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Gasoline, diesel and climate policy implications—Insights from the recent evolution of new car sales in Germany

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ABSTRACT

With the aid of detailed automobile sales data this paper looks into changes in car attributes and CO_2 emissions in Germany in the years 1998–2008, both at aggregate level and within individual car segments. New car CO_2 emissions have not decreased at the expected levels because of negligible downsizing and increasing power of diesel cars. Interestingly, today there are relatively more models available with higher-than-average emission levels than in the late 1990s. We further constructed matched pairs of gasoline and diesel models in order to explore how their power and emissions ratio has evolved during the same decade. Results imply that German consumers may not have chosen to buy the diesel powered matched pair of a gasoline car they would have bought a few years earlier; instead they selected among the variety of diesel cars available in the market, and preferred a more powerful diesel car than what they might have bought otherwise. These findings reinforce the view that low-carbon transport policies must address the issue of changes in vehicle size and performance, which compromise the environmental effectiveness of regulations. In contrast to current EU regulations, CO_2-related standards should discourage increases in a vehicle's weight and power.

1. Introduction

This paper attempts to shed some light in two questions related to the recent evolution of automobile fuel economy in Europe.

The first question is whether there has been a significant structural change in the carbon performance of the car market; has the whole automobile supply shifted homogenously towards lower-CO_2 cars, or are there 'fat tails' remaining in the distribution of vehicle emissions? To examine this, in Section 2 we will look into the distribution of engine size and CO_2 emissions among new cars sold in Germany in years 1998 and 2008, for different vehicle segments and fuels (gasoline and diesel). Although several analysts have observed the distribution of attributes and CO_2 emissions of newly sold cars in European countries (e.g. Cuenot, 2009, Gallachóir et al., 2009, Zervas, 2009), this is probably the first paper looking into distributions within individual car segments.

The second question that this paper is trying to address has been posed by Schipper (2011). He believes that, although diesel powered cars have improved a lot recently in terms of performance and comfort and are therefore a reliable lower-CO_2 alternative to gasoline vehicles of similar size and performance, policy makers should not overestimate the CO_2 benefit of this increasing popularity of diesel cars: consumers do not always purchase the diesel alternative of a gasoline car but may choose among larger and more powerful diesel cars, thus largely eliminating the emissions benefit. We analyse automobile sales data to examine this topic in Section 3.

To address both questions, we use data from the German new car market in years 1998 and 2008. These data are a subset of a larger dataset that was obtained from JATO Dynamics, a company that specialises in the collection of automotive data worldwide, for the entire period 1998–2008 and for nine European countries. The whole dataset, not presented here, contains 17 distinct vehicle attributes such as vehicle weight, engine size, horsepower, safety features etc., sales volume and sales price, for each one of a few hundred models or model versions per country every year.

2. Descriptive analysis of new car sales in Germany

2.1. Aggregate data by segment and fuel type

This section describes the evolution of main characteristics of the German new car market between the first and the last year of the database mentioned above, i.e. for years 1998 and 2008. These years correspond roughly to the period between the adoption of the voluntary agreement on reducing CO_2 emissions from new cars between the European Commission and automobile manufacturer associations (which was formally enacted in 1999–2000

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but had been under discussion for several years before), and the implementation of mandatory EU-wide CO_2 emission standards in early 2009. Some data of year 2009, although available, have not been used here because incentive schemes for accelerated car scrappage were implemented during that year as part of fiscal stimulus measures, which may have temporarily changed the overall market situation.

In the case of the German car market, the dataset comprises about 20,000 observations for each year, containing data about sales, prices and vehicle attributes. The database records two car models with the same engine size, fuel and transmission type but a difference in a minor characteristic (e.g. the availability or not of climate control) as different observations. Such models were merged in one, by summing up their sales and calculating a sales-weighted average price. This process of model aggregation led to a dataset of 1659 models for year 1998 and 3418 models for year 2008.

Table 1 shows some basic descriptive statistics of the German new car market in year 1998 by segment type (segments as defined by the automotive data provider), as well as separately for gasoline and diesel powered cars. Table 2 presents the same data for year 2008. Retail prices are presented for year 2008 only as the dataset has many gaps in price data for year 1998. Total number of sales and sales-weighted averages of car attributes are in very good agreement with the aggregate data published by the European Commission in the frame of the CO_2 Monitoring Mechanism established under the above-mentioned voluntary agreement (e.g. European Commission, 2010a).

With regard to the evolution of total car sales between 1998 and 2008 irrespective of differences in cars of various fuel types, the following can be observed:

- There has been a shift from 'regular' medium and large cars to multi-purpose vehicles and sports utility vehicles, both in terms of number of models available in the market and in terms of sales numbers. The sales shares of MPVs and SUVs have almost tripled during this decade.
- Sales-weighted average engine size has risen by less than 5%, but there are differences between segments: compact and small cars as well as MPVs had an almost 10% smaller engine on average in 2008 compared to 1998, whereas lower and upper medium size cars as well as large MPVs and SUVs had 6–12% larger engines.
- Changes in engine power have been rather uniform for almost all segments: maximum power has increased by 17–37% depending on segment type, and by 28% on average.
- CO_2 emissions have also declined quite uniformly in all segments, by 10–23%, and by 12% on average – from 186 g/km in 1998 to 164 g/km in 2008.

Table 1
Descriptive statistics for the German new car market in year 1998.

