NEW SOLD CARS IN SWEDEN 2007 – IS A NEW TREND MATERIALIZING?

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ABSTRACT

In 2006/2007 in Sweden, climate change was highlighted in the media, oil prices raised transport fuel prices, and policies to reduce CO_2 emissions from personal cars were introduced. How do sales patterns for new cars in Sweden reflect these issues? Traditionally Sweden has had the highest CO_2 emitting new cars in the European Union with the most powerful engines and largest weight. In previous studies we have mapped the changes that occurred in new sold cars in Sweden between 1985 and 2002 through statistical analysis and modelling of sales statistics combined with vehicle characteristics. Our main finding was that 35 % of the enhanced technology and design resulted in a net reduction in fuel consumption. The remaining 65 % served to meet consumer demands such as increased passenger space and improved acceleration. This analysis updated for 2007 shows that while lower fuel consumption has become increasingly important it has still not led to a downsizing, i.e., a reversal of the trend toward improved service attributes such as acceleration capacity and passenger space. Instead the main technological and market change has been a shift toward diesel and ethanol engines. Between 2002 and 2007 43 % of the technical development was offset by the amelioration of service and performance attributes, while 57 % resulted in actual reduced fuel consumption. However, had there not been a shift toward more diesel cars then the offset would have been 70 % instead. Diesel cars, while being more fuel efficient were primarily in the large-car segments, thus not contributing to an actual change in attribute trends. Vehicles with ethanol engines were also mainly present in the upper segments with higher fuel consumption. A sign for a possible slackening of the trend was an increasing share of vehicles with CO_2 emissions under 120 g/km. The average power and size of these cars have also increased, improving the cars' attractiveness to customers. Concluding, policies in Sweden so far have reduced average carbon emissions, but have not led to a downsizing of the new car fleet and the average new sold car in Sweden still has higher carbon emissions than the average new sold car in the EU.

Keywords: specific fuel consumption, downsizing, service and performance attributes, diesel cars, flex-fuel cars

1. INTRODUCTION

The transport sector in Sweden stands for a larger share of the national CO_2 emissions compared to many other nations; 41 % (Swedish Environmental Protection Agency 2009b) compared to 27 % in the USA and 21 % in the EU (World Resource Institute 2010), due to the low carbon intensities of the heating and electricity production. At the same times new cars sold in Sweden have the highest specific fuel consumption, largest mass and most powerful engines in Europe (European Commission 2009). This combination makes it of extra interest to look into the development of the Swedish new car fleet and to try to identify any possible signs of a change of trends.

While specific fuel consumption and consequently CO_2 emissions for new sold cars have had a sloping trend, Sprei et al. (2008) found that between 1985 and 2002 2/3 of the technological development was offset by improvements in consumer amenities such as larger vehicles and improved acceleration capacity and only 1/3 resulted in actual fuel consumption reductions. Since 2002 the policy and general debate has shifted its attention toward climate change and the environmental drawbacks of car driving. There has been an increased media coverage in Sweden on climate change (Sprei 2009) but also an increasing awareness and willingness to address the issue from the Swedish general public (Swedish Environmental Protection Agency 2008) and the Government. There have been a number of policies aimed at changing the composition of the Swedish new car fleet. The yearly registration tax that previously was based on vehicle weight was in 2006 changed to be based on CO_2 emissions instead. There has been a rebate program for "environment-friendly cars", i.e., vehicles emitting less than 120 g CO_2/km, flex-fuel cars, gas driven cars and electrical vehicles. Flex-fuel cars and gas driven cars have also received parking subsidies in about 40 municipalities in Sweden (including the three major cities Stockholm, Gothenburg and Malmö) and were exempted from congestion charging in Stockholm which was permanently introduced in 2006. Carbon and energy taxing of fossil fuels has continued to increase (6 % for petrol and 25 % for diesel between 2000 and 2008 (Sprei 2009)) and hybrids, flex-fuel cars and gas driven cars are given reduction on the fringe taxing for company provided cars.

In this paper we want to investigate how these policies and the change in awareness have affected the new car market from 2002 to 2007. Can any change in trends be seen concerning service, performance and fuel consumption? What effect has the differentiation of the new car fleet (more diesel and flex-fuel cars) had on service and fuel consumption?

Recently a number of published studies have analyzed the relationship between car attributes and fuel consumption of car fleets. Tolouei and Titheridge (2009) looking at the relationship between vehicle mass, fuel consumption and injury risk in the British car fleet, found conflicting goals between the safety and fuel consumption in relation to the development of the mass of vehicles. Meyer and Wessely (2009) studied the development of the Austrian vehicle fleet between 1990 and 2007 for parameters such as power, engine capacity, weight and fuel economy. They found an increasing penetration of diesel cars but most of the efficiency gains from diesels were offset by a demand of heavier and more

powerful cars and by more average vehicle kilometres driven. They did not quantify the offset of more powerful and bigger cars, though. Chen and Zhang (2009) analyzed the technological efficient frontier and adoption of fuel efficient technologies for US automakers between 1985 and 2002. Reynolds and Kandlikar (2007) looked specifically at Hybrid Electric Vehicles and found that heavier and more powerful HEVs have eroded the fuel consumption benefit of the technology. Cuenot (2009) concluded that the increase in weight for new cars in the EU has been a determining factor behind the failure of the Voluntary Agreement between car manufacturers and the EU. The US Environmental Protection Agency found that in the year 2004 fuel efficiency measured in miles per gallon (mpg) would have been 22 % higher had weight and acceleration remained at 1987 levels (EPA 2007).

In our analysis we estimate how service attributes (in this case passenger compartment space and acceleration capacity) have affected physical attributes (weight, power, engine capacity and air resistance) and in its turn fuel consumption (liter/100 km). The paper is organized as follows. In section 2 the methods used are presented. Section 3 gives an overview of the development of the new car fleet in Sweden for attributes up to 2007 through sales-weighted averages and distributions, and an analysis of engine downsizing. In section 4 we analysis the relationship between service attributes and fuel consumption. The paper ends with a discussion, section 5, and conclusions, section 6.

2. METHOD

Data for the calculations are based on a combination of two databases: one on sales statistics per vehicle model for 2007 and one on vehicle model characteristics with over 50 parameters per model for 1575 car models available for sale during 2007. Sale statistics were collected from the Swedish Road Administration, and vehicle model parameters from the private company Autograph-bilfakta AB. Additional data was collected from car manufacturers and other databases when this was needed. Privately imported cars and cars registered as light trucks are not included in the database. Data from earlier years (1975, 1985, 1995 and 2002) are from similar databases constructed for these years (see Sprei et al. 2009 and Sprei and Karlsson 2008).

From the database sales-weighted averages and distributions are calculated to give an overview of the new car market. These calculations are done for all the cars sold, petrol cars, diesel cars and flex-fuel cars. In the paper and the figures petrol cars represents two different groups: one of cars that can be fuelled with petrol only and the other one including cars that can be driven with ethanol or gas as well. To make it clearer "petrol+" cars means that flex-fuel cars, gas and hybrid cars are included. When written only petrol these are excluded. Figures for fuel consumption (FC) are given in petrol equivalents[1] for convenience in summing up and comparison of different types of cars and since our interest is actual gains in energy efficiency.

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[1] Energy values used: 9.04 MWh/m^3 for petrol and 9.96 MWh/m^3 for diesel (Swedish Energy Agency 2009).

For the analysis in section 4 on the effect of service and performance attributes on fuel consumptions the following method is used.

Increased *passenger compartment space* (called passenger space onward and measured with an index[2] I) implies (given no other changes) a larger mass[3] M. An average linear relationship between mass and passenger space index is estimated through linear regression analysis of all cars in 2007 with an index between 8500 and 10000, which means excluding two seat cars and larger 7 seated SUVs; this covers 95 % of the cars sold. The relationship gives the following equation for the implied mass in 2007:

$$M_s = M_{02} + k_m * (I_{07} - I_{02}) \qquad (1)$$

where k_m is the coefficient from the regression analysis.

In order for this change in vehicle mass not to alter the acceleration capacity, the engine power should also increase and in its turn the engine capacity. We here presume a one to one relationship between implied changes in engine capacity, power and vehicle mass:

$$\Delta V_I = \Delta P_I = \Delta M_s \qquad (2)$$

thus ignoring, in this step, any possible technical improvements.

Improved *acceleration capacity* is also translated into an additional implied change of power and engine capacity in 1:1 ratios:

$$\Delta V_{acc} = \Delta P_{acc} = \Delta Acc \qquad (3)$$

In total the presumed engine capacity change needed to compensate for improved service attributes is thus given by:

$$\Delta V_s = \Delta V_{acc} + \Delta V_I \qquad (4)$$

The inferred effect of increased passenger space on aerodynamic resistance (C_DA: aerodynamic drag coefficient times the vehicles frontal area) is estimated with a regression similar to that for mass:

$$C_DA_s = C_DA_{02} + k_{CDA} * (I_{07} - I_{02}) \qquad (5)$$

where k_{CDA} is the coefficient from the regression analysis between C_DA and passenger space index for all cars in 2007 with an index between 8500 and 10000.

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[2] The index has been developed by an independent Swedish company (Autograph-bilfakta AB), which successively measures and publishes data on most new commercially available car models in Sweden. The index is a sum (in mm) of nine passenger volume length measures, all adhering to the internatial SAE-standard.

[3] With mass we mean curb weight plus the 75 kg for the driver's weight.

