New car preferences move away from greater size, weight and power: impact of Dutch consumer choices on average CO_2-emissions

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Abstract

This paper assesses the separate effects of consumer preferences and technological advances on sales-weighted average CO_2 emissions of new passenger cars in the Netherlands. Since 2008, consumer preferences have been moving away from large size, weight and power whereby car buyers were offsetting more than 50% of the potential CO_2 reduction from technological advances. From 2008 to 2011 consumer choices not only ceased to offset a large share of the technological advances, but contributed more than an additional 30% to CO_2 reductions. Had consumer preferences not decoupled from the historical upward trend, the Dutch sales-weighted average CO_2 emissions of new passenger cars would have been 139 g/km rather than the 126 grams CO_2 per km in 2011.

Key words: Vehicle weight, Passenger car buying**:** Vehicle fuel efficiency**:** CO_2 emissions

1. Introduction

Reducing carbon dioxide (CO_2) emissions from passenger cars is an important policy goal, both at national and EU level. The influx of new cars into the existing car fleet is an important leverage to eventually change CO_2 emissions for the entire car fleet. With respect to new cars and their proportionally related fuel efficiency and CO_2 emissions, many countries have witnessed a seemingly endless upward spiral in consumer preferences for buying bigger, heavier and more powerful cars which has largely offset any fuel-efficiency gains from technological advances in the past (Knittel, 2011; Kwon, 2006; Sprei et al., 2008). Although the upward trend of car size, weight and power has long absorbed the CO_2-emissions reduction potential of new vehicle technologies, recent developments show stagnation and even a decline in these consumer amenities (Schipper, 2011; Sprei and Karlsson, 2013).

This paper isolates consumer preferences from technological advances to explain their impact on CO_2 emissions of new passenger cars in the Netherlands. The analysis covers the time frame 2000 to 2011 in which the historical continuous increase of consumer amenities has completely reversed. The impact of consumer buying preferences is decomposed into within-car segments shifts, between-car segments shifts and fuel types. Furthermore, the role of tax incentives to promote low-carbon cars is investigated as one of the potentially key drivers for downsizing consumer amenities. The impact and evolution of technological advances provides evidence from the Dutch car market to answer the question of whether average specific CO_2 emissions of manufacturers in Europe have decreased faster since the EU regulation on CO_2 emissions from new passenger cars became mandatory.

2. Analytical framework and data

Car manufacturers face trade-offs between a vector of vehicle attributes when introducing model variations on the market; e.g. interior volume, pan area, mass, maximum engine power, torque, power-to-weight ratio, engine size, acceleration, and fuel efficiency. Consumers face trade-offs between vehicle attributes when choosing from the make-model variations that are available. The most desirable situation to achieve CO_2 reductions would be a decline in the vehicle attributes both offered by manufacturers and chosen by consumers. The EU regulation setting CO_2-emissions performance targets for manufacturers' new car sales may push the potential technological trade-offs in favor of increased fuel efficiency (European Commission, 2007; 2009). In addition, national vehicle taxation policies may induce a demand pull towards more fuel-efficient and less CO_2-emitting cars.

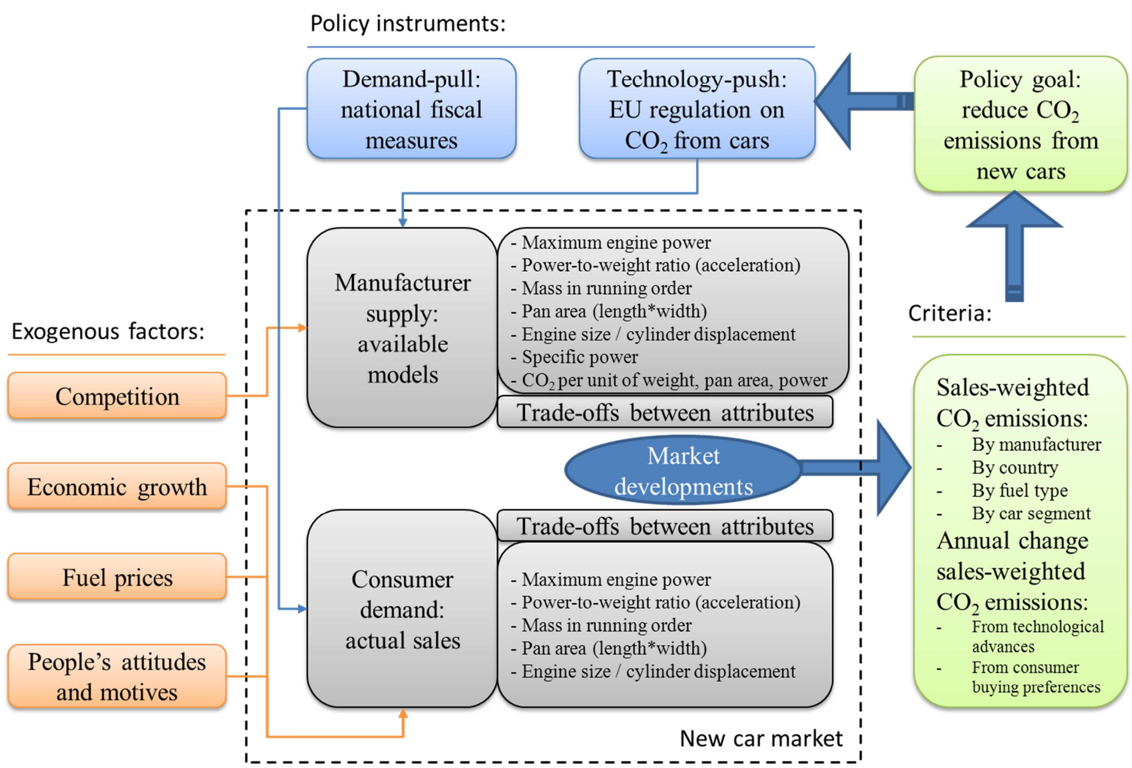


Fig. 1. Conceptual model of new car market and CO_2 emissions.