Segment	Number of models	% of total models	Engine size (litres)		Maximum power (HP)		CO_2 emissions (g/km)		Sales in year 1998	
			Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	No. of cars	Share (%)
Germany – 1998 – All cars										
Utility (micro) cars	65	3.9	1.144	0.273	56	18	144	68	199,294	5.4
Small cars	138	8.3	1.231	0.256	63	20	155	26	580,452	15.8
Lower medium-sized cars	289	17.4	1.602	0.357	90	32	174	30	1,032,492	28.1
Upper medium-sized cars	296	17.8	1.866	0.436	118	39	191	34	961,909	26.2
Mini and medium Multi-purpose vehicles	115	6.9	1.724	0.455	98	33	188	82	228,079	6.2
Small and medium sports utility vehicles	135	8.1	2.379	0.825	127	50	253	117	69,450	1.9
Large multi-purpose vehicles, large and luxury Sports utility vehicles	114	6.9	2.576	0.968	135	54	250	138	87,938	2.4
Large, executive and luxury cars	273	16.5	2.550	1.096	168	69	236	107	355,527	9.7
Sports cars	234	14.1	2.212	1.391	164	109	217	112	154,079	4.2
Total	1659	100.0	1.751	0.502	104	39	186	51	3,669,220	100.0
Germany – 1998 – Gasoline cars										
Utility (micro) cars	57	3.4	1.136	0.321	56	18	145	38	196,200	5.3
Small cars	116	7.0	1.214	0.547	63	31	155	63	561,804	15.3
Lower medium-sized cars	242	14.6	1.552	0.870	90	57	179	91	877,357	23.9
Upper medium-sized cars	236	14.2	1.837	1.060	121	73	200	102	749,059	20.4
Mini and medium multi-purpose vehicles	78	4.7	1.670	0.685	99	41	193	72	173,773	4.7
Small and medium sports utility vehicles	86	5.2	2.246	1.008	133	57	249	94	44,971	1.2
Large multi-purpose vehicles, large and luxury sports utility vehicles	73	4.4	2.775	1.102	160	56	275	83	49,830	1.4
Large, executive and luxury cars	211	12.7	2.570	1.633	179	108	248	123	262,017	7.1
Sports cars	233	14.0	2.213	1.673	164	124	217	112	153,541	4.2
Total	1332	80.3	1.690	0.923	104	60	189	88	3,068,552	83.6
Germany – 1998 – Diesel cars										
Utility (micro) cars	7	0.4	1.703	0.141	60	6	116	9	3,093	0.1
Small cars	19	1.1	1.745	0.302	67	12	141	25	18,633	0.5
Lower medium-sized cars	41	2.5	1.887	0.477	87	23	149	36	155,123	4.2
Upper medium-sized cars	56	3.4	1.971	0.618	105	33	160	50	212,845	5.8
Mini and medium multi-purpose vehicles	35	2.1	1.897	0.467	94	21	173	41	54,295	1.5
Small and medium sports utility vehicles	49	3.0	2.623	0.734	117	32	261	66	24,479	0.7
Large multi-purpose vehicles, large and luxury sports utility vehicles	40	2.4	2.314	0.590	103	26	216	49	38,107	1.0
Large, executive and luxury cars	60	3.6	2.496	0.803	138	45	201	57	93,508	2.5
Sports cars	1	0.1	1.896	0.077	90	4	160	7	538	0.0
Total	308	18.6	2.064	0.587	103	30	172	46	600,621	16.4

Table 2
Descriptive statistics for the German new car market in year 2008.

Segment	Number of models	% of total models	Engine size (litres)		Maximum power (HP)		CO_2 emissions (g/km)		Retail price (Euros)		Sales in year 2008	
			Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	No. of cars	Share (%)
Germany – 2008 – All cars												
Utility (micro) cars	86	2.5	1.032	0.191	67	14	116	19	11,191	2,076	117,052	3.9
Small cars	392	11.5	1.311	0.190	83	24	140	20	14,424	2,605	592,143	19.8
Lower medium-sized cars	488	14.3	1.697	0.519	123	45	152	26	21,865	5,302	616,869	20.6
Upper medium-sized cars	550	16.1	2.035	0.610	153	56	167	35	32,026	7,824	535,367	17.9
Mini and medium multi-purpose vehicles	492	14.4	1.707	0.347	114	31	163	33	22,892	6,587	499,056	16.7
Small and medium sports utility vehicles	312	9.1	2.101	0.835	156	58	194	42	31,574	13,049	171,835	5.7
Large multi-purpose vehicles, large and luxury sports utility vehicles	320	9.4	2.880	1.278	223	92	233	61	49,137	20,411	113,614	3.8
Large, executive and luxury cars	315	9.2	2.788	1.278	220	113	200	62	51,842	66,176	172,977	5.8
Sports cars	463	13.5	2.364	1.420	206	138	192	72	42,734	56,911	178,262	5.9
Total	3418	100.0	1.828	0.573	133	51	164	34	26,526	12,907	2,997,175	100.0
Germany – 2008 – Gasoline cars												
Utility (micro) cars	46	1.3	1.041	0.300	68	19	118	31	10,962	2,650	105,466	3.5
Small cars	181	5.3	1.291	0.712	83	46	143	67	14,139	6,635	526,491	17.6
Lower medium-sized cars	238	7.0	1.591	0.941	122	75	162	83	20,507	10,322	360,082	12.0
Upper medium-sized cars	280	8.2	1.986	1.291	162	105	185	103	30,879	16,641	175,841	5.9
Mini and medium multi-purpose vehicles	184	5.4	1.582	0.847	112	61	171	87	20,874	10,812	275,960	9.2
Small and medium sports utility Vehicles	135	3.9	1.946	1.291	149	91	201	89	26,195	13,540	52,695	1.8
Large multi-purpose vehicles, large and luxury sports utility vehicles	152	4.4	3.680	1.893	302	133	269	109	54,036	20,763	15,567	0.5
Large, executive and luxury cars	190	5.6	3.186	1.927	269	157	234	116	60,120	50,200	41,167	1.4
Sports cars	355	10.4	2.379	1.966	213	178	201	130	43,990	51,690	140,204	4.7
Total	1761	51.5	1.637	0.979	122	75	164	83	26,070	15,847	1,693,473	56.5
Germany – 2008 – Diesel cars												
Utility (micro) cars	8	0.2	0.917	0.138	50	7	97	12	13,556	1,416	9,800	0.3
Small cars	58	1.7	1.483	0.438	87	27	121	33	17,221	4,611	63,190	2.1
Lower medium-sized cars	100	2.9	1.856	0.686	125	48	141	52	24,042	8,160	248,848	8.3
Upper medium-sized cars	150	4.4	2.059	0.953	149	70	159	68	32,679	12,991	358,394	12.0
Mini and medium multi-purpose vehicles	124	3.6	1.865	0.760	117	51	156	63	25,868	10,389	209,519	7.0
Small and medium sports utility vehicles	107	3.1	2.172	0.942	159	63	195	74	34,554	12,374	116,653	3.9
Large multi-purpose vehicles, large and luxury sports utility vehicles	101	3.0	2.745	1.109	210	83	229	71	48,443	15,391	96,209	3.2
Large, executive and luxury cars	86	2.5	2.660	0.966	204	73	190	61	49,227	15,970	130,581	4.4
Sports cars	69	2.0	2.308	0.718	181	57	162	50	38,191	11,637	37,972	1.3
Total	803	23.5	2.081	0.842	147	60	164	61	27,954	9,603	1,271,166	42.4

More remarkable differences can be observed within individual segments if one looks into gasoline and diesel car sales separately. More specifically:

- There has been a sharp increase in the number of diesel car sales. In 1998, 19% of available models were diesel powered and accounted for 16% of total sales; in 2008, 23% of available models were diesel powered and represented over 42% of new car sales.
- The share of diesel car sales has risen in all segments, but has been particularly strong in mini and medium MPVs and SUVs.
- Whereas gasoline cars have become 18% more powerful on average with a slightly decreasing engine size between 1998 and 2008, diesel cars have become considerably more powerful (by 42%) at roughly the same average engine size; this demonstrates the great improvements in the performance of diesel engines that have been introduced during this period.
- CO_2 emissions have improved clearly more for gasoline cars than for diesel ones (13% and 4% respectively). As a result, the difference in emissions between the two fuel types that existed in 1998 (189 g/km for gasoline cars, 172 g/km for diesel cars) disappeared in 2008, when cars of both fuel types exhibited a sales-weighted CO_2 emission of 164 g/km. This change should be attributed to two reasons. First, as mentioned above, diesel cars have become much more powerful during this period, at a cost to their fuel economy and CO_2 performance. Second, while gasoline car sales have shifted mainly towards lower-emitting models (from 'upper medium sized' towards 'small' and 'mini-medium MPVs'), the most popular diesel car segment remained the same – 'upper medium-sized cars' – and exhibited a negligible change in average CO_2 emissions – from 160 g/km in 1998 to 159 g/km in 2008.