Changes in fuel consumption (FC) are computed through fuel consumption sensitivities derived from an analytical expression relating fuel consumption and driving cycle characteristics (see equation 10 and 11 below). The implied fuel consumption due to improved service attributes, considering no technical improvement is given by:

$$FC_s = FC_{02} + \Delta FC(\Delta M_s) + \Delta FC(\Delta V_s) + \Delta FC(\Delta C_D A_s) \qquad (6)$$

The actual change in mass ΔM_a does not necessarily correspond to the implied change in mass ΔM_s, due the combined effect of the adoption of light materials, more accessories and weight changes due to safety improvements. A second implied fuel consumption (FC_{sm}) is calculated based on the actual changes in the mass ΔM_a:

$$FC_{sm} = FC_{02} + \Delta FC(\Delta M_a) + \Delta FC(\Delta V_{sm}) + \Delta FC(\Delta C_D A_s) \qquad (7)$$

where the following assumptions were used:

$$\Delta V_m = \Delta P_m = \Delta M_a \text{ and } \Delta V_{sm} = \Delta V_m + \Delta V_{acc} \qquad (8)$$

Relying also on the actual changes in both engine capacity (ΔV_a) and aerodynamic resistance (ΔCdA_a) another implied fuel consumption is given by:

$$FC_{sa} = FC_{02} + \Delta FC(\Delta M_a) + \Delta FC(\Delta V_a) + \Delta FC(\Delta C_D A_a) \qquad (9)$$

These values of implied fuel consumption, derived by successively adjusting to actual values, are interpreted as the inferred effects of changes in the different attributes, respectively, between 2002 and 2007, and is also compared with the actual fuel consumption in 2007 (FC_{07}). Both FC_{02} and FC_{07} are sales weighted averages of the reported fuel consumption based on the New European Driving Cycle (NEDC) where diesel values have been recalculated to petrol equivalents.

To be able to calculate fuel consumption sensitivity for the attributes we used an analytical expression relating the fuel consumption to vehicle and driving cycle characteristics, see An and Ross (1993). Assume that fuel consumption may be approximated by a linear function of the engine power output:

$$P_{fuel} = a\,N + b\,P_b \qquad (10)$$

where P_{fuel} is the fuel use (kW), a is the engine friction characteristics (kJ/rev), N is the engine speed (rps- revolutions per second), b is the inverted thermal efficiency of the engine, and P_b is the brake power output (kW). The variables N and P_b are then expressed in terms of vehicle and test drive cycle characteristics (An & Ross, 1993):

$$FC_{TDC} = a'V\frac{1}{\overline{v_r}}\left[N_{pwr}(1-t_{br}) + \gamma N_{idle}(t_{br} + \frac{t_{st}}{1-t_{st}})\right]$$

$$+ b\left[\frac{1}{\varepsilon}(\frac{1}{2}\rho C_D A\lambda \overline{v_r}^{-2} + C_R Mg + \frac{1}{2}\beta M^* v_p^2 n) + \frac{P_{ax}}{v_r(1-t_{st})}\right]$$

$$(11)$$

In the equation the vehicle parameters are: FC_{TDC}: fuel energy consumed per unit distance of the test drive cycle [J/m] ; *a':a/V*; V : cylinder displacement volume [l]; N_{pwr} : average engine speed during the test drive cycle for the time when the engine delivers power [rps]; N_{idle} : average engine speed when the engine is idling [rps]; ε : drive train efficiency; C_D : air drag coefficient; A: frontal surface area [m^2]; C_R: rolling resistance coefficient; M: total vehicle mass in test drive cycle [kg]; M*: effective mass, M plus corrections for effects due to rotational inertia [kg]; P_{ax} : average power requirement for vehicle accessories [kW].

Driving cycle parameters are: $\overline{v_r}$: average running speed [m/s]; v_p^2 : the root-mean-square peak velocity over the driving cycle [m/s]; t_{br} : the percentage of time for brake use while the car is running; t_{st}: time that the vehicle is stopped in percent [s]; n: the number of stops per unit distance; γ: compensation for cold start; λ: approximation to handle air-resistance (1 or 2); β: adjustment to better capture braking energy. Further, ρ is the air density and g is acceleration due to gravity.

Through regression analysis a' and b are calculated for petrol cars and diesel cars separately.

Our analysis is a percentage-based decomposition of fuel consumption. The advantages of the method are the ease of interpretation and communication of the results, as well as its relevance to the processes influencing fuel consumption. The drawbacks are that the numerical results depend on method, base year, and order of calculation steps. Since the new car fleet is heterogeneous there are also uncertainties based on assumptions made and segment chosen to calculate relationships. However, these are small enough not to change the overall conclusions of the results. Our computation does not imply any conclusions on causality between technological development and improved service parameters, i.e., if technological improvements are made to compensate for the ameliorated services or if they enable them.

3. TRENDS IN THE CAR MARKET

3.1 Overview

Traditionally the Swedish new car fleet has been dominated by cars with petrol engines and manual gear boxes. During the last years a change toward a more differentiated new car fleet, considering engine choice, has emerged. Between 2002 and 2007, as seen in Fig. 1, manual petrol vehicles went from having almost 80 % of the market share to less than 50 %. Diesel engines have had approximately 5 % of the market share, while in 2007 the share

was over 30 %. The penetration of diesel cars in the market has occurred earlier in Europe (Schipper et al. 2002) and in 2007 the share in EU27 was roughly 50 % (European Commission 2009). Vehicles that can be driven on an alternative fuel such as ethanol or gas were another novelty on the Swedish car market. In 2007 12 % of the sold cars could be driven on an alternative fuel, the majority of these were so called flex-fuel cars, i.e., can be driven on E85[4]. The large share of flex-fuel vehicles is unique for Sweden in a European context.
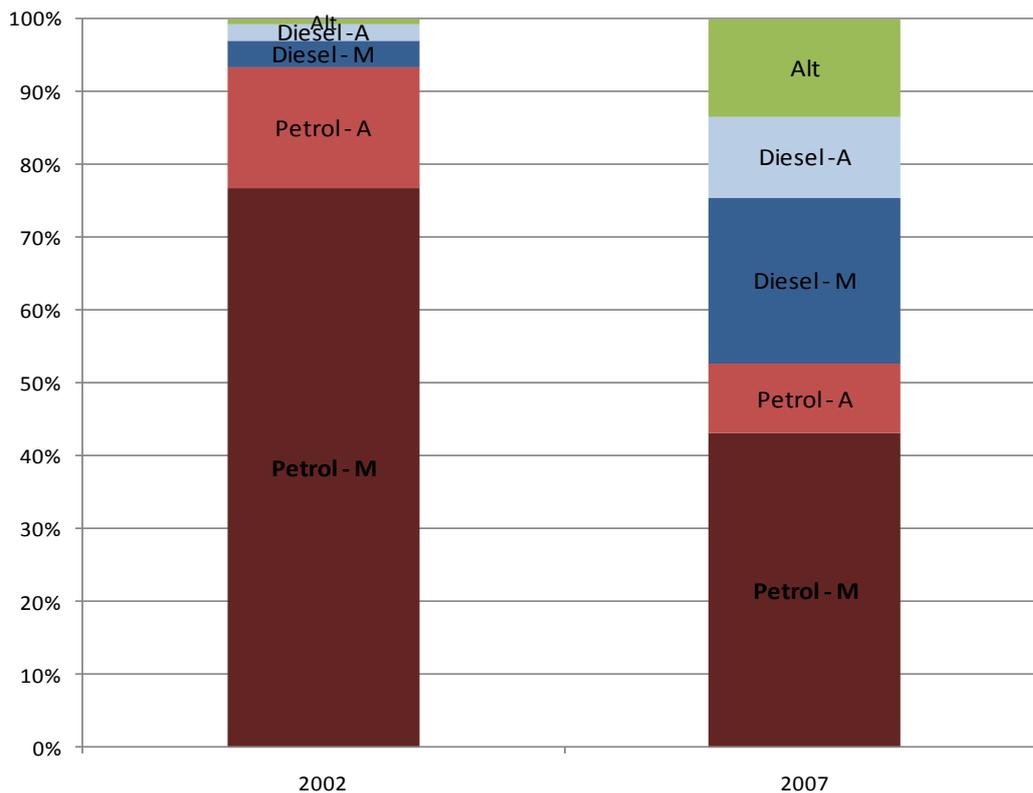
Figure 1 Distribution of fuel type (petrol, diesel and alternative fuels: ethanol or gas) and gear boxes (M-manual gear boxes; A-automatic gear boxes) for new sold cars in Sweden 2002 and 2007.

There is a continuous trend of enhancement of important car parameters and attributes and there are few signs of any form of saturation when studying the entire new car fleet, Fig. 2. The average new car weighs now almost 1500 kg, an increase by 30 % since 1975. Comparing to previous studied periods we see that the average weight of the cars has increased at a higher yearly rate (1 %/yr) between 2002 and 2007 than 1995 and 2002 (0.6 %/yr). Heavier cars have been a trend in Europe as well and the yearly increase has fluctuated around 1 % (European Commission 2009). The increase of the car weight in Sweden is coupled with larger passenger space: 9233 in the measured index compared to 8607 in 1975. The rate of increase in passenger space during the last 5 years has been the same as the previous seven years (0.2 %/yr). Performance of the vehicles has increased the most in relative terms since 1975 and average maximum power is now over 100 kW. The

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[4] The fuel mix sold of 85 % ethanol and 15 % petrol.

rate of increase during the last years seems, however, to have slowed down from 1.3 %/yr between 1995 and 2002 to 0.9 %/yr in 2002-2007. Improved acceleration capacity has led to shorter acceleration times and an average new sold vehicle in Sweden now accelerates from 0-100 km/h in 10.1 s compared to 15.2 s in 1975. The rate of change during the last years, just as for engine power, has diminished. It is however still early to judge if the slower rate of increase for power is a lasting trend. Between 1995 and 2002 the increase in weight seemed to have slowed down (Sprei et al. 2008), but this is no longer the case.

