

Consumers' preferences on the Swiss car market: A revealed preference approach[☆]

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ABSTRACT

This paper investigates demand responses to variations in the characteristics of the vehicles. Our investigation is based on number of sales for each model marketed over the period 2006–2015 in Switzerland, and puts particular emphasis on fuel efficiency, curb weight, horsepower, and the potential interactions between these attributes. We find that market shares are significantly higher for more efficient and powerful vehicles, while light cars are preferred to heavy ones. Our results also point to a gradual increase of sensitivity to fuel efficiency over the last decade. However, interaction effects between engine fuel efficiency and power indicate a lower marginal valuation of fuel efficiency in the market segments for relatively powerful cars, hence a lower sensitivity to fuel efficiency among the consumers with the highest potential for polluting emissions. Also, these findings point to potential rebound effects, where consumers give up part of the expected fuel savings by purchasing more powerful vehicles.

1. Introduction

Globally, transportation accounts for 14% of greenhouse gas (GHG) emissions (IPCC, 2014). In Switzerland, this share even exceeds 32%, of which two thirds are directly imputable to passenger cars (FOEN, 2017), making private transportation a target of choice for policies aimed at curbing GHG emissions. Identifying and shaping buyers' preferences in terms of car attributes is therefore a key element in the fight against pollution.

While improvements in fuel efficiency have been considerable during the last decades, trends in fuel consumption do not suggest an equally important reduction. GHG emissions from the transportation sector were in fact higher in 2015 than they were in 1990, even though they have slightly declined since 2010 (see FOEN, 2017). Opposing trends, most notably the number of cars on the roads and the vehicle-kilometer traveled, have more than offset the potential payoff of efficiency improvements. The stock of passenger cars indeed rose from less than 3 million to more than 4.5 million, increasing the car ownership

ratio from 45 to 54 per 100 people. Even though the yearly vehicle-km traveled by passenger car declined by around 10% (SFSO, 2012, 2017), the global outcome is a clear increase of the passenger car services' usage.

Moreover, the weight of cars has been increasing since 1990 (SFOE, 2018).¹ This evolution is mainly explained by the introduction of new equipment related to safety (e.g., ABS, airbags, electronic stability control, ...) and comfort (e.g., air conditioning, navigation systems, ...). Hence, it is apparent that part of the improvement in fuel efficiency was taken back under the form of heavier cars. This highlights the importance of a complete analysis of car buyers' behavior, not only in relation to car usage but also to various car attributes. Deepening the analysis by looking at the parallel evolution of consumers' attitude towards fuel efficiency and valuation of heavy and powerful cars might offer some insights into under-assessed components of the so-called rebound effect (Sorrell and Dimitropoulos, 2008), which is defined as an increased usage of energy services following an improvement in the technical efficiency of delivering those services, thereby eroding

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¹ A small decline, mainly cyclical in nature, was observed in 2009 and 2010. Also, we note that the weight increase has been much faster from 1990 to 2005, but quite moderate since 2006, which corresponds to the beginning of our observation period.

potential energy savings.

In this paper, we investigate buyers' preferences concerning major car attributes, namely list price,² fuel efficiency, curb weight, and horsepower. We analyze the evolution of the demand for new cars through market shares of each model marketed in Switzerland between 2006 and 2015. Our approach, based on new car sales, is in line with Alberini and Bareit (2016), Chandra et al. (2010), Klier and Linn (2010, 2012, 2013), Train and Winston (2007), and Vance and Mehlin (2009). In comparison to these previous studies, we put more emphasis on potential relationships between fuel efficiency and other car attributes that might play a role in substitution or in complement to it, such as weight and horsepower. While consumers do certainly not value weight per se, this variable may serve as a proxy for correlated valuable attributes such as car size, comfort, social signaling, and security feeling.³ However, weight is costly in terms of fuel consumption, so that a trade-off emerges. A similar reasoning applies with horsepower. On the one hand, power might be an attractive feature, for instance increasing the value of driving for those who like speed. On the other hand, more powerful cars are likely to yield higher fuel consumption costs, since vehicles with faster acceleration capabilities tend to consume more than those with slower acceleration capabilities (see for instance Akerlind et al., 2015, or Autosmart, 2014). Our empirical results eventually reveal that lighter vehicles are preferred over heavier ones, but power is positively valued.