One should keep in mind that the observations made above for Germany may not be representative of the EU-wide evolution of car attributes and emissions. For example, we examined the same data from Greece and found that – quite contrary to Germany – average engine size has increased in all segments, and engine power has increased even more strongly than in Germany. This has to be attributed probably to a combination of three factors: the availability of more powerful cars in the European car market (as evident in Germany too), the steep increase in real income in Greece during this decade, which enabled consumers to purchase larger cars, and changes in car taxation which effectively lowered the prices of bigger cars. Changes in income and taxation may be responsible for similar changes in other EU countries as well.

2.2. Distribution of CO_2 emissions in selected car segments by fuel type

Changes in sales-weighted vehicle characteristics and emission levels as reported in the previous section have also been observed to some extent by other analysts mentioned in the introduction. To gain insight into the evolution of the car market at a disaggregated level, we now turn to the more detailed data concerning CO_2 emissions and sales volumes of individual car models. The histograms in the following pages illustrate the distribution of two basic attributes – CO_2 emissions and engine size – of models in the German car market at the start and the end of the 1998–2008 period. The focus is on the three car segments with the highest sales shares, i.e. segments 'small cars', 'lower medium-sized cars' and 'upper medium-sized cars'; as shown on Tables 1 and 2, these three segments accounted for 70% and 58% of the market in 1998 and 2008 respectively.

More specifically, for segment 'small cars', the left column of each one of Figs. 1 and 2 shows the fraction of models that were available in the German market in years 1998 and 2008, by CO_2 emissions and engine size class respectively. The fact that these models were available does not mean that they were actually sold in proportional numbers; therefore, the right column of Figs. 1 and 2 demonstrates the corresponding shares of actual sales by CO_2 emissions and engine size. Furthermore, Fig. 3 focuses on the distribution of CO_2 emissions in the same segment in years 1998 and 2008, observing gasoline and diesel powered cars separately. Figs. 3 through 6 illustrate the same distributions as above, but for models belonging to segment 'lower medium-sized cars', and Figs. 7–9 show the same information for models in the 'upper medium-sized cars' segment.

Following are some general findings:

1. Although there are many models available over a wide range of engine size and emissions classes, in all segments and in both years 1998 and 2008, the models actually sold are more narrowly concentrated in some classes. Particularly large models with high emission levels exhibit a disproportionately small percentage of total sales. In other words, very powerful and high-emitting cars are not popular among consumers – or they are anyhow produced to appeal to a very small fraction of all consumers.
2. Compared to year 1998, models sold in year 2008 in all segments exhibit considerably lower CO_2 emission levels; the distribution of sales across emissions classes has clearly shifted to the left, i.e. towards lower emissions classes, within this decade. On the other hand, there has been no similar shift in the distribution among engine size classes, which is also reflected in the negligible change in average engine size between 1998 and 2008 as shown in Tables 1 and 2. This reinforces the finding mentioned above: cars have become more powerful and less CO_2 emitting at roughly the same engine size, and this is observed quite uniformly in all car segments.
3. The above observation seems to be valid even when examining gasoline and diesel cars separately (Figs. 3, 6 and 9): there is a general shift towards lower emission classes between 1998 and 2008 in all three segments observed here.

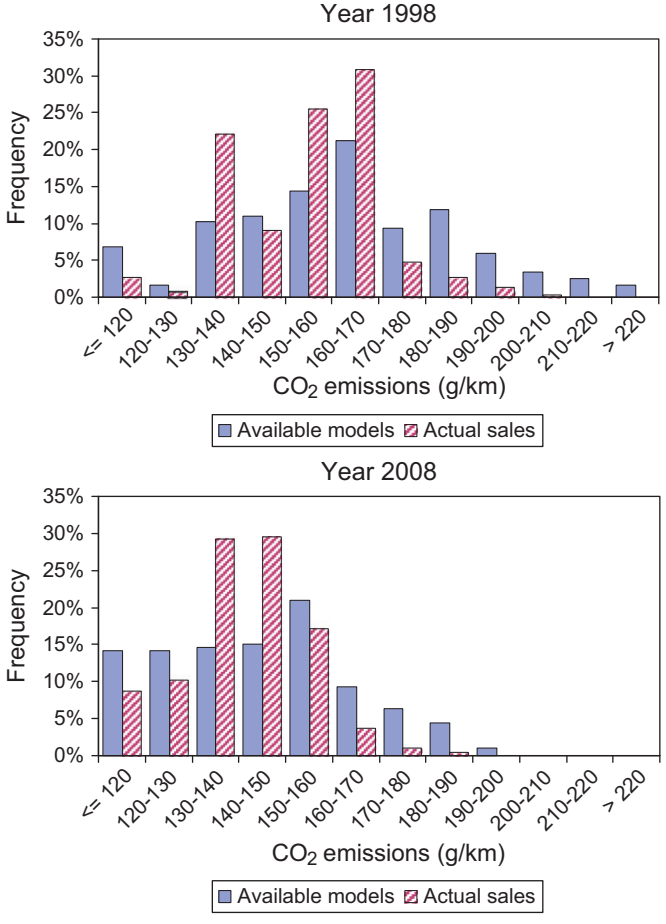

Fig. 1. Vehicle segment 'small cars': distribution of available car models (left column) and actual car sales (right column) by CO_2 emissions in years 1998 and 2008.

