatility of the fuel price, the price effect can lead to higher or lower energy consumption.

Fig. 11 also depicts the overall change in energy consumption due to a change in fuel intensity ($dE(dFI)$) and the price effect ($dE(dP)$). With respect to the fuel intensity effect savings in 2010 compared to the base year are about 560 PJ. In total the price and the FI effect brought energy savings dE of about 1420 PJ.

Fig. 12 puts the historic development of total energy consumption in comparison to the impact of fuel intensity and the fuel price for EU-15, base 1990. We can see that without price effect and without FI effect energy consumption would have been about 1420 PJ (about 25%) higher.

6. The impact of size

However, the analysis described above has been distorted because the used FI has been diluted by more powerful cars leading to lower FI reduction than the kW-related FIP, see Figs. 7 and 8.

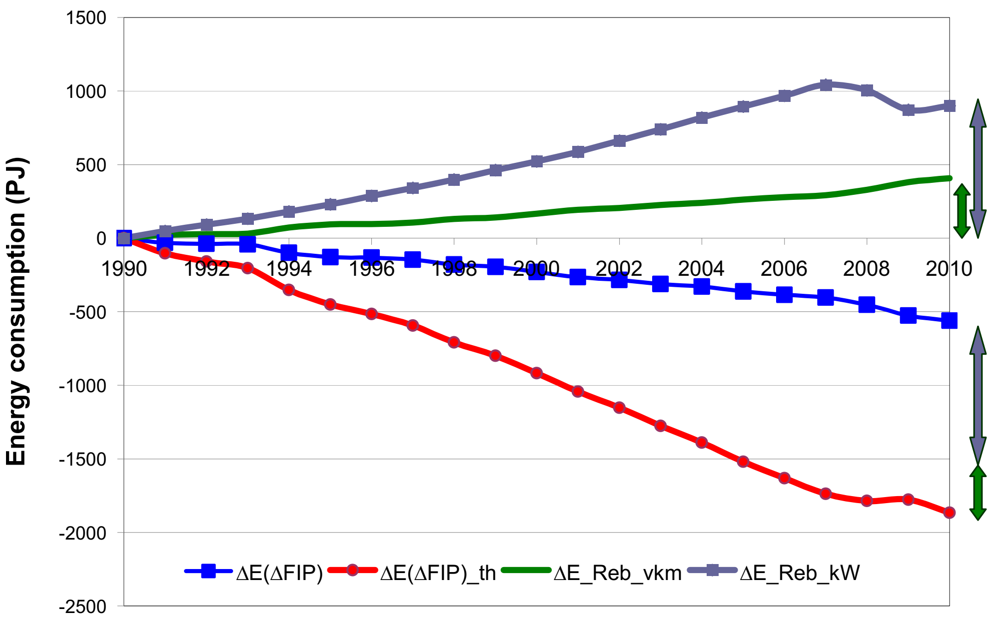

Fig. 13. The impact of more km driven and switch to larger cars on total passenger car energy consumption, base 1990.

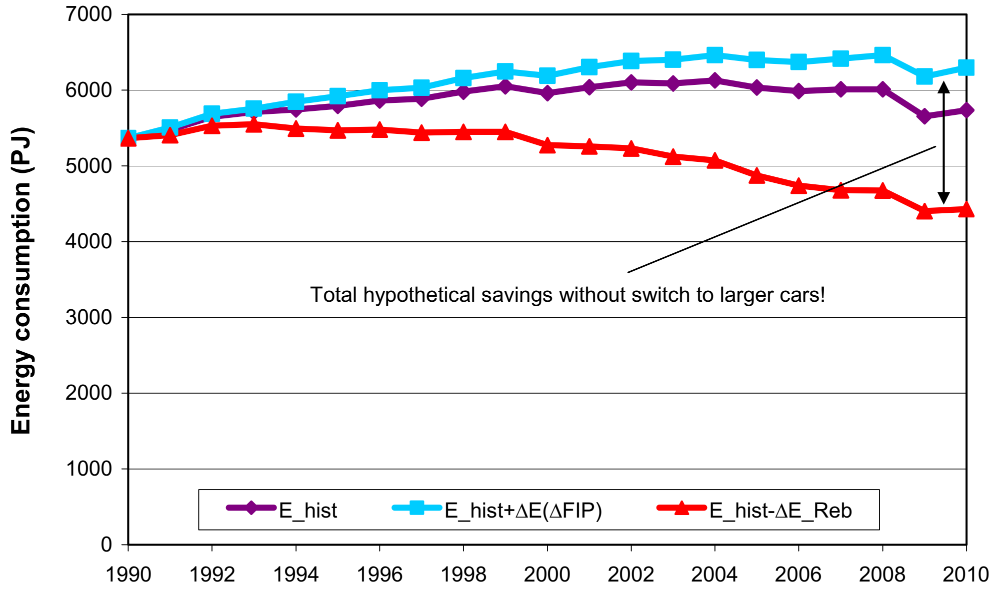

Fig. 14. Historic development of total energy consumption in comparison to the impact of fuel intensity and switch to larger cars, base 1990.