At the same time as the average car has become larger and more powerful, fuel consumption has decreased with 28 % since 1975. In Fig. 7 fuel consumption for the years 2000 to 2007 are plotted for the entire new fleet and divided by fuel type: petrol, diesel and flex-fuel cars (the values are not in petrol equivalents). Fuel consumption remained more or less unaltered for the new car fleet until 2004 and has since then decreased, coinciding with a larger share of diesel cars.
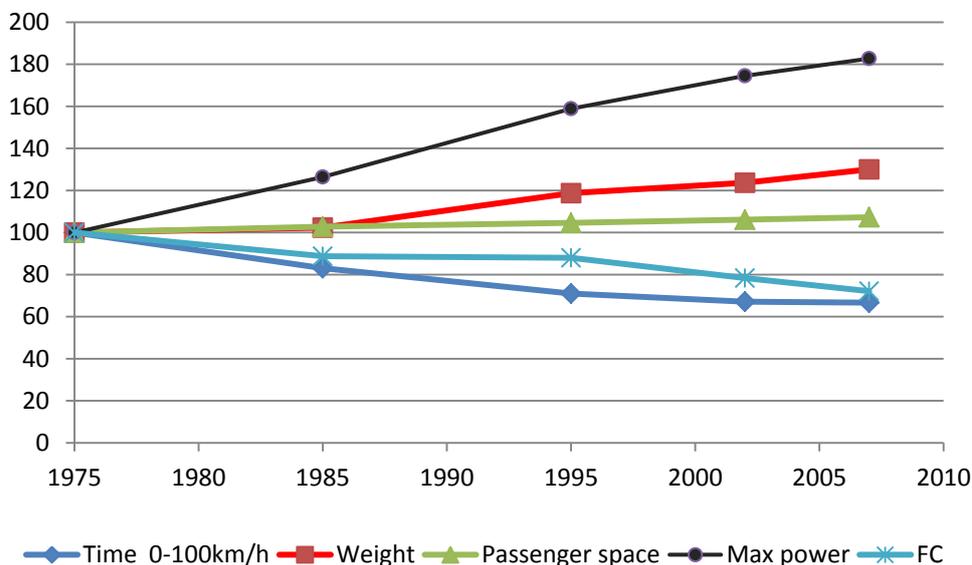
Figure 2 Relative development (Index 100=1975) of sales-weighted averages for the new car fleet in Sweden 1975-2007 for acceleration time, weight, passenger space, maximum power and fuel consumption (FC).

Distributions of the parameter values can reveal if there are any trends in the car market in a more detailed way compared to sales-weighted averages. The minor changes that occurred between 2002 and 2007 however confirm the picture given by the sales-weighted averages, Fig. 3. For weight the share of cars weighing between 1700 – 1900 kg increased and the share of cars within the range 1100-1300 kg almost halved. Passenger space is the only attribute that showed a different distribution with a major peak at 9100 to 9200. In this interval popular station wagons such as Volvo V50 and V70, Toyota Avensis, Ford Mondeo and Saab 9-3 are found. Station wagons represent a large share (57 %) of the new sold cars in Sweden. For maximum power the share of cars in the power interval of 80-90 kW has decreased while the relative number of cars in the following interval of 90-100 kW has increased instead. And for acceleration time more cars in the interval 9-10 s compared to 10-11 s have been sold. Engine capacity shows the same pattern 2002 and 2007 with small changes in the exact frequency of the peaks.
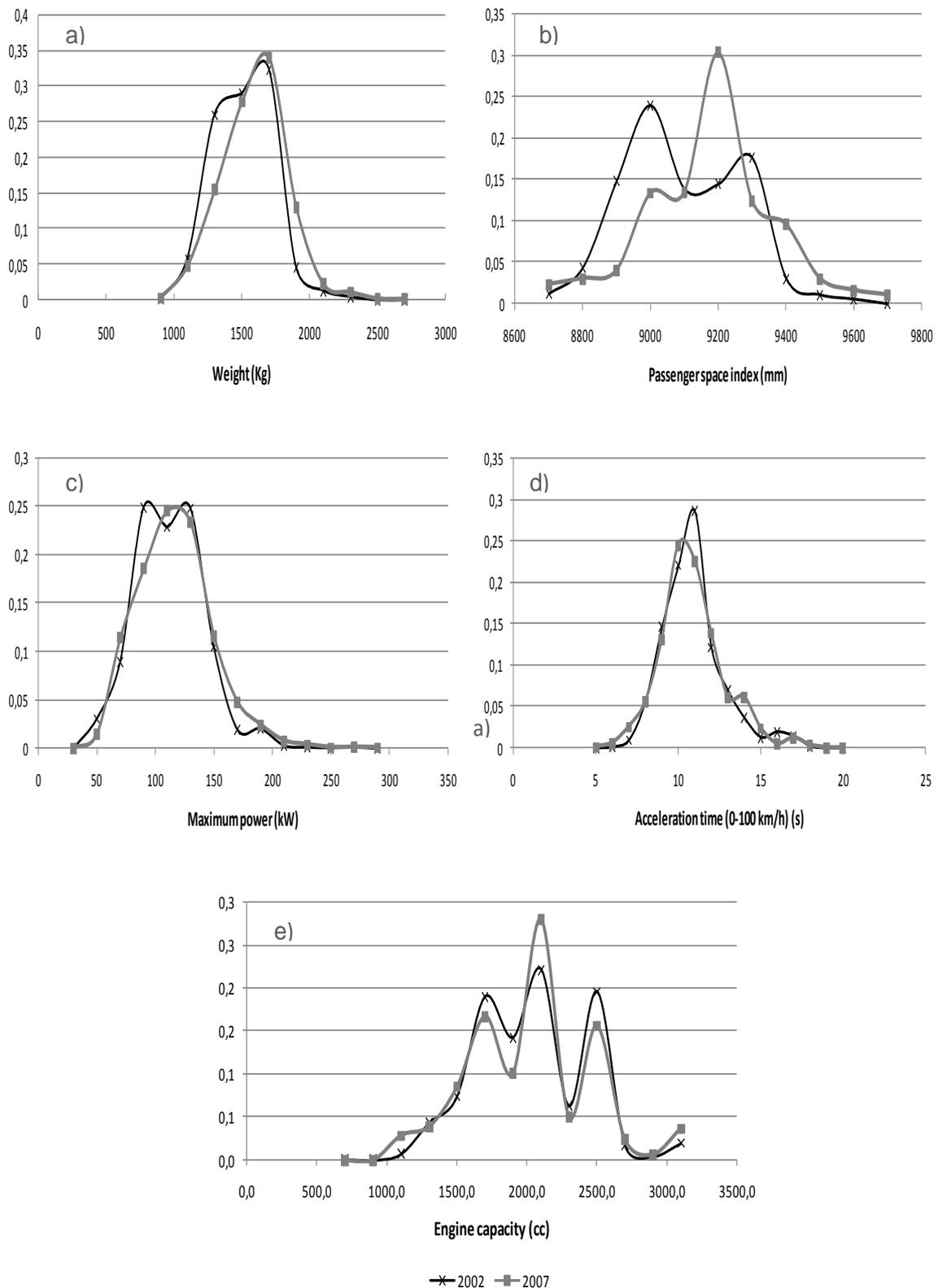
Figure 3 Distribution of weight (a), passenger space (b), maximum power (c), acceleration time (0-100km/h) (d) and engine capacity (e) for new sold cars in Sweden 2002 and 2007.

3.2 Engine downsizing

Engine downsizing is one of the strategies to reduce fuel consumption in cars. Potential fuel savings per vehicle for a 20 % downsizing have been found to be 6-14 % and up to 23 % if the downsizing is 40 % instead (Silva et al. 2009). Leduc et al. (2003) and Petitjean et al. (2004) find potentials in the same range. These savings presume that mass is kept constant, which has not been the case for the Swedish new car fleet. So while specific power (SP) for the average car has increased from 51 kW/l in 2002 to 54 kW/l in 2007, the question is how this technical downsizing has been used. For a given car weight, the engine becomes smaller (an absolute downsizing) if the relative increase in specific power outweighs the relative increase in the power to weight ratio. Fig. 4 shows the distribution of engine capacity per ton of car (l/ton) for models available and models sold, respectively. There is a shift toward fewer l/ton both when it comes to models available on the market and actual cars sold. The sales-weighted average has also been reduced from 1.36 l/ton to 1.30 l/ton. There is a larger share of car models available and sold with 1.1 l/ton or less. The other main shift is around 1.4 l/ton with a decrease in frequency in 2007 compared to 2002. There are also a number of models with higher values (>1.7 l/ton) but these are not sold to a high degree. There are thus signs of a possible engine downsizing in the car fleet both when it comes to models available and their sale-statistics.

