**Supplementary Material**

**Box 1 - Background on passenger car registrations in Germany**

Together, some 350,000 Volkswagen Golf, Opel Astra, and Ford Focus were registered in Germany in 2016 (Table S1). The three compact cars account for 10% of the German passenger car market (AMS, 1981-2004; KBA, 2017; VDA, 2017). The VW Golf outsells both the Opel Astra and the Ford Focus by more than a factor of two (Figure S1). Against a relatively stable German car market, the registrations of the Opel Kadett/Astra and Ford Escort/Focus have been declining since 2000. This observation suggests a shift in consumer preferences towards other compact car models or other types of passenger cars such as sport-utility vehicles (SUVs).



Figure S1: Yearly registrations of the three compact car models and all passenger cars in Germany between 1980 and 2016; Principal data source: AMS (1981-2004), KBA (2017), VDA (2017)

Table S1: Passenger car registrations in Germany between 1980 and 2016; Source: AMS (1981-2004), KBA (2017), VDA (2017)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | Volkswagen Golf [1000 cars] | Opel Kadett/Astra [1000 cars] | Ford Escort/Focus [1000 cars] | Sum [1000 cars] | Total passenger car registrations [1000 cars] |
| 1980 | 200.892 | 190.504 | 36.159 | 427.555 | 2426 |
| 1981 | 219.382 | 188.488 | 99.192 | 507.062 | 2330 |
| 1982 | 198.401 | 188.112 | 84.871 | 471.384 | 2156 |
| 1983 | 224.887 | 189.993 | 77.880 | 492.760 | 2427 |
| 1984 | 260.229 | 171.718 | 84.164 | 516.111 | 2394 |
| 1985 | 298.175 | 190.124 | 67.891 | 556.190 | 2379 |
| 1986 | 371.382 | 236.120 | 89.245 | 696.747 | 2829 |
| 1987 | 378.856 | 239.929 | 90.976 | 709.761 | 2916 |
| 1988 | 346.599 | 226.487 | 84.862 | 657.948 | 2808 |
| 1989 | 349.777 | 214.528 | 82.686 | 646.991 | 2832 |
| 1990 | 358.364 | 227.002 | 76.433 | 661.799 | 3041 |
| 1991 | 395.093 | 302.095 | 131.707 | 828.895 | 4159 |
| 1992 | 455.613 | 310.388 | 129.235 | 895.236 | 3930 |
| 1993 | 423.199 | 251.050 | 103.759 | 778.008 | 3194 |
| 1994 | 387.814 | 228.186 | 93.683 | 709.683 | 3209 |
| 1995 | 342.135 | 220.104 | 123.979 | 686.218 | 3314 |
| 1996 | 337.550 | 198.384 | 114.746 | 650.680 | 3496 |
| 1997 | 289.182 | 191.254 | 102.531 | 582.967 | 3528 |
| 1998 | 347.149 | 220.095 | 77.338 | 644.582 | 3736 |
| 1999 | 355.646 | 229.756 | 127.316 | 712.718 | 3802 |
| 2000 | 327.341 | 157.936 | 99.400 | 584.677 | 3378 |
| 2001 | 293.219 | 144.183 | 102.106 | 539.508 | 3342 |
| 2002 | 274.162 | 112.494 | 92.255 | 478.911 | 3253 |
| 2003 | 218.227 | 89.5670 | 77.468 | 385.262 | 3237 |
| 2004 | 226.515 | 110.218 | 78.306 | 415.039 | 3267 |
| 2005 | 237.990 | 122.841 | 78.899 | 439.730 | 3342 |
| 2006 | 236.980 | 108.313 | 72.128 | 417.421 | 3468 |
| 2007 | 214.368 | 83.0480 | 57.546 | 354.962 | 3148 |
| 2008 | 231.293 | 76.0690 | 66.244 | 373.606 | 3090 |
| 2009 | 366.231 | 104.750 | 64.225 | 535.206 | 3807 |
| 2010 | 251.078 | 72.685 | 53.72 | 377.483 | 2916 |
| 2011 | 258.059 | 86.579 | 61.157 | 405.795 | 3174 |
| 2012 | 240.702 | 66.981 | 47.936 | 355.619 | 3083 |
| 2013 | 244.249 | 50.322 | 45.485 | 340.056 | 2952 |
| 2014 | 255.984 | 46.193 | 49.494 | 351.671 | 3037 |
| 2015 | 272.094 | 56.079 | 51.677 | 379.85 | 3206 |
| 2016 | 236.581 | 65.173 | 47.99 | 349.744 | 3339 |