Next we analyse the impact of vkm driven and the increase of average car power (kW) explicitly.

To do so, service demand in Eq. (2) is extended to a short-term (vkm) and a long-term (kW) component (see also Ajanovic, Dahl and Schipper [19]):

$$E = S_{ST}S_{LT}\mathrm{FI}P = \mathrm{vkm}\cdot\mathrm{kW}\cdot\mathrm{FI}P \quad (13)$$

And for the change in energy consumption dE we obtain:

$$\mathrm{d}E(\mathrm{dFI}P) = \mathrm{dFI}P\cdot\mathrm{kW}\cdot\mathrm{vkm} + \mathrm{dkW}\cdot\mathrm{vkm}\cdot\mathrm{FI}P + \mathrm{dvkm}\cdot\mathrm{FI}P\cdot\mathrm{kW} \quad (14)$$

As our analysis builds on discrete data on a year by year basis we switch to a corresponding discrete formulation:

$$\Delta E(\Delta\mathrm{FI}P) = \Delta\mathrm{FI}P\cdot\mathrm{kW}_0\cdot\mathrm{vkm}_0 + \Delta\mathrm{kW}\cdot\mathrm{vkm}_0\cdot\mathrm{FI}P_1 + \Delta\mathrm{vkm}\cdot\mathrm{FI}P_1\cdot\mathrm{kW}_1 \quad (15)$$

In this equation the first term $\Delta\mathrm{FI}P$ vkm_0 kW_0 refers to the theoretical savings ($\Delta E(\Delta\mathrm{FI}P)$_th) due to the technical efficiency improvements if vkm and kW would have remained at the level 0 of 1990. What we are currently interested in is how big the energy conservation effect would have been if no switch to larger cars would have taken place. The term ΔkW vkm_0 FIP_1 is the additional energy consumption because of the rebound (ΔE_Reb_kW) due to the switch to larger cars. And the last term Δvkm kW_1 FIP_1 is the additional energy consumption because of the rebound ΔE_Reb_vkm due to more km driven with the more efficient and larger car.

Note that the overall change in energy consumption $\Delta E(\Delta\mathrm{FI}P)$ is equal to $\mathrm{d}E(\mathrm{dFI})$ in Eq. (8). It is the actual observed change in energy consumption.

However, in Eq. (15) we do not know the figures for ΔkW and kW_1. But we can use the definitions for the service price elasticity, see Eq. (7), and FIP, see Eq. (1), to calculate the last terms in Eq. (15) without identifying ΔkW and kW_1 explicitly.

In Fig. 13 this impact of better power-specific fuel intensity and switch to larger cars – about 900 PJ – on total passenger car energy consumption is depicted in addition to the rebound due to more kilometre driven which is about 410 PJ and is shown in Fig. 10.

How stable are our results and how are they compared to the literature? The most sensitive parameter is service price elasticity. With respect to service price elasticities an overview of studies on distance travelled is summarized in Ajanovic et al. [19]. This survey documents a range of −0.25 to −0.55 for long-run service price elasticities. Our estimated number of −0.42 fits quite well in this range.

Our result for energy conservation using this elasticity of −0.42 is 560 PJ. The sensitivity of this result, depending on the above mentioned range for the service price elasticity, is as follows: If the elasticity increases to −0.55 savings are reduced to 435 PJ. If the elasticity goes down to −0.25 the savings rise to 725 PJ.

Finally, in Fig. 14 the whole range of impacts on total energy consumption in passenger car transport is depicted. The top line shows how development would have been without better fuel intensity. The difference between the top line and the historical development depicts actual savings due to better FI. These were about 560 PJ (about 9%). The bottom line shows how consumption would have developed without a switch to larger cars. The difference between top and bottom line describes total hypothetical savings without switch to larger cars which would have accounted to about 1870 PJ. That is to say, if no switch to larger cars would have taken place additional about 900 PJ would have been saved.

7. Conclusions

The major sobering conclusions of this analysis are:

The remarkable efficiency improvements of the car stock in EU-15 have not led to the theoretically calculated energy savings of about 1870 PJ in 2010 compared to 1990. They have been compensated to a large extent by driving more and switching to larger cars. About 410 PJ (22%) less energy has been saved due to more driving and 900 PJ (48%) was less conserved due to larger cars leading to only about 560 PJ savings due to efficiency improvements.

In this context it is important to point out the effect of prices. They have led to 860 PJ of savings, more than due the FI effect.

This leads to the final major conclusion that for passenger cars policies that only strive for efficiency improvements will have very limited success. It is necessary to introduce proper additional fuel taxes (to curb the increase in vkm) and size-dependent registration taxes (to avoid excessive increases in car size) to finally harvest the full societal benefits of better car efficiency.

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