Fig. 5 gives for the available car models for 2002 and 2007 the distribution of specific power (SP) with car power to weight ratio (PWR), which is roughly proportional to acceleration capacity. The vertical axis, specific power (kW/l), corresponds to technical downsizing and the horizontal axis to a downsizing in performance such that the combined downsizing is maximized for a shift toward the upper left corner in Fig. 5. We see that for available models, generally higher specific power also implies higher performance (PWR) even if a certain bifurcation can be seen for car-models over 130 kW/ton. Sprei and Karlsson (2008) found that the line corresponding to SP=PWR, that is, one litre of cylinder volume per ton of car, to be a rough lower 'limit' for downsizing among the models then available (2002 and older). This is still the case for 2007 (see Fig. 5). Only a limited number of models cross the line and thus a full downsizing, i.e., combining engines with high specific power and low performance cars, still represents an unexploited saving potential in the new car fleet.
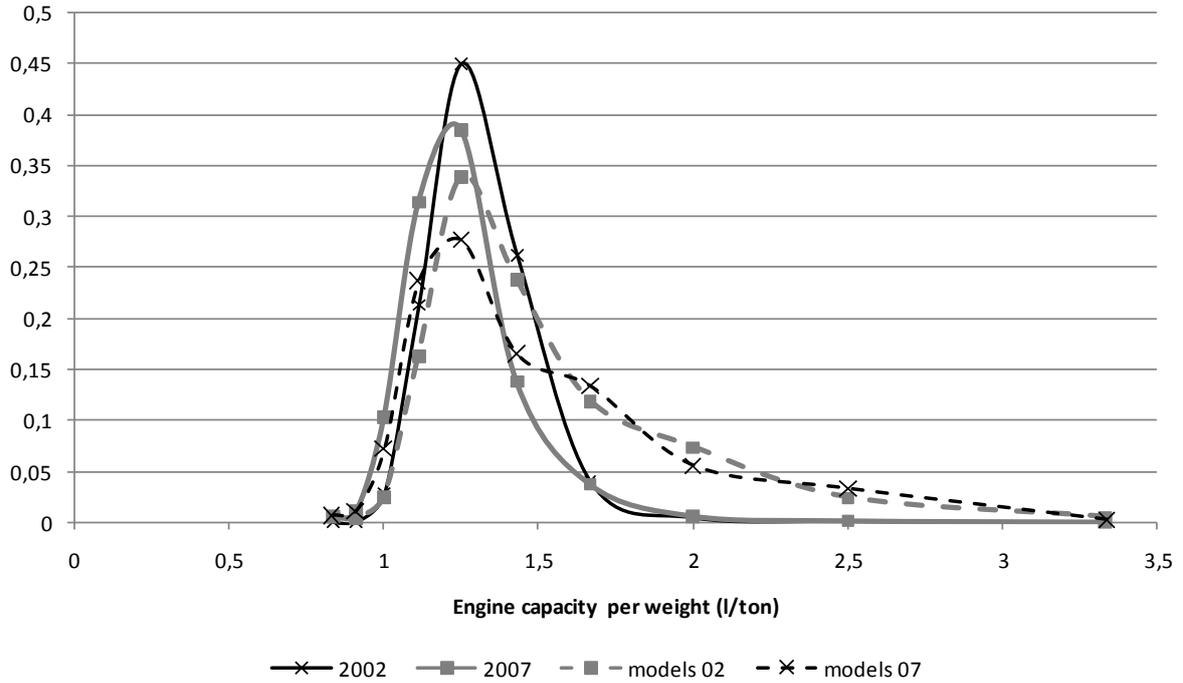
Figure 4 Distribution of engine capacity per car weight for car models available on the market models sold in Sweden for 2002 and 2007.
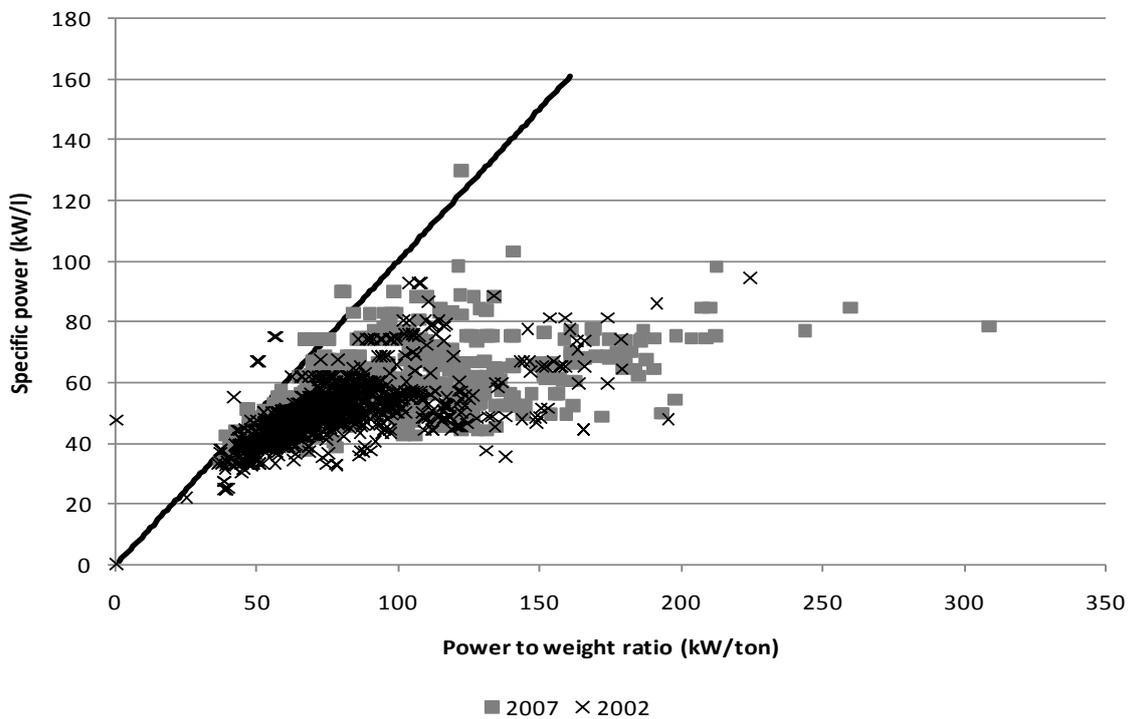
Figure 5 For the available car models in Sweden for 2002 and 2007 the distribution of specific power (SP) with car power to weight ratio (PWR), which is roughly proportional to acceleration capacity. The straight line SP=PWR is plotted.

3.3 2008

The distribution of CO_2 emissions has changed over the last years, Fig. 6. In 2002 there was a major hump for cars with CO_2 emissions between 200 and 250 g CO2/km, of which presumably a large share are company cars. Instead there is an increase in cars with emissions below 200 g CO_2/km. In 2008 we see specifically an increase in cars with emissions between 100 and 120 g CO_2/km. From April 2007 these cars were granted a rebate of 10 000 SEK from the Swedish Government.

The figures for 2008 point toward a continuing decrease in average fuel consumption and CO_2 emissions. There also seems to be some signs of a possible saturation of consumer amenities. The average weight of the new sold car remained the same as for 2007 and maximum power was reduced from 106 kW to 102 kW. The share of diesel cars increased to 36 % and flex-fuel cars to 23.4 % decreasing the share of pure petrol cars to 40.1 % (Swedish EPA, 2009). However, it should be taken into account that in 2008 car sales decreased markedly due to the financial crisis. Thus it might be hard to know if this is just a temporary weakening of the trends or the first signs of a shift of trends.
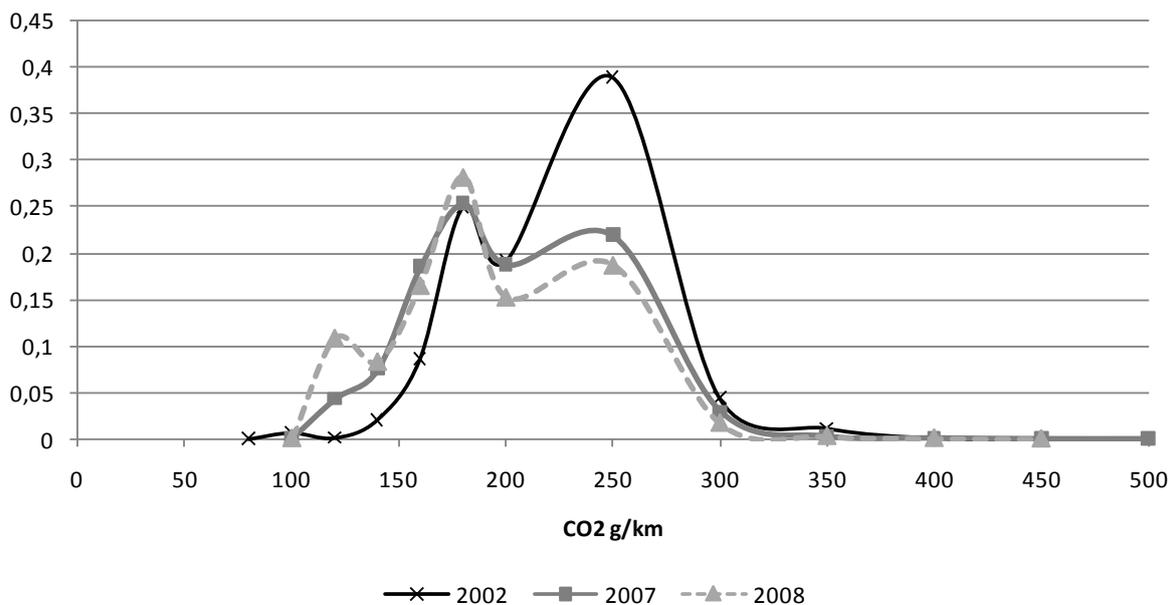
Figure 6 Distribution of CO2 emissions (g/km) for new sold cars in Sweden 2002, 2007 and 2008. Data for 2008 from official reporting EU (www.eea.eu).