Firstly, a deterministic analysis is used to analyze the effect of shifts in sales between car segments with different vehicle characteristics and shifts in sales between fuel types with different vehicle characteristics. Secondly, a regression analysis is used to additionally estimate the effect of shifts in sales within car segments (e.g. increasing sales of less powerful cars within the same size/weight class). The trade-offs made by manufacturers determine a number of technical relationships between vehicle performance attributes and the resulting CO_2-emissions and may therefore change over time. These relationships, such as CO_2 emissions per unit of weight, per unit of pan area or per unit of engine power, reflect the technological progress deployed by manufacturers and are independent of consumer choices. The evolution of these technology-associated vehicle characteristics together with a number of consumer-associated vehicle attributes (e.g. mass, pan area, engine power) are input to the regression analysis to determine the separate effects of consumer choices and technological advances (Fig. 1).

The data was obtained from the Dutch Road Authority (RDW, 2012) and includes the six million new car sales between 2000 and 2011 per make-model variation available and their corresponding technical-environmental specifications as measured for type approval, see Table 1. Type approval is the confirmation that production samples of a design will meet specified performance standards and is consequently accepted for sale in all EU member states. Each make-model-technical variation that has been approved has a unique, tested fuel consumption and CO_2 emissions value based on the New European Driving Cycle (NEDC). The CO_2 emissions data we use include only NEDC-test values; no on-road correction factor is applied.

Table 1. New car make-model variations and actual sales in the Netherlands, 2000-2011.

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Available models (x1,000)	10	10	11	13	13	14	14	14	14	14	14	14
Actual sales (x1,000)	596	529	509	486	481	455	480	498	493	385	479	553

Source: RDW (2012).

Since a comprehensive classification is difficult in the automotive industry, we use a fixed definition of car segments based on the pan area of cars[1]. Five segments are defined (Table 2) matching increases in size and improvements in performance of cars, and decreasing fuel efficiency. The classification is made in such a way that each segment captures the majority of the cars along the lines of the traditional classification used by the automotive industry between 2000 and 2011.

Table 2. Definition of car segments reflecting increasing size and performance.

Car segment	**Pan area (m^2)**	**Examples**
A (mini/city)	< 6.1	VW Lupo/Up, Ford Ka, Toyota Aygo, Renault Twingo
B (supermini/subcompact)	6.1 to 7.0	VW Polo, Ford Fiesta, Toyota Yaris, Renault Clio
C (lower medium)	7.0 to 7.9	VW Golf, Ford Focus, Toyota Corolla/Auris, Renault Megane
D (upper medium)	7.9 to 8.5	VW Passat, Ford Mondeo, Toyota Avensis, Renault Laguna
E+Other (executive/ luxury/sports/MPV)	> 8.5	VW Touareg, Ford Galaxy, Toyota Land Cruiser, Renault Espace

[1] A correction for sports cars is applied since, based on size, they could occasionally fit in segments B or C, but based on maximum engine power and CO_2 emissions belong to the 'E+Other' segment. Otherwise sports cars would hamper the technical analysis within each size class.

Three groups of fuel types are distinguished – gasoline, diesel and other. Up to and including 2011 only gasoline hybrids were sold in the Netherlands, with few pure electric cars being bought. For these reasons gasoline and hybrid-electric cars are merged into one group and referred to as gasoline; gasoline and diesel cars were over 97% of sales.

Two methods are used to isolate the effects of changes in consumer trends and technological advances. The first method is a relatively straightforward deterministic approach (Rogan et al., 2011). Changes in the distribution of car sales across segments and fuel types are assumed to be a result of the changing preferences of consumers. All other changes in the evolution of CO_2 emissions from cars are attributed to technological advances. To isolate the effect of sales shifts between car segments and fuel types it is assumed that the distribution of car sales in 2000 is 'frozen' between 2000 and 2011. What this does not do, is to capture any shifts in consumer choices with respect to car size, weight and power within each individual car segment and thus the combined impact of changes in consumer choices and technological advances is underestimated.

A second complementary approach based on regression analysis is used to determine the effect of sales shifts between- and within car segments and fuel types. The combined results of the deterministic and stochastic analysis enable the impact to be determined of each kind of sales shift on the average CO_2-emissions. Some of the consumer-associated or technology-associated predictor variables, such as vehicle weight and size, maximum engine power and acceleration are highly collinear. To handle this, principal component analysis is used to identify two factors that are to be used in a multivariate model to predict the average CO_2 emissions of new cars. Oblique factor rotation was applied to arrive at the most realistic clustering of variables being a simple structure. The oblique solution also provides information about the extent to which the factors are correlated with each other. The variables with the highest factor loadings per factor were standardized and used to construct a summated scale. Finally, because the impact of consumer preferences on CO_2 emissions is not necessarily independent of technological advances, a bilinear moderator effect between the factors is entered.

3. Results

Table 3 shows the evolution of market shares and sales-weighted average CO_2 emissions per segment of gasoline cars between 2000 and 2011. The impact of technological advances is calculated by multiplying CO_2 emissions per segment in each year by the 'frozen' distribution of car sales across the segments as observed in 2000. Conversely, the impact of consumer preferences is calculated by multiplying the market shares per segment in each year by the 'frozen' average CO_2 emissions as observed in 2000. The results of this analysis are shown in the two bottom rows of Table 3 and indicate that the isolated effect of consumer preferences increased until it peaked at 187 g/km in 2007, followed by a reversing trend to 183 g/km, 2.2% above 2000 levels. The isolated effect of technological advances resulted in a reduction of CO_2-emissions from 179 g/km in 2000 to 130 g/km in 2011.