**Box 2 - Collection of data on the actual on-road fuel consumption of vehicles**

In several cases the sample size of fuel consumption data for individual model variants obtained from Spritmonitor (2018a) is small (Figure S2). Whenever less than ten vehicle owners report their fuel consumption, averages for individual model variants may be biased. Moreover, vehicle data are often not specified at the level of detail that is sufficient to allocate fuel consumption data to a specific model variant. The collection of fuel consumption data and the matching of these data with individual car models and model groups therefore required expert judgment and introduces a random error into our analysis which we discuss in Section 4.1 of the article.



Figure S2: Frequency distribution of fuel consumption data as obtained from Spritmonitor (2018a) for model variants running on gasoline and diesel; fuel consumption data are available for 1,289 out of the 2,218 model variants initially identified

**Box 3: Overview – Car models covered in the sensitivity analysis**

 - Audi A3

 - BMW 3-series

 - Ford Fiesta

 - Ford Focus

 - Mercedes C-class

 - Opel Corsa

 - Opel Astra

 - Seat Cordoba

 - Seat Leon

 - Skoda Fabia

 - Skoda Octavia

 - Volkswagen Golf

 - Volkswagen Passat

 - Volkswagen Polo



Figure S3: Sensitivity analysis - Time series of mass (a), power (b), on-road fuel consumption (c), and on-road CO2 emissions and of selected car models sold in Germany; shaded areas represent the 95%-confidence intervals of the fitted regression line; data on front area were not collected; Data source: Irrgang (2018) based on Spritmonitor (2018a)



Figure S4: Sensitivity analysis - Time series of on-road CO2 emissions of selected gasoline (a) and diesel (b) car models sold in Germany; shaded areas represent the 95%-confidence intervals of the fitted regression line; Data source: Irrgang, 2018 based on Spritmonitor (2018a)

Table S2: Sensitivity analysis - Coefficients and summary statistics of the regression models applied to the data sample of 700 variants of 14 models (4 small cars, 6 compact cars, and 4 midsize sedans) from 8 individual manufacturers; data about the front area of vehicles were not collected