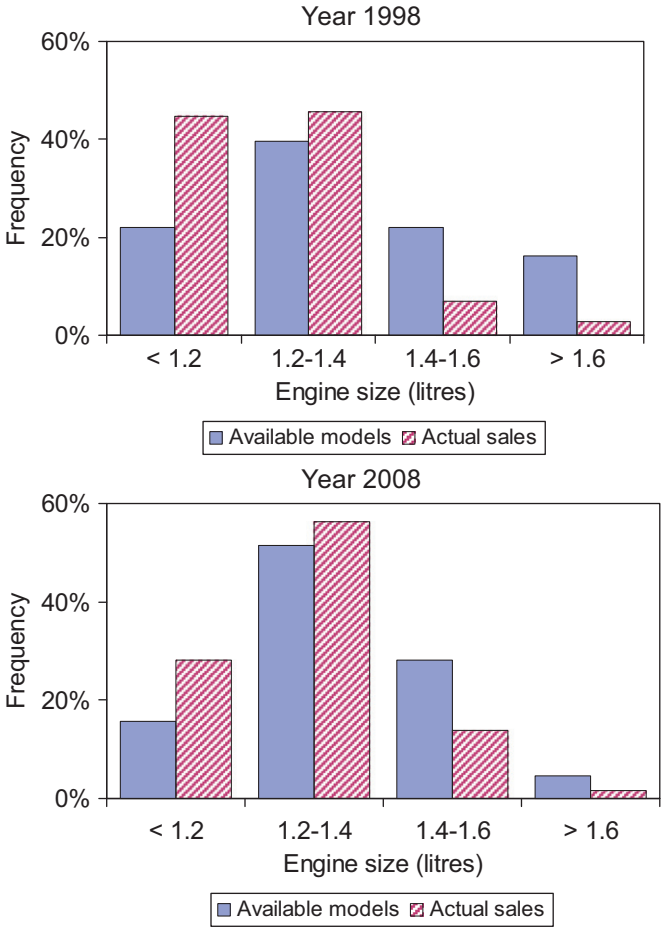

Fig. 2. Vehicle segment 'small cars': distribution of available car models (left column) and actual car sales (right column) by engine size in years 1998 and 2008.

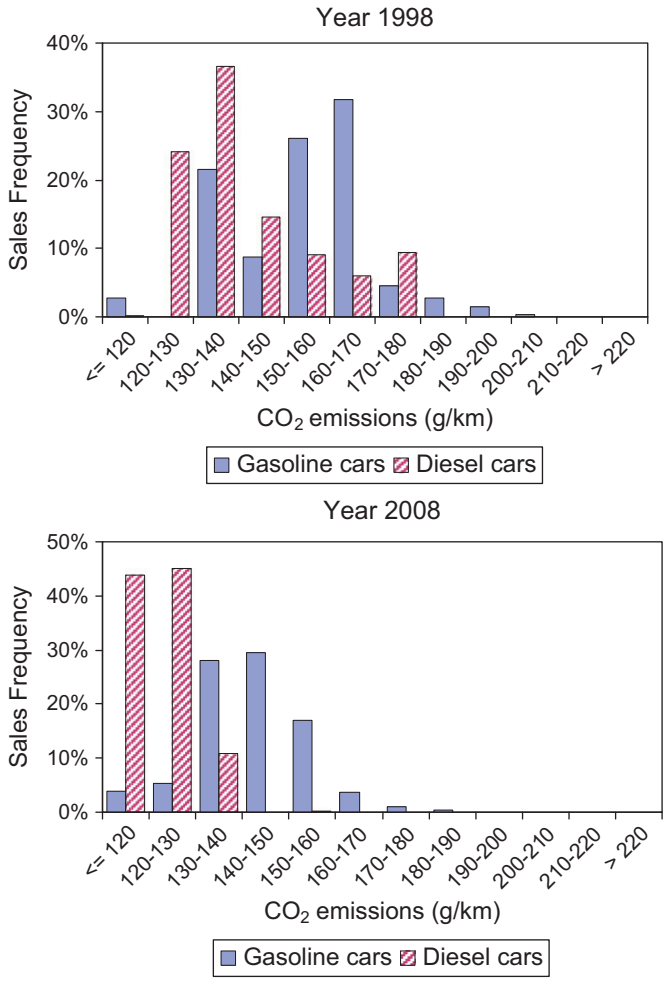

Fig. 3. Vehicle segment 'small cars': distribution of actual car sales by CO_2 emissions class and fuel type in years 1998 and 2008.

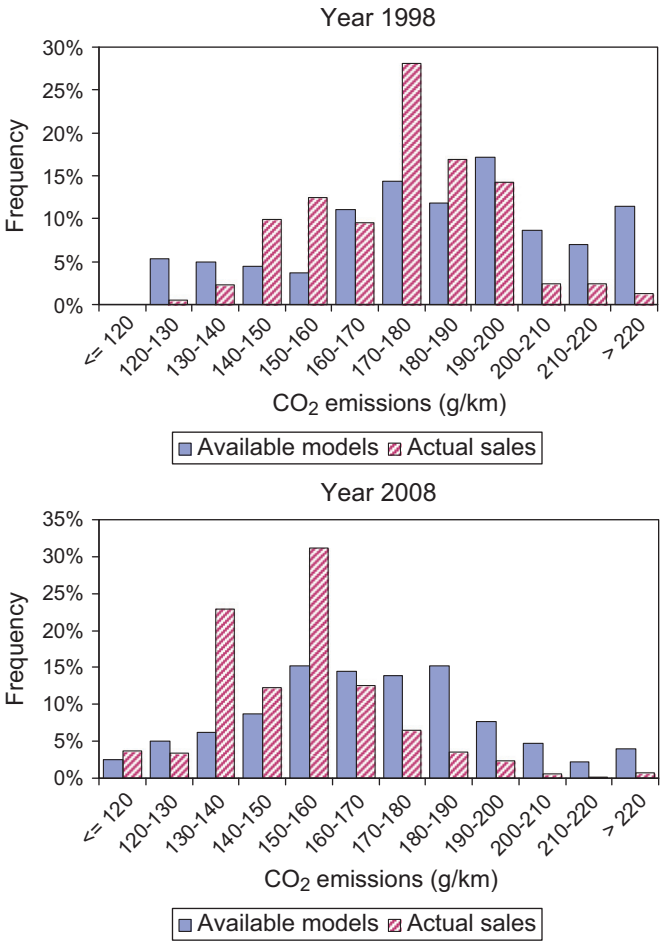

Fig. 4. Vehicle segment 'lower medium-sized cars': distribution of available car models (left column) and actual car sales (right column) by CO_2 emissions in years 1998 and 2008.

4. If one calculates the skewness of the emission distributions of models by segment and fuel type (results not shown here), one realises that the distributions of year 2008 models are more skewed to the right than those of their year 1998 counterparts. This finding holds for all three major segments 'small cars', 'lower medium-sized cars' and 'upper medium-sized cars', for all models together as well as for gasoline and diesel models separately. This may indicate that, along with considerable emissions improvements between 1998 and 2008, today there are relatively more models available with higher-than-average emission levels than in the late 1990 s. Be it due to the delay of some auto manufacturers to improve the CO_2 performance of some of their models, or because manufacturers believe that CO_2 emissions do not matter to consumers – and hence to producers – very much unless emission reductions are mandatory, this finding indicates that car buyers may have more high-carbon models to choose from (compared to the average emissions of models in each segment) than they used to have a decade ago.