Table 3. New gasoline cars: market share and CO_2 emissions by segment.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Car segments (%)												
A – gasoline	23	18	18	14	18	16	17	17	21	24	30	32
B – gasoline	23	24	26	29	27	27	32	29	27	26	22	21
C – gasoline	41	40	37	36	35	30	25	24	23	21	20	20
D – gasoline	8	11	12	12	14	18	18	21	19	18	18	17
E+Other - gasoline	5	7	6	7	7	9	9	9	10	10	9	10
CO_2-emissions (g/km)												
A – gasoline	151	149	144	143	141	137	129	125	121	113	110	107
B – gasoline	166	161	159	158	156	153	151	149	145	139	133	126
C – gasoline	185	183	182	181	179	179	176	170	161	149	139	135
D – gasoline	218	210	207	204	199	190	188	186	178	168	164	157
E+Other - gasoline	257	244	243	246	246	241	234	230	210	193	185	170
All – gasoline observed	179	179	176	176	174	173	167	165	156	146	138	131
Technology effect	179	176	173	172	170	167	163	159	152	142	136	130
Consumer effect	179	183	182	184	184	186	185	187	186	185	183	183

From 2000 to 2009 the diesel sales distribution became highly skewed towards the larger and more CO_2-emitting D and 'E+Other' segments (Table 4). This shift increased the effect of consumer preferences on CO_2 emissions by 15.0% until it peaked at 183 g/km in 2009. As a result, the average diesel car sold did not have any observed CO_2-advantage over the average gasoline car sold in 2007 or 2009. Subsequently, the market share of B-segment diesel cars witnessed a remarkable increase in 2010 and 2011. This shift to smaller diesel segments resulted in a sharp drop in the effect of consumer preferences to 168 g/km in 2011, 5.7% above 2000 levels. As a consequence the average diesel car again became a lower carbon alternative to gasoline cars. Tables 3 and 4 show that CO_2-emissions of each diesel segment is always below those of gasoline segments. However, since the average diesel car sold has greater size and weight than the average gasoline car, the CO_2-advantage of diesel cars is reduced and at times is at a CO_2-disadvantage. Thus, to assess dieselization as a low-carbon alternative to gasoline, it is more appropriate to compare the sales-weighted average CO_2-emissions of both fuel types than CO_2-emissions based on matched segments or matched pairs of cars of equivalent size. Furthermore, the isolated effect of technological advances resulted in a reduction of CO_2-emissions from 159 g/km in 2000 to 112 g/km in 2011.

Table 4. New diesel cars: market share and CO_2 emissions by segment.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Car segments (%)												
A – diesel	2	1	1	0	0	0	0	0	0	0	0	2
B – diesel	10	10	9	9	8	7	9	8	6	5	27	38
C – diesel	59	55	45	43	41	33	27	24	23	18	13	13
D – diesel	20	20	28	29	32	36	34	37	34	33	29	18
E+Other - diesel	10	15	17	19	18	24	30	32	37	44	31	28
CO_2-emissions (g/km)												
A – diesel	128	114	113	120	118	119	120	115	113	98	92	92
B – diesel	143	137	130	129	128	126	126	124	120	113	93	92
C – diesel	152	151	150	149	149	150	148	142	137	131	116	107
D – diesel	163	164	167	166	159	154	155	156	151	143	130	122
E+Other - diesel	215	195	199	205	207	197	197	197	183	172	165	144
All – diesel observed	159	158	161	163	161	161	163	163	158	152	128	114
Technology effect	159	155	155	155	154	153	151	148	142	135	121	112
Consumer effect	159	162	165	166	166	170	174	175	178	183	172	168

The combined effects of gasoline and diesel cars are depicted in Table 5. In addition to shifts between segments, this also takes into account shifts between fuel types using 'frozen' market shares of fuel types when calculating the effect of technological advances. The effect of switching between fuel types is within the range -0.4 to 1.1 g/km in each year between 2000 and 2011. The isolated effect of consumer preferences on CO_2 emissions increased 5.9% to peak at 185 g/km in 2009, followed by a decreasing trend to 179 g/km in 2011. The isolated effect of technological advances resulted in a reduction of 27.8% in CO_2-emissions from 174 g/km in 2000 to 126 g/km in 2011.

Table 5. New car market shares by fuel type, deterministic impact of technological advances and consumer preferences.

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Market share (%)												
Gasoline	77	77	78	77	75	73	73	72	75	80	80	72
Diesel	23	23	22	23	25	27	27	28	25	20	20	28
CO_2-emissions (g/km)												
All fuels - observed	174	174	173	173	171	170	166	164	157	147	136	126
Technology effect	174	171	169	168	166	164	161	157	150	140	132	126
Index: 2000=100	100.0	98.1	96.9	96.5	95.4	94.1	92.1	89.8	85.9	80.6	75.8	72.2
Consumer effect	174	178	178	180	179	182	182	183	184	185	180	179
Index: 2000=100	100.0	102.0	102.3	103.1	102.8	104.4	104.5	105.2	105.4	105.9	103.5	102.4

Two effects are not captured. First, consumers could choose a car with different fuel efficiency within the same segment, and secondly, consumers could choose to switch to a different segment or fuel type in combination with different fuel efficiency than the average fuel efficiency applicable for that segment or fuel type. Therefore, a more holistic approach is needed taking into account different 'facets' of consumer preferences that have an impact on the average CO_2 emissions of cars.

As Figs. 2 and 3 show, nine vehicle attributes are seen as potentially useful predictors of the evolution of the sales-weighted average CO_2 emissions. Predictor variables associated with consumer preferences are 'mass in running order', 'vehicle pan area', 'maximum engine power', and the 'power-to-weight ratio (acceleration potential)'. Predictor variables associated with technological advances are considered to reflect technical relationships between vehicle attributes and CO_2 emissions independent of consumer choices. These variables are 'CO_2 emissions per unit of vehicle weight', 'CO_2 emissions per unit of vehicle pan area', 'CO_2 emissions per unit of engine power, and 'specific power measured as engine power per unit of engine cylinder displacement'. The engine size, measured as cylinder displacement, could reflect both technical downsizing of engines and market downsizing (Sprei and Karlsson, 2008). The latter refers to consumers choosing smaller cars with smaller engines and less power, while the former refers to manufacturers trying to maintain at least equal maximum engine power and/or torque with a smaller engine by increasing the specific power. Engine size may therefore turn out to be less useful in isolating the effects of consumer preferences and technological advances.