3.4 Attributes per fuel type

Petrol and petrol+ cars

Looking exclusively at petrol cars, i.e., excluding those that can also be driven on an alternative fuel, Fig. 8, we see that there has been a halt in the increase of attributes except for an increase in passenger space from 9123 to 9149. Including vehicles with alternative fuels as done in Table 1, the changes in parameters for ""petrol+" cars between 2002 and

2007 gives a minor increase in parameters. Passenger volume space and weight increased with less than one percent, while aerodynamic resistance increased with about 3 %. Maximum power increased with almost 3 % but the average acceleration time was almost unaltered. From a technical development point of view we can note that the engine capacity was reduced. Fuel consumption for "petrol+" was steady from 2000 to approximately 2004 and decreased slightly thereafter, Fig. 7.
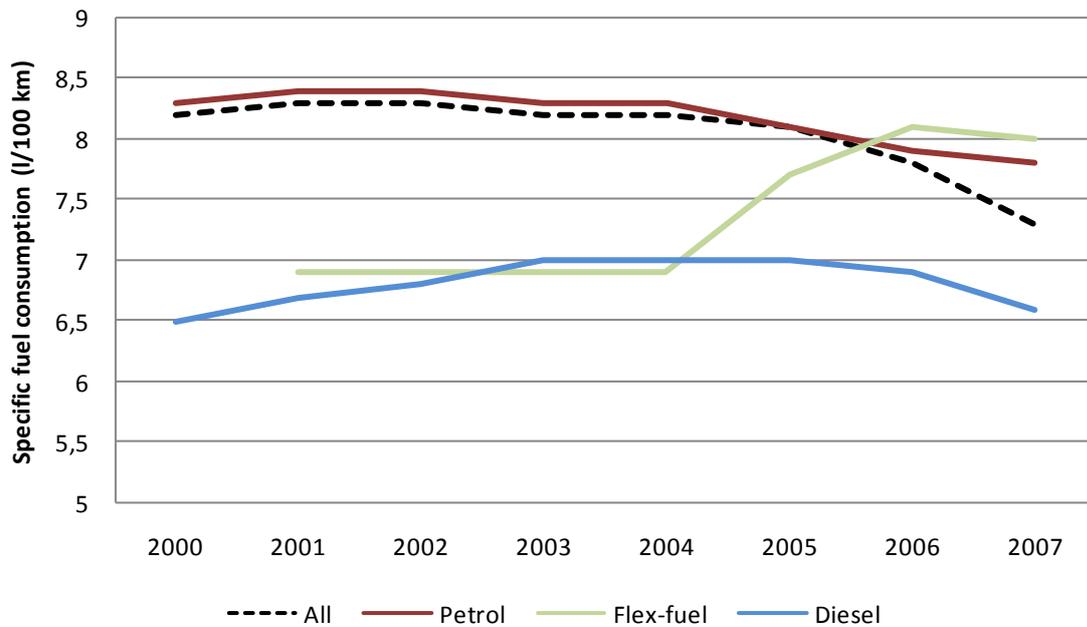
Figure 7 Specific fuel consumption 2000-2007 for all new cars sold, "petrol+" cars, diesel cars and flex-fuel cars (FFV). Note: For all cars and diesel cars the figures are not in petrol equivalent. Had they been the curve for diesel would be shifted up approximately 10 % and the curve for all cars should be slightly shifted up, especially after 2005 when the share of diesel increased. Data source: Swedish Road Agency.
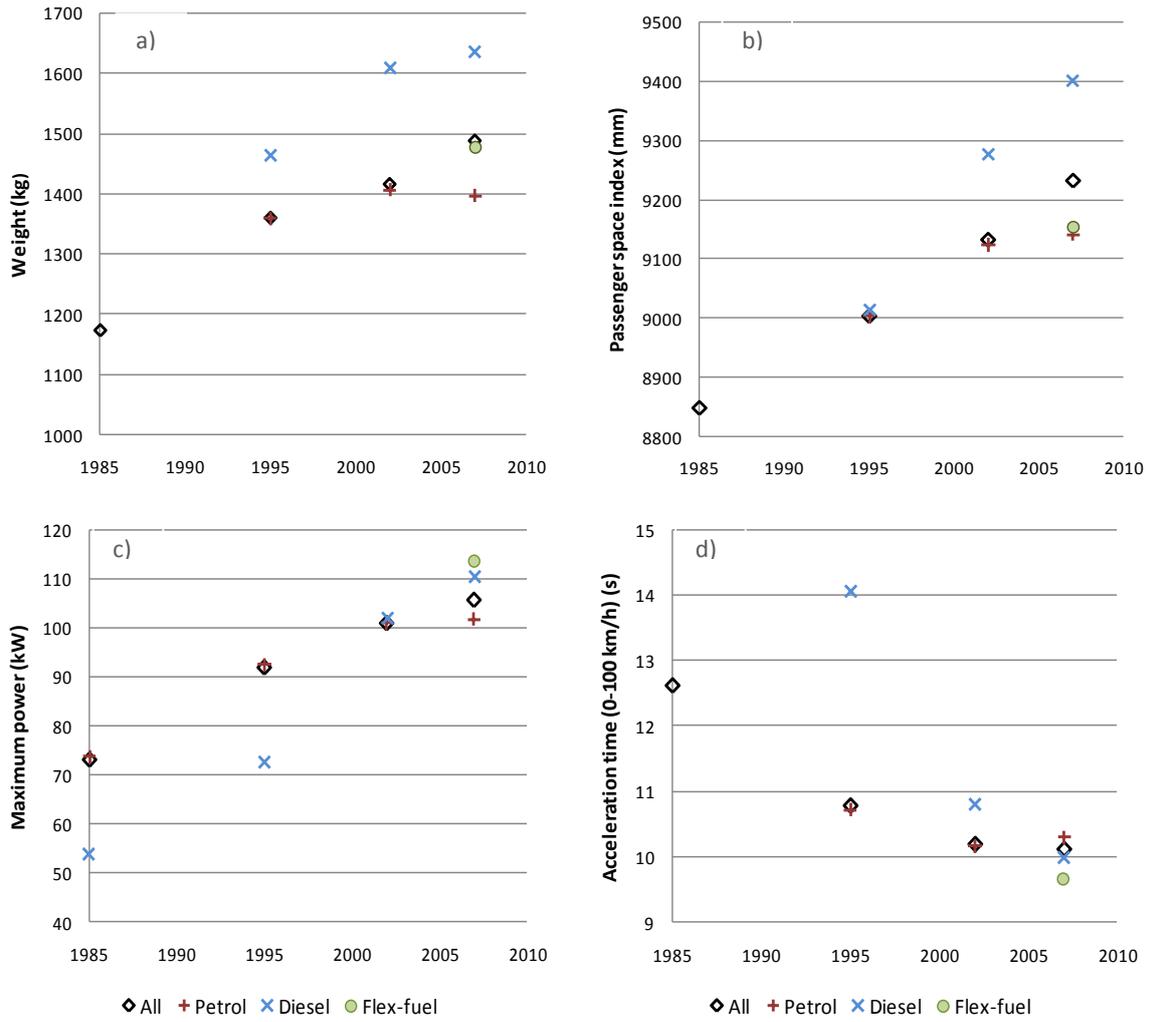
Figure 8 Development of the sales-weighted average for weight (a), passenger space (b), maximum power (c) and acceleration time (0-100 km/h) (d) 1985-2007 for all cars, petrol cars, diesel cars and flex-fuel cars.
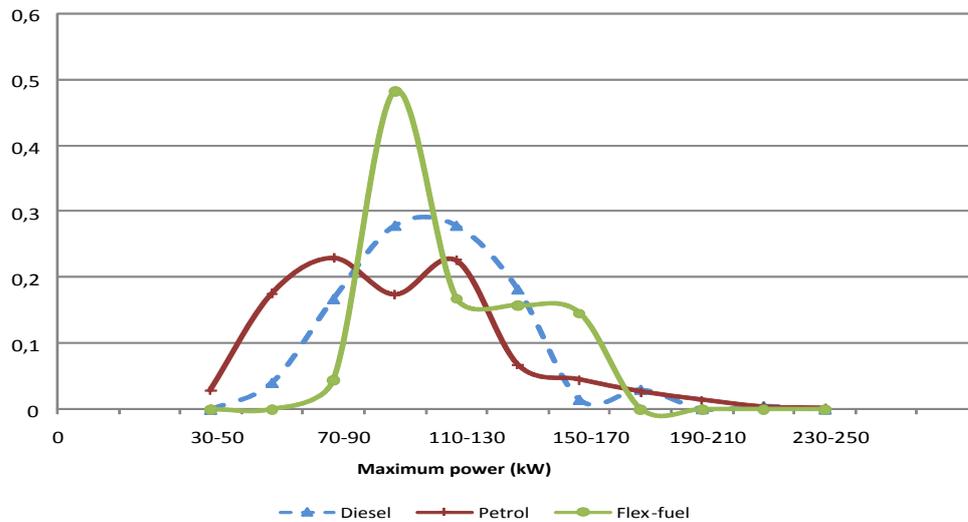
Figure 9 Distribution of maximum power for new sold petrol cars, diesel cars and flex-fuel cars in 2007.

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Table 1 Sales-weighted averages for "petrol+" cars, diesel cars and all cars sold in 2002 and 2007 and change in percentage 2002-2007.