3. Analysis of matched pairs

We now use the same dataset to explore the hypothesis mentioned in the introduction: As the comfort and performance of diesel cars has greatly improved in recent years, many new car buyers have switched their preferences towards diesel vehicles. The European market contains numerous automobile models that could be regarded as 'matched pairs', i.e. two model versions with similar attributes such as mass, engine size, power, torque etc., one having a gasoline powered engine and one running on a diesel engine. Fuel consumption and CO_2 emission levels of a diesel car are usually lower than those of its gasoline pair. If a consumer chooses to purchase a diesel car rather than its gasoline pair, this will result in lower CO_2 emissions per kilometre driven with this car,[1] leading to a considerable benefit in CO_2 emissions. There is a possibility, however, that most of the increase in diesel car sales that has been observed recently has not been directed to purchases of the diesel powered version of a matched pair but to larger and more powerful diesel cars; if this is the case then the CO_2 benefit may be lower than anticipated – or may even not exist.

To examine this hypothesis the following steps are necessary:

– Observe individual vehicle models in the German car sales dataset, for each one of the years 1998 and 2008, identify potential matched pairs and construct a list of these models;

[1] Depending on differences in fuel economy and fuel prices, the choice between a gasoline and a diesel matched pair may also result in different distance driven with each model; the (usually cheaper to run) diesel car may be used more intensively and therefore the emissions benefit due to lower CO_2 emissions per kilometre may be largely diminished. We do not examine this aspect here, implicitly assuming that a new car buyer has a pre-determined preference for the distance he will drive annually with this car; in other words we assume that the elasticity of car use with respect to fuel price is negligible.

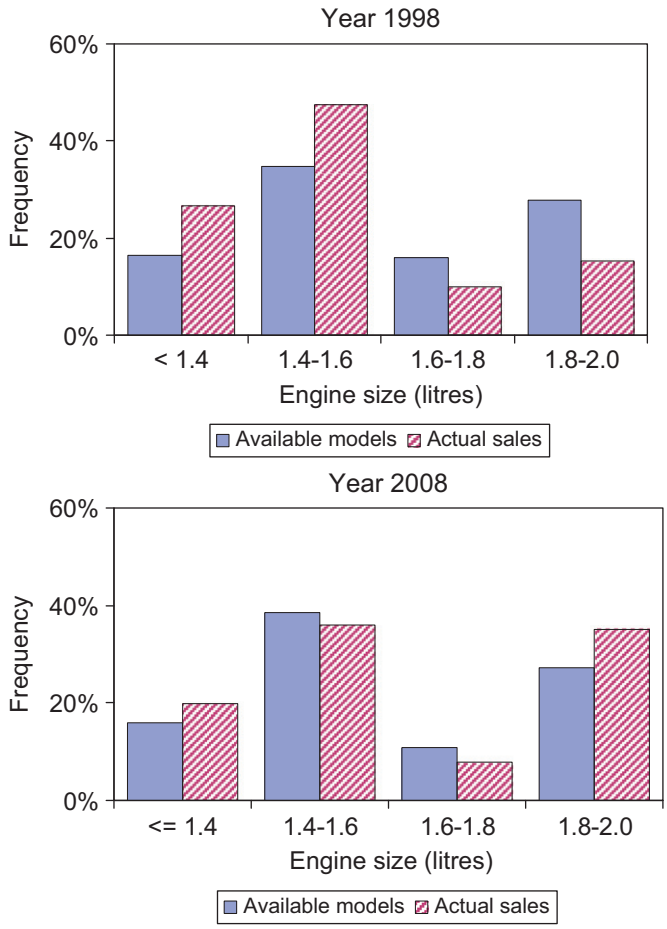

Fig. 5. Vehicle segment 'lower medium-sized cars': distribution of available car models (left column) and actual car sales (right column) by engine size in years 1998 and 2008.

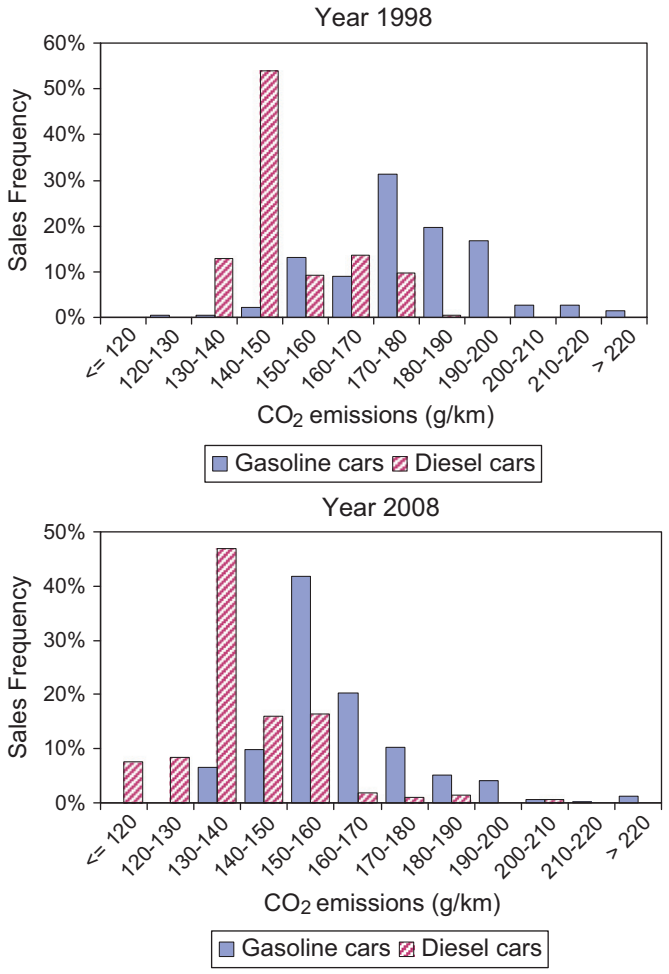

Fig. 6. Vehicle segment 'lower medium-sized cars': distribution of actual car sales by CO_2 emissions class and fuel type in years 1998 and 2008.

- Compute the ratio of attributes of the diesel model of a matched pair divided by the corresponding value of its gasoline counterpart – e.g. the ratio of engine power of the diesel model over the engine power of its gasoline pair;
- Calculate the sales-weighted average ratio of these attributes for all matched pairs identified in the dataset;
- Compute the aggregate sales-weighted ratio of the same attributes for the entire set of car models sold during that year, e.g. sales-weighted average engine power of gasoline cars over the sales-weighted average engine power of diesel cars;
- It is then possible to compare the two average ratios. If the aggregate ratio is close to the matched pair ratio then attributes and emissions of matched pairs are similar to those of total car sales; otherwise matched pairs may be a special case with different characteristics than the average sales in the market;
- Carry out these calculations and comparisons for both years of this period, and thus compare the evolution of total sales-weighted averages and matched pair sales-weighted averages over the years.