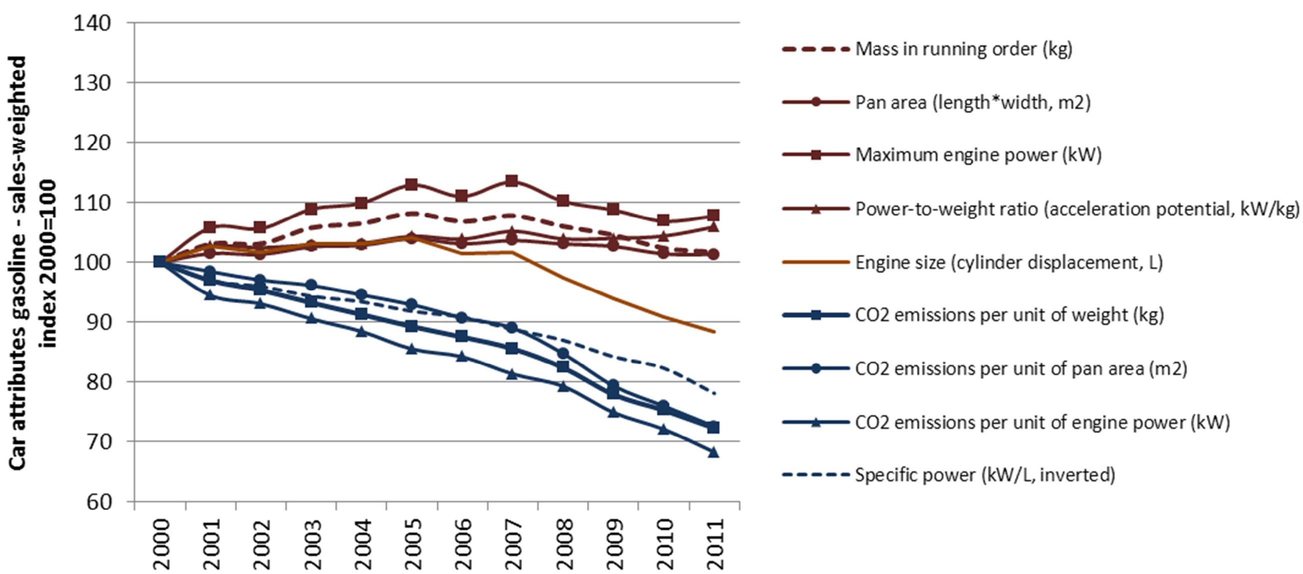


Fig. 2. Evolution of sales-weighted average gasoline vehicle attributes, 2000-2011.

As Fig. 2 shows, consumer-associated variables (in dark red) for gasoline cars increased between 4% and 13% from 2000 to 2007. From 2008 onwards the increasing trend stabilized and even reversed towards smaller size, weight and power. By 2011 the vehicle attributes associated with consumer preferences almost returned to 2000 levels. The vehicle attributes associated with technological advances all show a similar rate of improvement, although at a slightly faster rate from 2008.

The trends in vehicle attributes of diesel cars, as depicted in Fig. 3, show a number of remarkable differences compared to gasoline cars. First, the dispersion of the rate of change in vehicle attributes is much higher for diesel cars. Second, the upward trend of vehicle attributes associated with consumer preferences does not peak in 2007, but in 2009. Consumer-associated variables increased much stronger, 10 to 35% between 2000 and 2009, followed by a much stronger reversing trend towards smaller size, weight and power compared to gasoline cars. The vehicle attributes associated with technological advances show more variation in the rate of improvement. In terms of specific power diesel engines improved much faster than gasoline engines.

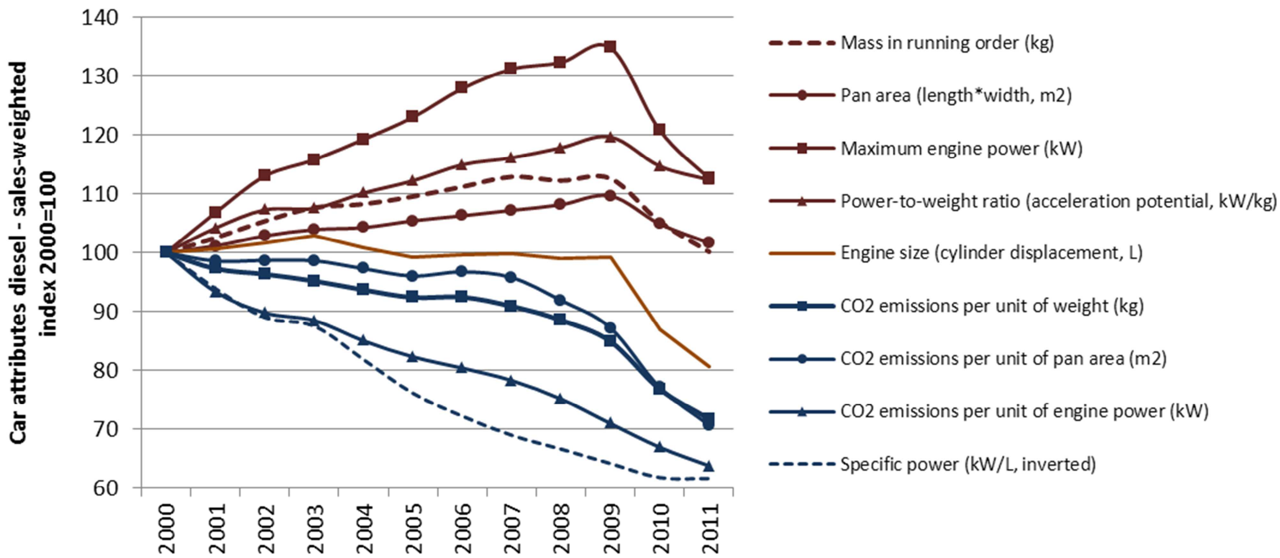


Fig. 3. Evolution of sales-weighted average diesel vehicle attributes, 2000-2011.

These nine vehicular attributes are included in the principal component analysis to extract two factors for fuel types, and one each for consumer preferences, and technological advances. Four variables are excluded from the analysis because they did not share enough variance with the factors or hampered the achievement of a simple structure. Table 6 shows that both for gasoline and diesel cars three consumer-associated variables have high factor loadings on component 1 and low loadings on component 2 while the two technology-associated variables exhibit the opposite feature. A viable structure is achieved with 90% of the variance explained. The factors extracted using oblique rotation, have positive correlations below 0.1 for gasoline and 0.3 for diesel. The variables with the highest loadings, over 0.8, are standardized and used to construct four composite scales, ‘consumer preferences’ and ‘technological advances’ for the two fuel types[2].