	Petrol +			Diesel			All		
	2002	**2007**	**%**	**2002**	**2007**	**%**	**2002**	**2007**	**%**
Passenger space index [mm]	9124	9147	*0.25*	9277	9402	*1.34*	9133	9233	*1.09*
Acceleration time 0-100km/h [s]	10.16	10.20	*0.39*	10.80	10.00	*-7.42*	10.21	10.13	*-0.75*
Weight [kg]	1406	1415	*0.63*	1610	1636	*1.58*	1417	1490	*5.12*
Maximum power [kW]	101.2	103.9	*2.8*	102.2	110.5	*8.1*	101.2	105.9	*4.7*
Cylinder volume [cc]	1956	1883	*-3.73*	2184	2105	*-3.65*	1969	1958	*-0.55*
Cd x frontal area [m^2]	0.670	0.695	*3.67*	0.688	0.728	*5.89*	0.671	0.706	*5.16*

Diesel cars

The average values of all the attributes of diesel cars are higher than the average petrol car and the sales-weighted average of all new cars sold. In average a diesel car is 17 % heavier than a pure petrol car, 3 % larger in passenger space index and has an 8 % more powerful engine. This has not always been the case, specially not for performance related attributes such as maximum power and acceleration time. The relative increase for diesel cars the last years has also been higher compared to "petrol+" cars (including flex-fuels and gas cars) for all parameters and most markedly for the performance related ones. Size related parameters such as passenger space index and weight have increased between 1 and 2 %. The average cylinder volume of diesel cars has decreased with about the same relative magnitude as for all the petrol cars. Between 2000 and 2003 the average fuel consumption for diesel cars actually increased, coinciding with an increase in average attribute values. First after 2005 we see a lowering of average fuel consumption, Fig. 7.

Diesel cars are most often found in the upper segments of the market. The share of diesels in the premium, large and SUV segments of the market in 2007 was 41 %, while for small cars the share was only 13 %. The concentration of diesel in the upper segments is not exclusive for Sweden: Meyers and Wessely (2009) find the same development in Austria and Schipper et al. (2002) for a number of European countries. If looking only at the models available on the market the highest maximum power and the model average for petrol cars is higher, but for diesels the sales in higher ranges of power are larger. In Fig. 9 the difference in distribution of maximum power between fuel types can be seen. The distribution of diesel cars is roughly shifted with 20 kW upwards compared to petrol cars.

The percentage difference in weight between diesel cars and petrol cars is larger than the difference in maximum power and reflected in the sales-weighted power to weight ratio (67 kW/ton for diesel cars and 71 kW/ton for petrol cars). However, acceleration capacity is higher for diesel cars, that is, they accelerate in average faster from 0 to 100 km/h. We do not have data to compare at what engine speed power and torque are available for the different cars which would give a more accurate picture of perceived driveability of the

vehicles and would explain the higher acceleration capacity. Diesel cars have traditionally not been perceived as fun to drive as petrol cars and have had longer acceleration times. The increased share of diesel cars in the Swedish new car fleet has occurred simultaneously with an improvement of the driveability of these cars. Thus the customers that have chosen diesel vehicle have not made any sacrifices when it comes to performance, rather the opposite.

Diesels engines are generally more energy efficient than petrol engines even if the difference is diminishing through technologies such as turbocharging, direct gasoline injection, etc. The average diesel car is at the same time larger and has a more powerful engine compared to the average petrol car. What fuel consumption would the average diesel car have given maintained consumer amenities but an average petrol engine? And reversely what would the fuel consumption be given the average petrol attributes but average diesel engine? The calculation is based on equation (11) and the estimated values for the coefficients a' and b for petrol and diesel. The relationship between weight and passenger space (based on regression analysis) is similar for petrol cars and diesel cars and thus weight is used as a proxy for passenger space. The relationships between power and cylinder volume are also similar for the fuel types and thus the cylinder volume in equation (11) can be seen an approximation for maximum engine power. If the petrol car values for a' and b are used, i.e., characteristics for an average petrol engine but weight and cylinder volume for an average diesel, the fuel consumption for the average diesel car would increase by 11 %. If instead coefficients for the average diesel engine are used together with weight and cylinder volume for the average petrol car, the fuel consumption would decreases by 20 %.

The larger share of diesel cars in the Swedish new car fleet can be seen as a combination of policy and market push. While diesel cars have not received as clear policy advantages as flex-fuel cars, there have been signals that they are more on the level. Between the 1st of July 2006 and 31st of December 2007 diesel cars with particle filters received a one-time reduction of the yearly registration tax of 6000 SEK. In the formula to calculate the yearly registration tax based on CO_2 emissions the tax for diesel cars is multiplied with a factor of 3.3 compared to the petrol car with the same emissions (to compensate for lower fuel tax). Despite this factor the reform of the yearly registration tax still implied a lowering of taxes for many diesel car models. There is also a plan to diminish the difference in taxation between petrol and diesel cars both when it comes to the yearly registration tax and fuel tax. These tax reforms have been combined with a market shift with more diesel models available and with performance of diesel cars that even exceed petrol cars.

Flex-fuel cars

Flex-fuel cars, i.e., cars that can be driven on ethanol do not differ significantly from pure petrol cars or the average car when it comes to their size and weight, but have in average more powerful engines. The average maximum power of 113 kW is even higher than for diesel cars. The acceleration time is consequently also shorter. The value of the attributes, and specially the distribution of cars based on these attributes (see e.g., the peak at 90-100 kW in Fig. 9) is highly determined by the models available on the market. While the number of models have been increasing there are still no small flex-fuel cars available and very few

in the middle segment (6 models). From 2004 the average fuel consumption for flex-fuel cars has increased, Fig. 7, mainly due to the introduction of more vehicle models in the upper segment with higher fuel consumption. In 2007 the average fuel consumption for flex-fuel cars was higher than for petrol cars. The explanation is again found in the lack of availability of low-consuming models and not a worse efficiency per se. In comparison with petrol engines with same power and weight the fuel consumption does not deviate.

Policy pressure concerning fuel efficiency in flex-fuel cars has been weak (Sprei 2009). The rebates and subsidies for these cars have either not had any specification on fuel efficiency or such a generous one that all car models have been eligible. Flex-fuel cars, despite higher fuel consumption represent a possibility to reduce carbon emission. The environmental gain is however dependent on the cars being fuelled with E85 and not petrol. The actual E85 refuelling rate has been very dependent on the relative price difference between E85 and petrol, e.g., sales of E85 plummeted at the end of 2008 when petrol prices fell (Swedish Petroleum Institute 2009). The Swedish EPA and Road Agency have also recently reduced the presumed CO_2 saving potential of flex-fuel cars from 56 % to 22 % mainly due to the decreasing sales of E85 fuel (Swedish Road Agency 2009).

Cars with CO2-emissions below 120 g/km

Five percent of the new cars sold in 2007 had CO_2 emissions below 120 g/km. While this is still a moderate number it is an increase compared to less than 1 % share in 2002. There is also a difference in appeal of these cars. The number of models has increased form 13 to 40. In 2002 the models had a weight range between 800 kg and 1325 kg and a power range between 30 and 50 kW. In 2007 the range had expanded upward and models with 105 kW were available on the market as well as weights up to 1450 kg. Not only the model range but also the sales-weighted averages have increased, specially for maximum power that has increased by 31 % and the acceleration time that has decreased by 20 %. This has also diminished the gap between the sales-weighted averages of these low-emitting cars and the average car sold. In 2002 the maximum power was 54 % lower and in 2007 45 % lower. The average mass of these cars had also decreased from 24 % below the overall average to 17 % below. Cars with CO_2 emissions have thus gone from being small, not too attractive cars to more standard cars. This development has continued and in 2009 even some models in the middle premium class such as Volvo V50 had emissions below 120 g CO_2/km. Since the share of these low emitting vehicles is still small the effect on the average fuel consumption is low. Calculating the sales-weighted average while excluding these vehicles gives only a 1 % increase to 7.4 l/100 km (calculated with official values for diesel cars).

4. EFFECTS OF ATTRIBUTE TRENDS ON FUEL CONSUMPTION

There is a continuous trend toward improving service and performance attributes in the new car fleet, paralleled with lower fuel consumption. In this section we examine how this trend in attributes has offset part of the technical improvements that could have resulted in even lower fuel consumption. The calculations in this section are done on three different sets of data: "petrol+" cars, diesel cars and all cars sold[5]. Figures on fuel consumption given are in petrol energy equivalents.

The effect of changes in passenger space on weight (ΔM_s) is computed using equation (1) and compared with actual change (ΔM_a), Fig. 10. "Petrol+" cars have not increased much in size and the effect on weight is minor. The increased size of the diesel cars would have implied an increase in mass by roughly 6 % while the actual increase in weight was less than 2 %. For all the cars larger passenger space would have implied a 6 % increase in weight while the actual change was 5 %. For all three cases there is a net reduction of weight which is the balance between an increase of weight due to other services such as more comfort, improvements in safety and more/heavier accessories, minus the weight savings achieved from the application of lighter materials and design. The data does not render possible a further analysis of this balance or an explanation of why the net mass decrease is larger for diesel cars.
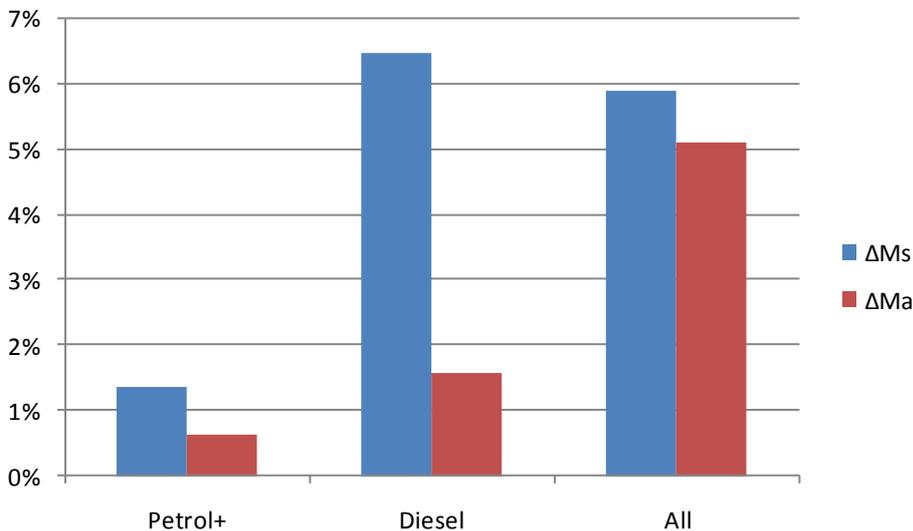
Figure 10 Implied changes in weight (ΔM_s) due to increased passenger space and actual change in weight (ΔM_a) 2002-2007 for "petrol+" cars, diesel cars and all cars sold.