To perform this task, we examined all individual models in the German dataset. The main criteria for identifying a matched pair of gasoline and diesel cars were that the two models should (a) belong to the same model family, (b) have similar horsepower and (c) have the same transmission type (either both models with an automatic gearbox or both with a manual gearbox). We ignored models with a very small sales volume (less than 5) as these are outliers in a market as large as the German one. As the number of available diesel models has increased in 2008 compared to 1998, many more matched pairs were identified for year 2008 – there was simply a larger number of gasoline-diesel model combinations that could be regarded as a matched pair. Table 3 displays the fraction of sales of models treated as matched pairs over the total sales in Germany in years 1998 and 2008. Interestingly, the sales share of diesel cars that belonged to matched pairs has dropped in this decade: 92% of all diesel car sales were matched pair models in 1998, to fall to 86% in 2008, although the number of matched pair models in our dataset has increased. The increasing sales share of non-matched-pair models, along with the overall increase in the share of diesel cars in total sales shown in the last row of Table 3, indicate that the sales volume of non-matched-pair diesel cars has risen strongly during this decade.

Table 4 presents the results of this analysis. For years 1998 and 2008, it shows sales-weighted average engine horsepower, engine size, fuel consumption and CO_2 emissions of gasoline cars that have been included in a matched pair, and the same sales-weighted average attributes for all gasoline cars sold during the same year. Then it displays the same attributes for diesel cars. The bottom part of the table shows the calculated attribute ratios, first for matched pairs only, and then for the total car sales in the same year.

In 1998 a typical matched pair consisted of (a) a gasoline car with a horsepower of 100 hp and a 1.7-litre engine, and a diesel car with similar horsepower (104 hp) and a 2-litre engine.

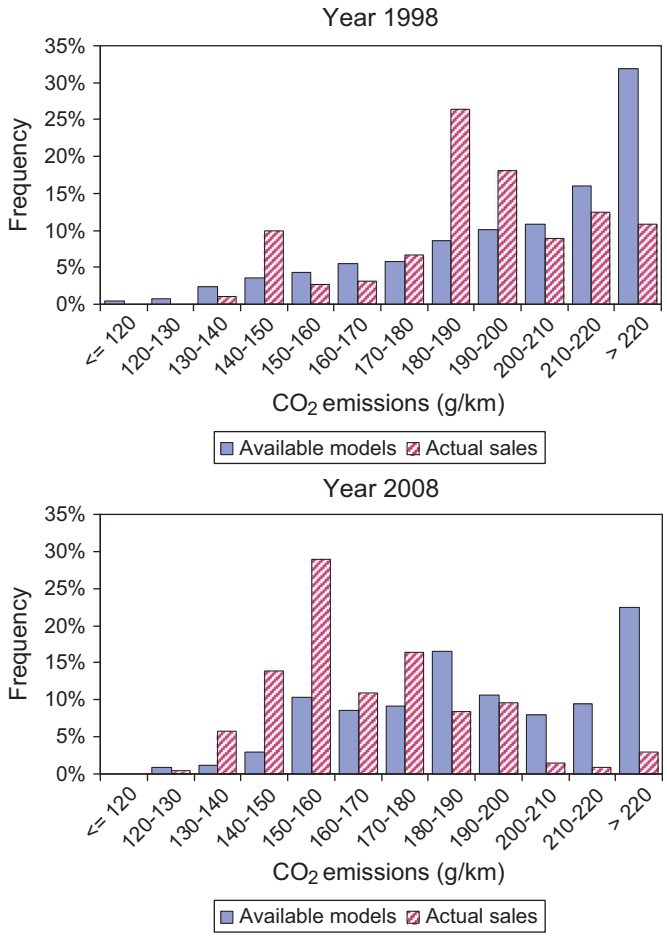

Fig. 7. Vehicle segment 'upper medium-sized cars': distribution of available car models (left column) and actual car sales (right column) by CO_2 emissions in years 1998 and 2008.

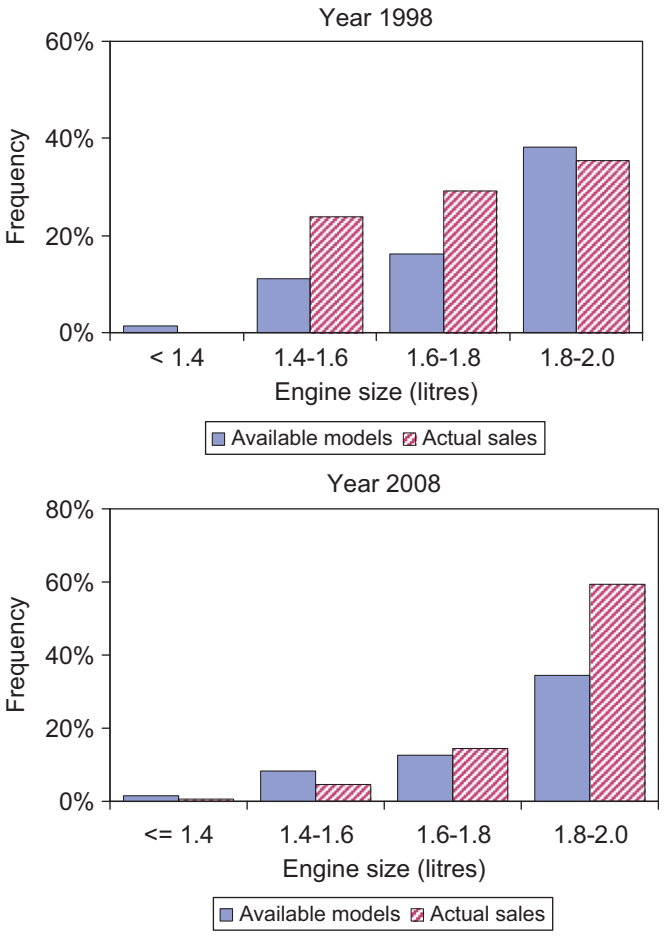

Fig. 8. Vehicle segment 'upper medium-sized cars': distribution of available car models (left column) and actual car sales (right column) by engine size in years 1998 and 2008.

The corresponding sales-weighted average attributes were very close to those of the matched pairs. In year 2008 horsepower rose significantly, particularly for diesel cars, as already shown in Section 2 of this paper, and especially for the average of the total fleet, whereas engine size dropped somewhat for gasoline cars and remained essentially constant for diesel cars. CO_2 emission levels decreased considerably for gasoline cars during this decade, whereas the fall in diesel emissions was less pronounced – as already shown in Tables 1 and 2.

The test of the hypothesis of Schipper (2011) is shown at the bottom part of Table 4. If we examine how much the attribute ratio has changed between 1998 and 2008 for (a) the matched pairs and (b) total car sales, we find the horsepower ratio to be close to unity for matched pairs, during both 1998 and 2008. Conversely, the same ratio rose by 22% when we examine all car sales. This means that if we focus on matched pairs only we find out that not much has changed during this period; when we observe total sales, however, the picture changes considerably, and diesel cars have become considerably more powerful than their gasoline counterparts within a decade. Coming to engine size, diesel cars have remained larger than gasoline ones, but their size difference seems to have decreased within matched pairs, whereas in total sales diesel cars have become even larger in 2008 than what they used to be in 2008 – they had 22% larger engine size in 1998 which became 28% in 2008. And most importantly, the CO_2 emissions ratio has not changed during this decade within matched pairs: diesel models emitted 85% of the CO_2 levels of their gasoline pairs in 1998, and the number remained at 85% in 2008. However, average numbers for total car sales tell a different story: the CO_2 advantage of diesel cars was smaller in 1998 (they emitted 92% of the levels of the sales-weighted average gasoline car) and disappeared in 2008: the emissions ratio has become equal to unity.