[2] All scales have Cronbach’s alphas greater than 0.85 meeting the criteria for internal consistency

Table 6. Factor loadings in factor analysis.

	Component 1	Component 2
Gasoline[a]		
Mass in running order	0.980	0.013
Pan area	0.940	-0.110
Maximum engine power	0.915	0.163
CO_2 emissions per unit of weight	-0.162	0.958
CO_2 emissions per unit of pan area	0.215	0.963
Diesel[b]		
Mass in running order	0.914	0.140
Pan area	0.935	-0.123
Maximum engine power	0.836	0.040
CO_2 emissions per unit of weight	-0.112	1.000
CO_2 emissions per unit of pan area	0.183	0.915

[a] Variance explained = 92.7%; [b] Variance explained = 87.8%

Consequently, two multiple models are estimated for gasoline and diesel cars. The estimation of the models is based on vehicle characteristics of 4.5 million gasoline car sales and 1.4 million diesel car sales between 2000 and 2011. Table 7 shows the regression results to predict the sales-weighted average CO_2-emissions of new cars. In addition to the summated scales 'X_1: consumer preferences' and 'X_2: technological advances' being the primary predictor variables in the equation, the incremental change of explained variance R^2, by adding the moderator effect X_1X_2, proves to be statistically significant. This means that the effect of consumer preferences on CO_2 emissions decreases the more fuel-efficient the car technologies become.

Table 7. Regression results.

	Unstandardized coefficient	Standardized coefficient	Significance
Model 1: Gasoline cars[a]			
Constant	164.823		0.000
X_1: Consumer preferences	10.475	0.753	0.000
X_2: Technological advances	11.876	0.791	0.000
X_1X_2: Moderator effect of X_2 on X_1	0.559	0.114	0.000
Model 2: Diesel cars[b]			
Constant	152.863		0.000
X_1: Consumer preferences	7.146	0.455	0.000
X_2: Technological advances	12.197	0.740	0.000
X_1X_2: Moderator effect of X_2 on X_1	0.543	0.113	0.000

[a] Explained variance R square = 0.993; [b] Explained variance R square = 0.992

Fig. 4 shows the results of both the regression and the deterministic analysis to separate the isolated effects of consumer preferences and technological advances on CO_2 emissions of gasoline cars. The results for consumer preferences show how the sales-weighted average CO_2 emissions would have developed from 2000 to 2011 had there been no technological improvements in gasoline cars. Until 2007, the regression results show a stronger upward trend in consumer preferences than the deterministic results. Apparently, in addition to shifts towards larger and less fuel-efficient car segments, consumers also shifted towards larger, heavier and more powerful cars within the same car segment. From 2007 to 2011 this gap gradually decreased indicating a stronger 'downsizing' of consumer preferences within the same car segments than 'downsizing' as a result of shifts toward smaller car segments.

The results for technological advances show how sales-weighted average CO_2 emissions would have developed from 2000 to 2011 had there been no changes in consumer preferences. The dashed red line indicates that the more the effects of consumer preferences are underestimated by the deterministic analysis (gap between the solid and dashed blue lines) the more the effects of technological advances are also underestimated by the deterministic analysis.

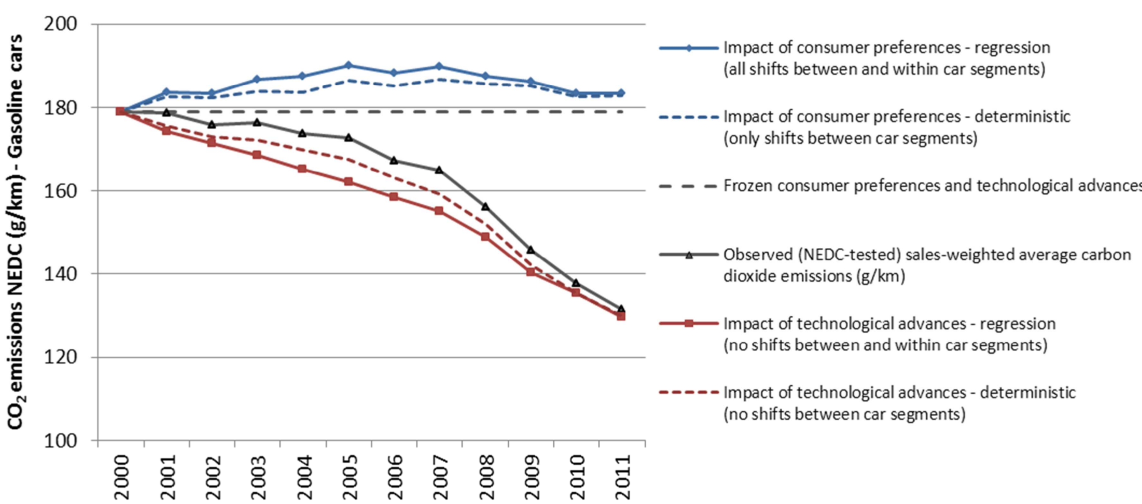


Fig. 4. Impact of consumer preferences and technological advances on CO_2 emissions of gasoline cars.

Fig. 5 shows the results for diesel cars. The upward effect of consumer preferences is much steeper for diesel than for gasoline cars until 2007. Although consumers were still shifting towards larger and less fuel-efficient segments between 2007 and 2009, the regression results indicate that on the contrary consumers already by 2007 started shifting towards more fuel efficient cars within the same car segments. Between 2009 and 2011 a much more radical reversal of consumer preferences are observed compared to the gasoline results and the 'downsizing' of consumer preferences within the same car segments continues to contribute an additional CO_2 reduction. Furthermore, as soon as the within-segment consumer preferences start to contribute in addition to CO_2 reductions from between-segment shifts, the deterministic and regression results for technological advances are equal.

The effect of within-segment compared to between-segment shifts was about 15 to 20% between 2000 and 2011 for diesel cars. For gasoline cars it was about 50% until 2007, and only 20% in the last four years. This indicates that for diesel car consumer preferences are mainly captured by between-segment shifts, whereas for gasoline car consumer preferences while previously dominated by both within- and between-segment shifts, more recently have been more influenced by between-segment shifts.