The implied changes in engine capacity are shown in Fig. 11 (ΔV_s and ΔV_{sm}). For "petrol+" cars there is little change in service attributes (passenger space, weight and acceleration

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[5] For "petrol+" and all the cars sold fuel consumption sensitivities are derived from equation (11) using a' and b for petrol cars in 2007.

capacity), which also gives a small change in implied engine capacity (plus 2 %). In reality the average engine capacity decreased by almost 4 %. The changes in diesel vehicles would result in an almost 14 % larger engine capacity. Half of this increase can be attributed to larger vehicles and half to improved acceleration capacity. However, even for this group of vehicles the actual change is -4 %. When comparing the average of all cars sold, increased service parameters would have implied an increased engine capacity by 6 % (almost all from larger vehicles) while the actual reduction was -1 %. The technological improvement that thus can be observed is increased specific power, yielding an actual reduction of engine capacity instead of an increase.

For aerodynamic resistance (C_DA_s) the regression analysis in equation (5) between passenger space and C_DA gave a coefficient of zero. There is no systematic difference in aerodynamic resistance between small cars and larger cars, implying that even if larger cars might have larger frontal area they are designed more aerodynamically, i.e., with a lower C_D. From 2002 to 2007 the average C_DA has increased and to be able to take this into consideration in our calculations, ΔC_DA_s is set equal to the change in the actual C_DA (ΔC_DA_a).
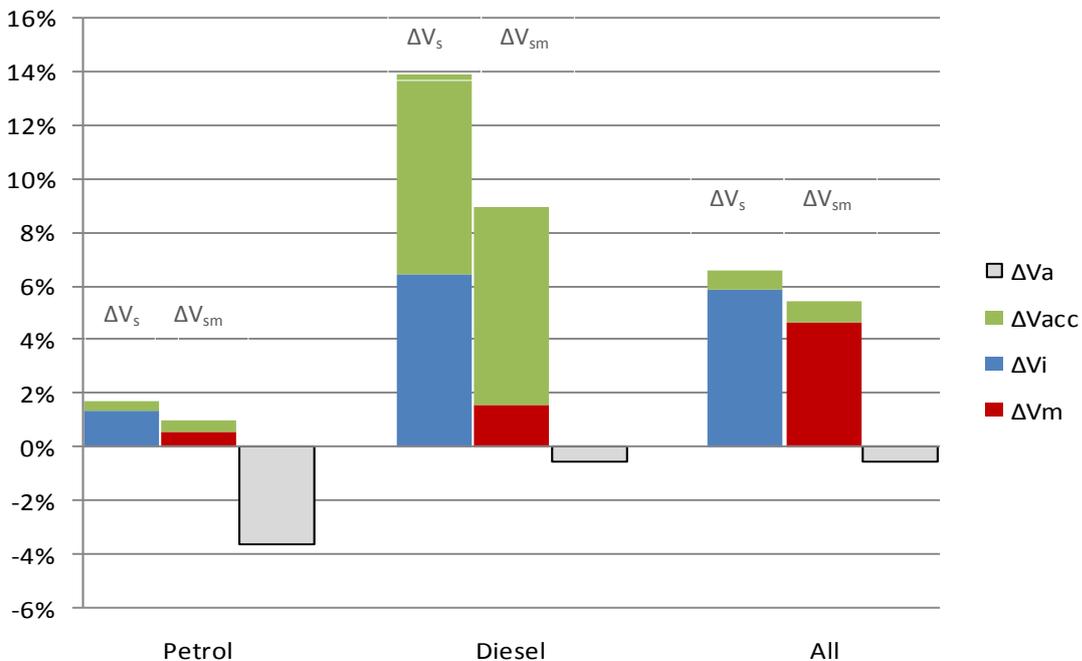
Figure 11 Implied changes 2002-2007 in engine capacity due to improved service and performance (ΔV_s and ΔV_{sm}) based on larger passenger space (ΔV_i), actual change in weight (ΔV_m) and improved acceleration capacity (ΔV_{acc}). Actual change of engine capacity (ΔV_a) is also plotted.

Taking into consideration all the implied effects of increased passenger space and acceleration we find that the fuel consumption (FC_s) should have increased to 8.7 l/100 km, Fig. 12. Net reductions in mass give a slightly lower FC of 8.6 l/100 km (FC_{sm}). The increased specific power and thus the smaller engine capacity reduces FC to 8.4 l/100 km (FC_{sa}). The effect of an increased share of diesels is calculated by presuming that the average diesel car maintains its attributes but has an average petrol engine instead. A new sales-weighted

average of the whole fleet FC_{dies} is thereafter calculated as 8.0 l/km. The difference between FC_{sa} and FC_{dies} is a balance term with improvements that the used method and data cannot identify. It includes technical improvements and changes such as higher thermal efficiency, reduced pump losses, reduced gear ratios, and lower rolling resistance. The actual value in 2007 (all fuel consumptions in petrol equivalents) was 7.5 l/100 km.
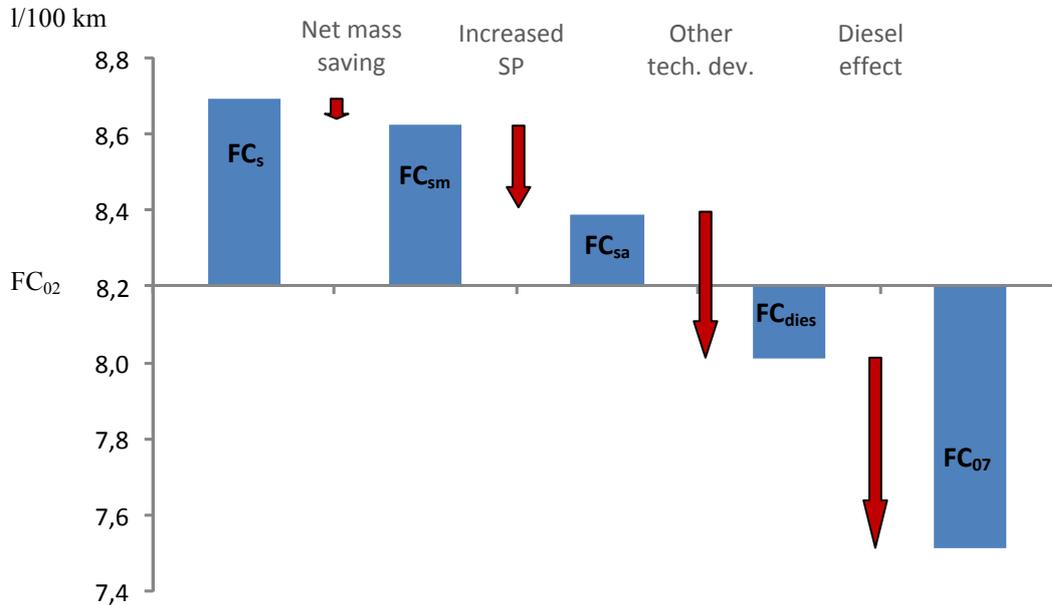
Figure 12 Implied fuel consumption relative FC in 2002 (X-axis) due larger passenger space and improved acceleration (FC_s); taken into consideration actual mass change (FC_{sm}) and actual change in engine capacity (FC_{sa}); FC given no diesel engines (FC_{dies}) and actual FC in 2007 (FC_{07}).

FC_s is 6 % higher than FC in 2002 and the actual FC in 2007 was 8 % lower. This implies that 43 % of the technological improvements related to fuel consumption were directed toward increased services and performance, while the remaining 57 % resulted in actual reductions in fuel consumption. This is a shift compared to previous periods studied in which the opposite relationship existed. However, a major part of the reduction is due to a shift to diesel engines since, given only petrol engines but the same service attributes, the reduction in fuel consumption would only have been 2.4 %. Thus about 70 % of the technological development would have been offset by ameliorated consumer amenities. The most prominent change of trends that can be observed is a change of fuel and engine type and not a shift of market when it comes to preferences of car attributes.

5. DISCUSSION

Car buyers have shifted toward diesel or flex-fuel cars. Wickelgren et al. (2009) found, based on qualitative consumer interviews, that car buyers often wanted the same car as before (or better) when it came to size and performance but with lower fuel consumption. In this perspective, diesel powered cars have been an attractive option. The increased penetration of diesel cars has been coupled with improvements in performance of these vehicles

implying that a shift to diesel cars has not meant worse driveability, rather the opposite. Our research cannot determine whether these customers have acquired heavier and more powerful cars because they bought a diesel (or flex-fuel) or if they would have chosen the same service and performance even if the car purchased would have been a petrol car.