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Vehicle | Coefficients | Estimate | Standard error | *t* value | Pr (>abs *t*) | *p* value | Adjusted *R*-squared |
|  | *Equation 1: On-road fuel consumption = α1+β1mass* |
| Gasoline | Intercept | 4.37 | 0.51 | 8.64 | <0.001 | <0.001 | 0.13 |
| Mass | 2.70e-3 | 4.40e-4 | 6.14 | <0.001 |
| Diesel | Intercept | -2.78 | 0.78 | -3.57 | <0.001 | <0.001 | 0.31 |
| Mass | 7.34e-3 | 6.16e-4 | 11.92 | <0.001 |
|  | *Equation 1: On-road CO2 emissions = α1+β1mass* |
| Gasoline | Intercept | 101.9 | 11.8 | 8.64 | <0.001 | <0.001 | 0.13 |
| Mass | 0.06 | 0.01 | 6.14 | <0.001 |
| Diesel | Intercept | -73.4 | 20.6 | -3.57 | <0.001 | <0.001 | 0.31 |
| Mass | 0.19 | 0.02 | 11.92 | <0.001 |
|  | *Equation 2: On-road fuel consumption = α2+β2power* |
| Gasoline | Intercept | 5.64 | 0.12 | 45.61 | <0.001 | <0.001 | 0.45 |
| Power | 0.021 | 0.001 | 15.19 | <0.001 |
| Diesel | Intercept | 3.52 | 0.16 | 22.23 | <0.001 | <0.001 | 0.55 |
| Power | 0.034 | 0.002 | 21.02 | <0.001 |
|  | *Equation 2: On-road CO2 emissions = α2+β2power* |
| Gasoline | Intercept | 131.4 | 2.88 | 45.61 | <0.001 | <0.001 | 0.45 |
| Power | 0.48 | 0.03 | 15.19 | <0.001 |
| Diesel | Intercept | 92.85 | 4.18 | 22.23 | <0.001 | <0.001 | 0.55 |
| Power | 0.90 | 0.04 | 21.02 | <0.001 |
|  | *Equation 4: On-road fuel consumption = α4+β4mass+ β5power+ β7year* |
| Gasoline | Intercept | 206.9 | 11.16 | 18.54 | <0.001 | <0.001 | 0.64 |
| Mass | -1.25e-3 | 2.70e-4 | -4.63 | <0.001 |
| Power | 0.033 | 1.13e-3 | 29.37 | <0.001 |
| Year | -0.100 | 5.64e-3 | -17.81 | <0.001 |
| Diesel | Intercept | 237.7 | 19.3 | 12.29 | <0.001 | <0.001 | 0.72 |
| Mass | 1.99e-3 | 5.34e-4 | 3.73 | <0.001 |
| Power | 0.034 | 1.73e-3 | 19.84 | <0.001 |
| Year | -0.118 | 9.71e-3 | -12.17 | <0.001 |
|  | *Equation 4: On-road CO2 emissions = α4+β4mass+ β5power+ β7year* |
| Gasoline | Intercept | 4590 | 275 | 16.69 | <0.001 | <0.001 | 0.68 |
| Mass | -0.020 | 8.64e-3 | -2.36 | 0.019 |
| Power | 0.653 | 0.034 | 18.92 | <0.001 |
| Year | -2.22 | 0.14 | -15.95 | <0.001 |
| Diesel | Intercept | 6276 | 511 | 12.29 | <0.001 | <0.001 | 0.72 |
| Mass | 0.053 | 0.014 | 3.73 | <0.001 |
| Power | 0.907 | 0.046 | 19.84 | <0.001 |
| Year | -3.119 | 0.256 | -12.17 | <0.001 |



Figure S5: Sensitivity analysis - On-road CO2 emissions as a function of vehicle mass (a) and power (b); shaded areas represent the 95%-confidence intervals of the fitted regression line



Figure S6: Sensitivity analysis - On-road fuel consumption as a function of vehicle mass (a) and power (b); shaded areas represent the 95%-confidence intervals of the fitted regression line



Figure S7: Sensitivity analysis - Fuel consumption (a) and CO2 emissions (b) as observed and projected for gasoline and diesel model variants of passenger cars, assuming current trends persist (red dots), mass and power was kept at 1980-levels (blue dots), and mass and power will be kept at 2018-levels (green dots)



Figure S8: Diagnostic residuals plots - multiple linear regression analysis to predict fuel consumption of gasoline cars as a function of vehicle mass, power, front area, and year of market introduction; residuals plots for CO2 emissions follow analogously and are not depicted here



Figure S9: Diagnostic residuals plots - multiple linear regression analysis to predict fuel consumption of diesel cars as a function of vehicle mass, power, front area, and year of market introduction; residuals plots for CO2 emissions follow analogously and are not depicted here



Figure S10: Diagnostic residuals plots – sensitivity analysis for predicting the fuel consumption of gasoline cars by vehicle mass, power, and year of market introduction; residuals plots for CO2 emissions follow analogously and are not depicted here



Figure S11: Diagnostic residuals plots - sensitivity analysis for predicting fuel consumption of diesel cars as sampled by vehicle mass, power, and year of market introduction; residuals plots for CO2 emissions follow analogously and are not depicted here



Figure S12: Diagnostic pair plot of attributes of the three compact cars - year of market introduction, mass [kg], power [kW], front area [m2], fuel [diesel, gasoline], and fuel consumption [l/100 km]; each panel represents a scatterplot between the two adjacent variables; the pair plot for CO2 emissions follows analogously and is not depicted here



Figure S13: Diagnostic pair plot of vehicle attributes as sampled for the sensitivity analysis - year of market introduction, mass [kg], power [kW], front area [m2], fuel [diesel, gasoline], and fuel consumption [l/100 km]; each panel represents a scatterplot between the two adjacent variables; the pair plot for CO2 emissions follows analogously and is not depicted here