These results lend some support to Schipper's hypothesis. He conjectured that the sales-weighted power and weight of new diesel cars may far exceed the corresponding attributes of diesels that belong to matched pairs. As Table 4 shows, this is not the case in Germany: average power and engine size of diesel cars, both in 1998 and 2008, were not that much different from those of the diesel models belonging to a matched pair.[2] Where there is considerable difference, however, is in the power, engine size and CO_2 emissions ratio of the average diesel vs. gasoline car sold in the market compared to the corresponding ratios of cars that belong to matched pairs.

The average diesel car bought in Germany, which had 8% lower CO_2 emissions per kilometre than the average gasoline car in 1998 (176 g/km compared to 192 g/km), did not have any CO_2 advantage in 2008 (both gasoline and diesel cars had a sales-weighted average CO_2 emission of 165 g/km). On the other hand, if one were observing the emissions ratio within each matched

[2] We do not report vehicle weight here because weight data in our dataset are incomplete for year 1998 and would therefore be misleading.

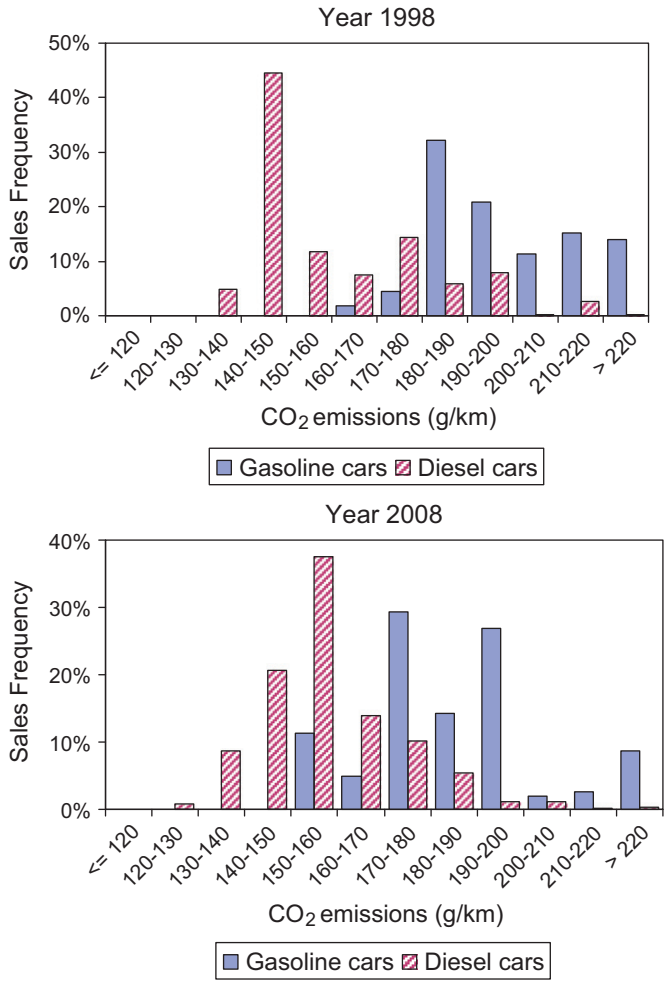

Fig. 9. Vehicle segment 'upper medium-sized cars': distribution of actual car sales by CO_2 emissions class and fuel type in years 1998 and 2008.

Table 3
Fraction of sales of car models classified as matched pairs over total new car sales in Germany.
Source: JATO Dynamics.

	1998	2008
% of matched pairs in total sales, all cars	48.9%	72.9%
% of matched pairs in total sales, diesel cars	92.2%	86.1%
% of matched pairs in total sales, gasoline cars	40.6%	62.5%
Ratio sales diesel/gasoline cars (matched pairs only)	0.44	1.09
Ratio sales diesel/gasoline cars (total sales)	0.19	0.79

pair and weighted all ratios according to the sales of each pair, one would come up with a ratio of 0.85, i.e. it would turn out that diesel cars offered 15% lower CO_2 emissions in 1998 compared to their gasoline pairs, and that this benefit remained unchanged in 2008.

This means that German consumers do not generally purchase a diesel car by choosing to buy the diesel powered matched pair of a gasoline car that they would have bought a few years earlier; instead they choose among the variety of diesel cars available in the market, and seem to prefer a more powerful diesel car than what they might have bought otherwise – the average power of all new diesel cars was equal to that of gasoline cars (104 hp) in 1998 but has become 21% higher in 2008 (147 vs. 121 hp). New diesel cars in 2008 are also considerably more expensive (by 44%) than the average gasoline car, and this price difference is obviously much more pronounced than the corresponding difference of matched pairs (11%). Although our dataset does not contain information on retail car prices in 1998 it is justified to assume that the price difference would be much lower than 44%. This may indicate a preference of high-income buyers towards powerful diesel cars that are more widely available than in the past: according to Tables 1 and 2 the number of diesel vehicle models has more than doubled during this decade – from 308 models in 1998 to 803 models in 2008, whereas the number of gasoline powered models has increased by a smaller amount. Moreover, as the same Tables show, the fraction of diesel powered large, luxury and sports cars has jumped from 3.5% of total sales in 1998 to 8.9% in 2008, while the corresponding fraction for gasoline powered cars of the same segments declined from 12.7% to 6.6% in the same period.[3] Perhaps it is not just high-income consumers but also

Table 4
Attributes of newly sold cars in Germany – sales-weighted averages for total new car sales, and corresponding averages for car models classified as matched pairs.
Source: JATO Dynamics.