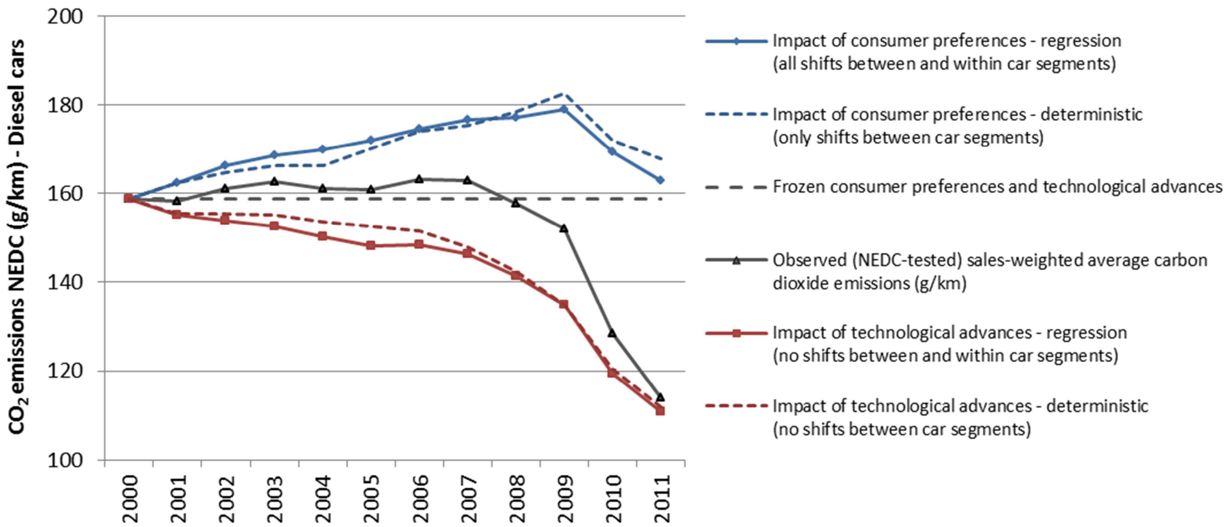


Fig. 5. Impact of consumer preferences and technological advances on CO_2 emissions of diesel cars.

Fig.6 shows the combined results for gasoline and diesel cars taking into account the effect of consumer preference shifts between the fuel types. The maximum impact of shifts between fuel types on the average CO_2 emissions is only 1.1g/km. The sales-weighted average CO_2 emissions of new cars in the Netherlands decreased modestly between 2000 and 2007 and then at a much faster rate until 2011. If consumer preferences had remained constant between 2000 and 2011, CO_2 emissions would have dropped to 153 g/km instead of 164 g/km by 2007 and to 125 g/km instead of 126 g/km by 2011. If technological advances had remained constant between 2000 and 2011, CO_2 emissions would have peaked at 186 g/km in 2007 before falling to 177 g/km in 2011. When the trend in consumer preferences between 2000 and 2007 is extrapolated to 2011, the resulting sales-weighted average CO_2-emissions would have only reached 139 g/km in 2011, well above the actual 126 g/km. The figure also illustrates how much the technological advances have been offset by changing consumer preferences between 2000 and 2011 (shaded area). Compared to the baseline year 2000, 67% of the technological advances between 2000 and 2007 have on average been offset by consumer preferences, while since then it has only been 15%.

If the annual change of CO_2 emissions is considered, rather than making comparisons with 2000, different results are extracted. As soon as consumer preferences decrease, consumers start to contribute in addition to the annual technological improvements. From this perspective, as seen in Table 8, 56% of the cumulative annual technological improvements were offset by consumer preferences for increasingly larger, heavier and more powerful cars between 2000 and 2007. In contrast, from 2008 to 2011 consumer preferences did not only cease to offset the annual technological advances, they contributed 31% on top of the annual CO_2 reduction from technological improvements (9 g/km on top of 28 g/km adding up to the observed CO_2 reduction of 38 g/km).

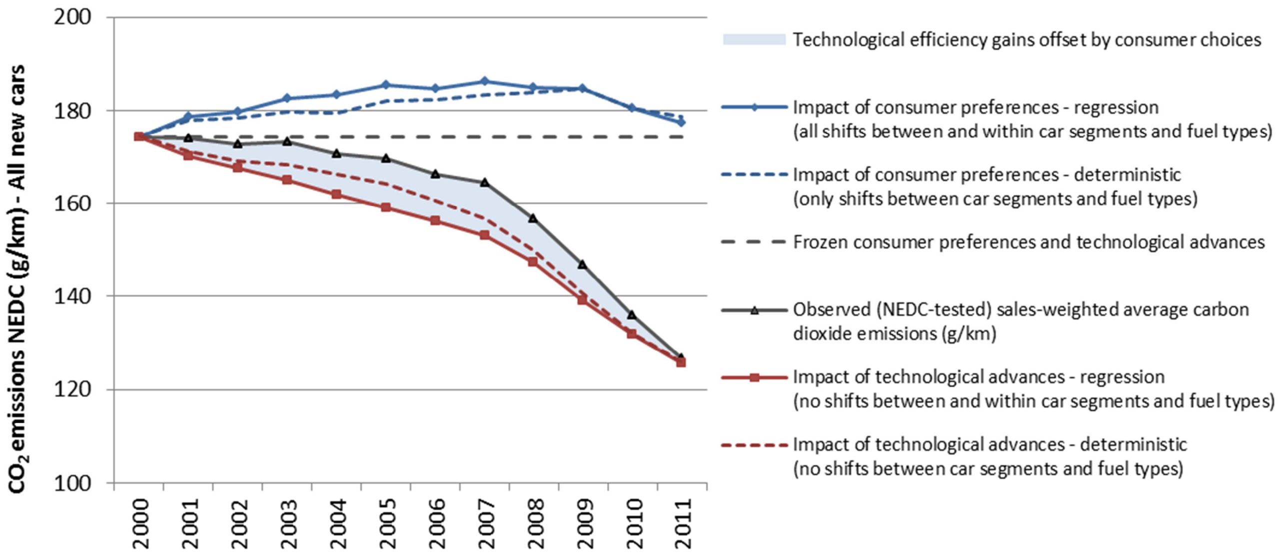


Fig. 6. Impact of consumer preferences and technological advances on CO_2 emissions of all cars.