Consumer preference trends during the observed period (2002-2007) in Europe have been divergent. On on hand fuel economy has been ranked high in consumer surveys carried out in European countries (Johansson-Stenman and Martinson 2006; Popp et al. 2009). On the other the share of SUVs on the market has increased (Green Car Congress 2007). There is also reported a gap between attitude and action in when it comes to environmental behaviour (Lane and Potter 2007; Kollmuss and Agyeman 2002).

Concerning fuel consumption or CO_2 emissions of the vehicle there is an environmental gain of shifting to a diesel or a flex-fuel car. However there are a few factors that may erode the environmental gain. For diesel cars there is a risk of a "rebound" effect leading to longer driving distances due to lower running costs (Schipper 2009; Schipper et al. 2002). Again it is hard to determine to what extent the persons shifting to diesel already were driving longer distances or they increased their driving due to lower running costs. For flex-fuel cars the fuel rate of E85 has a crucial role. Recent trends show that the fuelling rate of E85 in Sweden has gone down despite the increased sales of flex-fuel vehicles.

The development of consumer amenities is troubling in the context of meeting the goals set by the EU Commission for the CO_2 emissions of new sold cars. Fontaras and Samaras (2010) find the 130 g/km target hard to meet despite presumed weight reductions of about 10 % and mean powertrain efficiency improvements of 7.5 %. Zevras and Lazarou (2008) model different scenarios of weight changes and their impact on CO_2 emissions and assert the importance of this attribute for further reductions of emissions. Cuenot (2009) attributed part of the failure of the Voluntary Agreement between the car industry and the EU Commission to heavier vehicles. While average specific fuel consumption has decreased in Sweden during the last years this can partly be attributed to a larger share of diesels. Further long-term reductions require a larger focus on downsizing and weight reduction as well.

Downsizing and fuel efficiency could be fostered by a revision of the criteria for "environment-friendly cars". Today more or less all cars that can be driven on an alternative fuel meet the criteria, more stringent regulations of fuel consumption should be set to promote fuel efficiency even among these vehicle types. The limit of 120g CO_2/km for petrol and diesel cars should also be revised considering the rapid development of car models. Another policy in need of revision is the fringe taxing of company cars. As it is today the fringe tax is only based the financial value of the car (with the exemption of reduction of flex-fuel cars and gas driven cars). The current system has made it very cheap to have a larger car compared to private ownership and has thus promoted the sales of premium vehicles with higher fuel consumption and larger service attributes. From a fuel efficiency point of view a system based on e.g., carbon emission would be more appropriate. Carbon and energy taxes are important policies to promote both energy efficiency and shorter driving distances, thus any policy option should ensure that these continue to increase.

6. CONCLUSIONS

The main results of the analysis of new sold cars in Sweden between 2002 and 2007 are:

- The major change of the new car market is a differentiation of fuel type. While previously petrol cars dominated the market, in 2007 only roughly 50 % of the cars sold were pure petrol ones and instead diesel cars and flex-fuel cars have taken a larger share of the market.
- Sales-weighted average fuel consumption for the entire new car fleet has decreased; flex-fuel cars have in average a higher fuel consumption than pure petrol cars.
- Service related car attributes such as car size, weight, maximum power and acceleration capacity have continued to increase. The attributes of diesel cars have in average increased more than petrol cars.
- There is in average a slight engine downsizing of the new car fleet (fewer l/ton car) however, the full potential, i.e., a combination of engines with high specific power and low performance car, is still unused.

Compared to 1985-2002 the share of technical development that has been offset by consumer amenities seems to have decreased. However, had there not been a shift toward diesel cars than the offset would have been higher instead. Thus the result that the change in trends is mainly a change of fuel type and not a change of demand in consumer amenities is reinforced. These changes of the new car fleet reflect the fact that the policies in place in Sweden have been more focused on a shift of fuel than on increased fuel efficiency and downsizing. However, if stricter reductions of CO_2 emissions are expected then these issues have to be addressed more directly.

ACKNOWLEDGEMENTS

REFERENCES

An, F. and M. Ross (1993). A Model of Fuel Economy and Driving Patterns. SAE Paper 930328.

Chen, C. and J. Zhang (2009). The inconvenient truth about improving vehicle fuel efficiency: A multi-attribute analysis of the technology efficient frontier of the US automobile industry. Transportation Research Part D, 14, 22-31.

Cuenot, F. (2009). CO_2 emissions from new cars and vehicle weight in Europe; How the EU regulation could have been avoided and how to reach it? Energy Policy, 37, 3832-3842.

EPA (2007). Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2007.EPA420-R-07-008. United States Environmental Protection Agency.

European Commission (2009). Report from the Commission to the European Parliament and the Council - Monitoring the CO2 emissions from new passenger cars in the EU: data for the year 2008. COM/2009/0713 final.

Fontaras, G. and Z. Samaras (2010). On the way to 130 g CO_2/km-Estimating the future characteristic of the average European passenger car. Energy Policy, 38, 1826-1833.

Green Car Congress (2007). SUVs gaining European market share.
www.greencarcongress.com [Accessed 20/04/2010]

Johansson-Stenman, O. and P. Martinsson (2006). Honestly, why are you driving a BMW? Journal of Economic Behavior & Organization, 60, 129-146.

Kollmuss, A. and J. Agyeman (2002). Mind the Gap: why do people act environmentally and what are the barriers to pro-environmental behavior? Environmental Education Research, 8, 239-260.

Lane, B. and S. Potter (2007). The adoption of cleaner vehicles in the UK: exploring the consumer attitude-action gap. Journal of Cleaner Production, 15, 1085-1092.

Leduc, P., B. Dubar, A. Ranini and G. Monnier (2003). Downsizing of Gasoline Engine: an Efficient Way to Reduce CO_2 Emissions. Oil &Gas Science and Technology, 1, 115-127.

Meyer, I. and S. Wessely (2009). Fuel efficiency of the Austrian passenger vehicle fleet-Analysis of trends in the technological profile and related impacts on CO_2 emissions. Energy Policy, 37, 3779-3789.

Petitjean, D., L. Bernardini, C. Middlemass and S.M. Shahed (2004). Advanced Gasoline Engine Turbocharging Technology for Fuel Economy Improvements. SAE paper 2004-01-0988.

Popp, M., Van de Velde, L., Vickery, G., Van Huylenbroeck, G., Verbeke, W. and B. Dixon (2009). Determinants of consumer interest in fuel economy: Lessons for strengthening the conservation argument. Biomass and bioenergy, 33, 768-778.

Reynolds, C. and M. Kandlikar (2007). How hybrid-electric vehicles are different from conventional vehicles: the effect of weight and power on fuel consumption. Environmental Research Letters, 2, 014003.

Schipper, L., C. Marie-Lilliu and L. Fulton (2002). Diesels in Europe. Analysis of Characteristics, Usage Patterns, Energy Savings and CO_2 Emission Implications. Journal of Transport Economics and Policy, 36, 305-340.

Schipper, L. (2009). Automobile Fuel; Economy and CO2 Emissions In Industrialized Countries: Troubling Trends through 2005/6. Embarq, World Resource Institute.

Silva, C., M. Ross and T. Farias (2009). Analysis and simulation of "low-cost" strategies to reduce fuel consumption and emissions in conventional gasoline light-duty vehicles. Energy Conversion and Management, 50, 215-222.

Sprei, F. and S. Karlsson (2008). The role of market and technical downsizing in reducing carbon emissions from the Swedish new car fleet. Energy Efficiency, 1, 107-120.

Sprei, F., S. Karlsson and J. Holmberg (2008). Better performance or lower fuel consumption. Technological development in the Swedish new-car fleet 1975-2002. Transportation Research Part D: Transport and Environment, 13, 75-85.

Sprei, F. (2009). Vilka styrmedel har ökat personbilarnas energieffektivitet i Sverige? FRT 2009:1. Physical Resource Theory, Chalmers University of Technology, Sweden.

Swedish Environmental Protection Agency (2008). Genusperspektiv på allmänhetens kunskaper och attityder till klimatförändringen (tidigare växthuseffekten). ARS P1003. Swedish EPA, Stockholm.

Swedish Environmental Protection Agency (2009a). Index över nya bilars klimatpåverkan 2008. I riket, länen och kommunerna. Rapport 5946. Mars 2009. Swedish EPA, Stockholm.

Swedish Environmental Protection Agency (2009b). National Inventory Report 2010, Sweden. Swedish EPA, Stockholm.

Swedish Petroleum Institute (2009). Statistics Sweden. Volumes. Deliveries fuel, per month. www.spi.se [Accessed 28/12/2009]

Swedish Road Agency (2009). Uppdaterade reduktionsvärden för etanol- och gasfordon till bilindex. 2009-10-06. Swedish Road Agency, Borlänge.

Tolouei, R. and H. Titheridge (2009). Vehicle mass as a determinant of fuel consumption and secondary safety performance. Transportation Research Part D, 114, 385-399.

Wickelgren, M., F. Sprei and S. Karlsson (2009). Requirements for change in consumer car buying practices- observations from Sweden. Proceedings of ECEEE Summer Study, La Colle sur Loup, France 1–6 June 2009.

World Resource Institute (2010). Climate Analysis Indicators Tool (CAIT UNFCCC) Version 3.0. (Washington, DC: World Resources Institute, 2010). [Accessed 18/01/2010]

Zevras, E. and C. Lazarou (2008). Ifluence of European passenger cars weight to exhaust CO_2 emissions. Energy Policy, 36, 248-257.