	Year 1998	Year 2008	Change 1998–2008
Gasoline cars			
Matched pairs			
Engine horsepower (hp)	100	111	10.9%
Engine size (cc)	1,651	1,536	−7.0%
Retail price (Euros at 2005 prices)	n.a.	20,296	–
Fuel consumption (l/100 km)	8.2	6.8	−16.7%
CO_2 emissions (g/km)	194	162	−16.3%
Total car sales			
Engine horsepower (hp)	104	121	16.7%
Engine size (cc)	1,689	1,627	−3.7%
Retail price (Euros at 2005 prices)	n.a.	22,271	–
Fuel consumption (l/100 km)	8.1	6.9	−14.2%
CO_2 emissions (g/km)	192	165	−13.7%
Diesel cars			
Matched pairs			
Engine horsepower (hp)	104	144	38.7%
Engine size (cc)	2,038	2,051	0.7%
Retail price (Euros at 2005 prices)	n.a.	31,405	–
Fuel consumption (l/100 km)	6	6	−4.6%
CO_2 emissions (g/km)	172	163	−5.2%
Total car sales			
Engine horsepower (hp)	104	147	42.0%
Engine size (cc)	2,058	2,078	1.0%
Retail price (Euros at 2005 prices)	n.a.	32,109	–
Fuel consumption (l/100 km)	6.6	6.3	−5.3%
CO_2 emissions (g/km)	176	165	−6.1%
Ratio of diesel/gasoline cars			
Matched pairs			
Engine horsepower (hp)	0.97	1.00	3.1%
Engine size (cc)	1.20	1.12	−6.8%
Retail price (Euros at 2005 prices)	n.a.	1.11	–
Fuel consumption (l/100 km)	0.76	0.78	2.6%
CO_2 emissions (g/km)	0.85	0.85	0.0%
Total car sales			
Engine horsepower (hp)	1.00	1.21	21.7%
Engine size (cc)	1.22	1.28	4.8%
Retail price (Euros at 2005 prices)	n.a.	1.44	–
Fuel consumption (l/100 km)	0.82	0.90	10.4%
CO_2 emissions (g/km)	0.92	1.00	8.8%

Notes: (1) Fuel consumption has not been corrected for the different energy content of gasoline and diesel fuel. (2) Average values for total car sales may slightly differ from those of Tables 1 and 2 because models with a very small sales volume and some special-purpose vehicles in the dataset have been omitted here. (3) n.a.: Data not available in the dataset.

[3] Schipper (2011, p. 367) regards this as a potential 'rebound effect enabled by the technical advantages of diesel'.

companies that increasingly choose to purchase powerful diesel cars – our dataset does not distinguish between individual and company buyers. It is also possible that consumers driving longer distances increasingly prefer diesel cars whose fuel costs per kilometre are lower – although automotive diesel is not as cheap as it used to be in Germany: its retail price per litre was less than 80% of the price of gasoline in 2000 and has become 92% of the gasoline price in 2008 (European Commission, 2010b).

Whatever the reason is, it seems that the overall CO_2 emissions level of new cars in Germany is increasingly independent of the relationship between the CO_2 performance of two similar cars running on different fuel. It would be necessary to extend the matched pair analysis to other EU countries in order to check whether this finding is valid at EU level too. A decomposition analysis conducted by Schipper et al. (2011) indicates that most of the improvement in CO_2 emissions per kilometre achieved across the EU since 1995 was due to technological improvements of both gasoline and diesel powered vehicles, and that shifts from gasoline to diesel car sales have only played a minor role to CO_2 reductions. This is generally in line with our findings for Germany – we should not expect too much improvement in automobile CO_2 emissions by relying on shifts from gasoline cars to similarly sized diesel vehicles because a large part of the shift to diesels is made towards larger cars; technological improvements are key for both engine types but should also be complemented with measures that discourage the continuous increase in engine power if stated carbon reduction targets are to be achieved.

4. Conclusions

With the aid of detailed automobile sales data we have looked into changes in new car attributes and CO_2 emission levels in Germany in the years 1998–2008, a period characterised by: the voluntary commitment between the European Commission and the automobile industry for reduced CO_2 emissions of new cars; the great technological improvements in vehicle fuel economy; and the eventual adoption at EU level of a regulation for mandatory new car CO_2 cuts until 2020. We have observed changes in the distribution of CO_2 emission levels both at aggregate level and within individual segments. It has turned out that the CO_2 emissions decrease may not have reached the expected levels because diesel cars have become much more powerful during this period, at a cost to their fuel economy and CO_2 performance, and also because, whereas gasoline car sales have shifted mainly towards lower-emitting models (from 'upper medium sized' towards 'small' and 'mini–medium MPVs'), the most popular diesel car segment remained the same – 'upper medium-sized cars' – and exhibited a negligible change in its average CO_2 emissions.

Looking into the distribution of car models across different engine size and CO_2 emissions classes, and the evolution of this distribution from year 1998 to year 2008, we have found that the distribution of sales across emissions classes has clearly shifted to the left, i.e. towards lower emissions classes, for all car segments within this decade, as a result of fuel economy improvements induced by the voluntary commitment. On the other hand, there has been no similar shift in the distribution among engine size classes, which reinforces the finding that cars have become more powerful and less CO_2 emitting at roughly the same engine size, which is observed quite uniformly in all car segments. Interestingly, the distributions of year 2008 vehicle models are more skewed to the right than those of their year 1998 counterparts; this shows that, along with considerable emissions improvements between 1998 and 2008, today there are relatively more models available with higher-than-average emission levels than in the late 1990s.

We further constructed matched pairs of gasoline and diesel models with similar characteristics in order to explore how their power and emissions ratio has evolved during the same decade. It turned out that the power, engine size and CO_2 emissions ratio of the average diesel vs. average gasoline car sold in the market has changed differently from the corresponding ratios of cars that belong to matched pairs. This implies that German consumers did not generally purchase a diesel car by choosing to buy the diesel powered matched pair of a gasoline car that they would have bought a few years earlier; instead they selected among the variety of diesel cars available in the market, and they preferred a more powerful diesel car than what they might have bought otherwise. Irrespective of the reasons for such a shift in sales, it has led to a less steep decrease in diesel car CO_2 emissions, which largely explains the relatively slower CO_2 improvement of new cars observed in Germany in recent years.

Evidently the above findings are relevant for Germany only, and are not necessarily representative of the evolution in the whole European Union – although Germany is the largest automobile market in the EU and accounted for more than 20% of EU new car sales in 2008 (European Commission, 2010b). A similar analysis with equally detailed data has to be carried out for multiple countries in order to derive EU-wide conclusions. Still, the description of German automobile sales data in this paper makes it clear that low-carbon transport policies must address the issue of changes in vehicle size and performance induced by technological progress; such changes most often compromise the environmental effectiveness of energy efficiency technologies applied to modern automobiles. Policy makers cannot rely on technological advances alone for achieving a socially optimal environmental target; if consumers are not faced with the real-world social costs of their choices they will tend to prefer larger and more powerful cars that do not help attain environmental objectives; and car manufacturers in turn will attempt to satisfy demand overlooking environmental targets unless regulatory and/or economic constraints induce the market to adjust accordingly. Therefore, in contrast to current EU regulations, CO_2-related standards should not offer incentives for keeping or increasing a vehicle's attributes such as weight and power as this reduces regulatory effectiveness (Dings, 2012); consumer preferences for vehicle size and comfort may be maintained by differentiating a standard according to another measure such as the vehicle's footprint, as is currently the case with fuel economy standards for light trucks in the USA (Walsh, 2012). Finally, it is important to keep in mind that, as carbon-related damage costs are caused by the total amount of CO_2 emitted in the atmosphere, effective policies will have to tackle both the amount of CO_2 per kilometre and the total kilometres driven – a topic that has not been addressed in this paper.

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