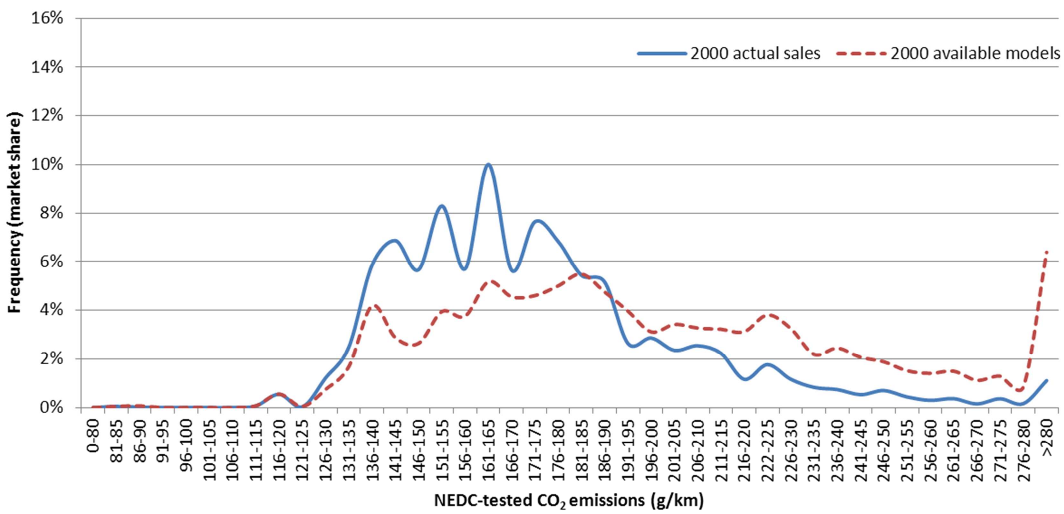
Table 8. Decomposition of CO_2 reduction into consumer trends and technology.

Decomposition	Cumulative CO_2 change 2000-2007	Cumulative CO_2 change 2008-2011	Average annual change 2000-2007	Average annual change 2008-2011
Observed	-10 g/km	-38 g/km	-0.8%	-6.4%
Consumers	12 g/km	-9 g/km	0.9%	-1.2%
Technology	-21 g/km	-28 g/km	-1.8%	-4.9%

Table 8 also reveals that since the announcement of the EU regulation on CO_2 emissions for new cars in 2007 and its implementation in 2009, technological advances seem to have accelerated. The annual CO_2 reduction was on average 1.8% from 2000 to 2007, compared with 4.9% between 2008 and 2011.

While a number of exogenous factors, as well as policy instruments, may have affected consumer preferences in favor of smaller, less heavy, less powerful and consequently more fuel-efficient cars, we focus on taxation. Vehicle taxes in the Netherlands used to be primarily based on pre-tax or after-tax retail prices, vehicle weight or fuel type, but since 2008 vehicle registration (VRT), the annual motor (AMT) and the company car taxes (CCT) have become increasingly dependent on a cars' NEDC-tested CO_2-emissions. Between 2010 and 2013, the VRT has gradually become fully based on CO_2-emissions. By 2011 approximately 50% of the VRT was based on CO_2-emissions and cars below the threshold values of 111 g/km (gasoline) and 96 g/km (diesel) were exempted from paying this part of the tax. For the AMT the same threshold values applied for exemption, increasing from 50% in 2008 to 100% in 2010 and 2011. Lastly, for the CCT the same threshold values applied for a tax reduction from 25% to 14% of the retail price of a car to be added to the taxable income when privately used. In addition, two more threshold values were introduced in 2009 for a CCT tax reduction from 25% to 20% for gasoline cars below 141 g/km and diesel cars below 117 g/km.

To investigate the impact of fiscal incentives in promoting fuel-efficient cars in a context of changing supply (the available models) and changing demand (the actual sales) a comparison was made between the frequency of available models and actual sales across the spectrum of CO_2-emissions in the years 2000 and 2011.



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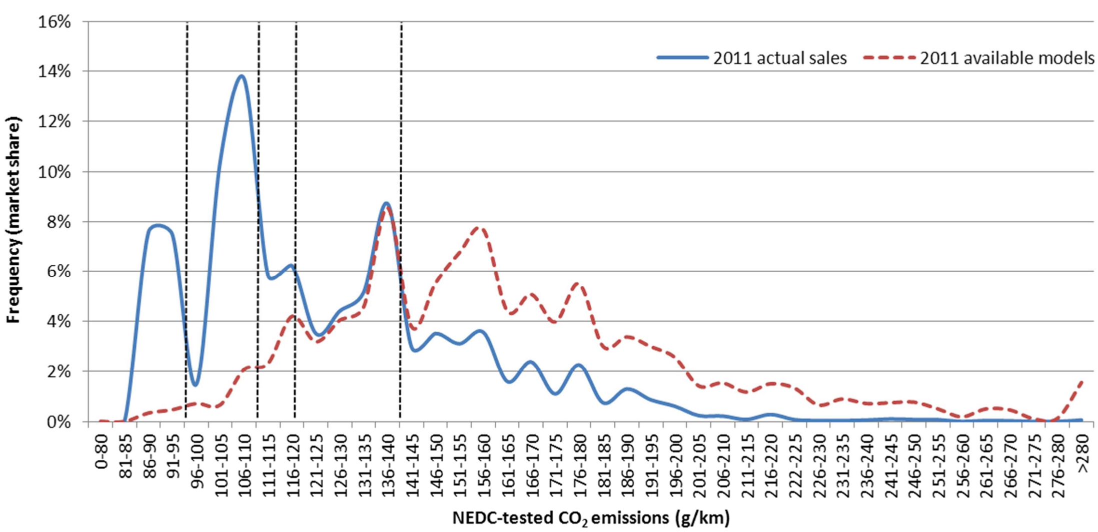

Note: The vertical dashed lines represent the four threshold values for tax exemptions.

(2011)

Fig 7. Distribution of available car models and actual sales across CO_2-emission classes

As shown in Fig. 7, demand and supply were relatively balanced in 2000. The 10% most fuel-efficient available car models (<144 g/km) made up 16% of the actual sales. In addition, the middle 50% of the available models corresponded to 47% of the actual sales. By 2011 when stringent fiscal incentives had been applied, the 10% most fuel-efficient car models (<119 g/km) available made up 52% of the actual sales. Furthermore, the middle 50% of the available models corresponded to merely 27% of the actual sales, which indicates that demand had become extremely left-skewed toward low-carbon cars. Fig. 7 also shows how responsive the Dutch consumers had become to the four threshold values for tax exemptions (see the four vertical dashed lines). Just below every threshold value for gasoline and diesel cars are clear high sales volumes. As much as 33% of all gasoline sales are below the threshold value of 111 g/km and 45% of all diesel sales below the threshold value of 96 g/km.

4. Conclusion and discussion

4.1 Conclusion

Our results indicate a trend break after 2008 in the car preferences in the Netherlands away from the purchase of large, heavy and powerful cars. Between 2000 and 2007, 56% of CO_2 reduction from technological advances had been offset by increases in larger vehicles, but from 2008 to 2011 this effect was neutralized, and purchasing trends reduced CO_2 by 31% over those from technological advances. Had consumer preferences not decoupled from the historical trend, the Dutch sales-weighted average NEDC-tested CO_2 emissions of new passenger cars would not have reached the observed 126 g/km CO_2 in 2011, but would have been 139 g/km instead. From the deterministic and regression analyses it was found that for diesel cars consumer trends are mainly captured by shifts between car segments. For gasoline cars consumer trends used to be equally captured by shifts within and shift between car segments, whereas recently the relative importance of between-segment shifts has increased. The impact of sales shifts between fuel types on the average CO_2 emissions is negligible as the average diesel car sold is larger and heavier than the average gasoline car sold. This diminishes the observed CO_2-advantage of diesel cars for matched car segments and at times means that the average diesel car, in terms of CO_2 emissions, is a worse alternative than gasoline cars. Consumer preferences within each fuel type largely determine whether or not the average diesel car sold is a lower carbon alternative to the average gasoline cars sold.

Due to very stringent tax incentives gradually introduced from 2007 onwards, consumer demand has become extremely skewed toward low-carbon cars compared to the available models. The CO_2-based threshold values for tax exemptions indicate that consumers are very responsive to fiscal incentives. Nevertheless, more research is needed to determine to what extent the turnaround in consumer preferences and reduction of CO_2-emissions can be attributed to taxation policies or other exogenous factors and whether these policies have been a cost-effective instrument to bring about CO_2 emission reduction from cars. The isolated impact of technological advances on the sales-weighted average CO_2 emissions indicates that manufacturers have accelerated the deployment of technological advances since the EU regulation on CO_2 emissions for new cars has become mandatory. The average annual CO_2 reduction from technological advances was 1.8% from 2000 to 2007, compared with 4.9% in the last four years.

4.2 Discussion

Consumer buying preferences could ‘help’ or hamper car manufacturers to achieve their CO_2-emissions targets. The sales-weighted average CO_2 emissions of new cars is an important measure to design and monitor national as well as European environmental policies and is used to monitor the progress of car manufacturers towards achieving CO_2 reductions from new cars. Consumer choices therefore also affect car manufacturers and their progress towards achieving the mandatory EU target of 130 gCO_2/km by 2015 and the newly announced target of 95 gCO_2/km by 2020 (EC, 2012). As this regulation refers to an average target value for all manufacturers and all sales within Europe, a lead ahead of this target in one country, as observed in 2011 in the Netherlands, means that the sales-weighted average CO_2 emissions in other member states could potentially be allowed to lag behind this target. That car manufacturers are ‘helped’ by changed consumer buying preferences holds the potential rebound effect that in the long term the automotive industry will have less incentive to deploy technological advances. This rebound could pose a problem if the turnaround in consumer preferences is just temporary. The sales-weighted average CO_2 emissions of manufacturers could change, again lagging behind in the future.

Another important question concerns how ‘solid’ the environmental benefits are of lower specific CO_2-emissions? A number of issues are of concern when assessing the environmental impact of consumers buying smaller and more fuel efficient cars (Kok et al., 2011). First, buying more fuel efficient cars changes driving costs per kilometer. A rebound effect of lower driving costs is to drive more. The second issue concerns the apparent gap between tested and on-road fuel efficiency and CO_2 emissions. The fuel efficiency shortfall between tested and on-road driving conditions seems to have a positive correlation with the fuel efficiency of cars: on average the shortfall is larger for more fuel efficient cars (TNO, 2010). Consequently, the environmental impact of consumers buying less CO_2-emitting cars decreases the more fuel efficient new cars become. Besides, the discrepancy between tested and on-road CO_2 emission values is increasing over time, especially since 2007 (Mock et al., 2012). Three reasons have been suggested to explain this gap. First, an increasing share of new car sales is equipped with an air conditioning system, which consumes fuel when turned on, but is shut off during the test procedure. Second, that the NEDC driving cycle is unable to reflect real-world driving behavior (e.g. speed, acceleration, idling, transmission shift points, driving resistance, share of urban and extra-urban speed patterns). Third, manufacturers may have optimized the use of flexibilities in the test procedure for type approval (e.g. road load values reflecting driving resistance, laboratory ambient test temperature, vehicle weight, transmission shift schedule).

The mandatory EU regulation on CO_2 from new cars may have created an incentive for manufacturers to further explore the NEDC-test procedure allowances in the laboratory conditions and to optimize them accordingly. A recent study for the European Commission identified a number of potential flexibilities allowable within the type approval procedure whose use may contribute to a reduction in CO_2-emissions as measured on the type approval test (TNO, 2012). The study has generated convincingly strong indications that for passenger cars, up to one third of the observed net reduction of CO_2-emissions between 2002 and 2010 may have been achieved by use of flexibilities. The estimation of past and present use of flexibilities indicates that many of the identified flexibilities may not yet even have been utilized to their full potential. In this context the CO_2 reduction from technological advances as presented in this paper could be considered an upper estimate. The impact of technological advances is likely to be considerably smaller when experienced by consumers in real-world driving conditions.

Acknowledgements

We thank the Dutch road authority for providing the data on car sales and technical specifications.

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