This paper contributes to the debate in two respects. First, contrary to what is done in the widely used hedonic pricing and stated preference approaches, we devise a revealed preference approach in which car sales occupy a central position. We assess the consumers' valuation for fuel efficiency and other car attributes by identifying the impacts of these attributes on market shares. Second, while most of the literature focuses on the willingness-to-pay for fuel efficiency, we consider two additional closely linked car attributes: weight and horsepower. By lowering car weight or diminishing horsepower, fuel efficiency will indeed be improved. Our decomposition of fuel efficiency into engine's fuel efficiency and car weight also emphasizes these interrelationships. Integrating the various attributes in the analysis allows to investigate possible tradeoffs and substitutions patterns, which can be considered as a less-analyzed aspect of the rebound effect: A fuel efficiency improvement not only triggers a reaction in the distance traveled (the standard rebound effect), but may also influence the choice of a car and its attributes.

The remainder of the paper is organized as follows. Section 2 provides details about our econometric framework and Section 3 presents the data used. Results are presented in Section 4 and discussed in Section 5. Section 6 summarizes and concludes with policy-oriented recommendations.

2. Methodology

Consumers' valuation of fuel efficiency has been mainly studied using hedonic pricing approach (e.g., Alberini et al., 2014; Espey and Nair, 2005; Goodman, 1983) and stated preferences (e.g., Greene et al., 2013; Potoglou and Kanaroglou, 2007). So far, however, the literature has not reached a consensus: While some point to a significant under-valuation of fuel efficiency compared to expected savings, others indicate an over-valuation or approximately correct valuation. As

² The list price is the price at which the manufacturer recommends the retailer to sell the car. It is also known as the manufacturer's suggested retail prices (MSRP). For the sake of brevity, we thereafter use "price" as a synonym for list price.

³ A number of studies clearly establish the influence of vehicle's weight on the risk incurred by passengers: In two-vehicle collisions, a difference in masses decreases significantly the risk of major injury or death of the heavier vehicle's passengers (see e.g., Anderson and Auffhammer, 2014; Anderson and Ponte, 2012; Fredette et al., 2008, or Toy and Hammitt, 2003).

indicated by Helfand and Wolverton (2011) or Greene et al. (2013), the existing body of econometric studies is approximately evenly split between the two.

Market shares are an alternative measure of consumer preferences and have some advantages over prices. In particular, hedonic pricing methods might not be the most adequate approach to retrieve consumers' preferences when only list prices can be obtained. A variety of prices may in fact be observed due to price discrimination mechanisms in car markets.

Our empirical approach relies on the random utility theory (McFadden, 1986), in which a decision maker is assumed to select the alternative providing the greatest utility among the set of all products available. The researcher, however, does not observe utility but only some attributes of the alternatives faced by the decision maker. Assuming that consumers derive utility from the product attributes, the representative utility can be built as a function of these observables.

In the present paper, we consider the probability a consumer has selected car model i in year t among all models available on the Swiss market. In this setting, the market share s_{it} of model i in year t equates to the probability of this model being selected among all models available and can be written as follows (see Train, 2009):

$$s_{it} = P_{it} = \frac{e^{\beta'x_{it}}}{\sum_{j=1}^J e^{\beta'x_{jt}}} = \frac{e^{\beta'x_{it}}}{e^{\delta\tau_t}} \quad (1)$$

where $\beta'x_{it}$ is the so-called representative utility and is assumed to be linear in the parameters. The last term is obtained by recognizing that the denominator is a yearly constant value, which can thus be collapsed into a year fixed effect τ_t . Taking the logarithms, (1) can be rewritten as:

$$\ln(s_{it}) = \beta'x_{it} + \lambda\tau_t \quad (\text{with } \lambda = -\delta) \quad (2)$$

Therefore, it appears that the logarithm of market shares can be modeled by standard regression methods including year fixed effects. The latter equation is equivalent to (14) in Berry (1994), the "outside" good being absorbed by the year fixed effects.

In our analysis, price, engine's fuel intensity,⁴ curb weight, and horsepower are considered as the determinants of consumers' utility, and these are included in logarithms in vector x_{it} . Quadratic terms and an interaction between engine fuel intensity and horsepower are also included to account for potential non-linearities.⁵ Because these variables are in logarithms and are centered on their median weighted by sales, the coefficients of the linear terms can be directly interpreted as elasticities at the median because the quadratic terms drop out in the calculation at the median.⁶

Additionally, we account for the availability of various versions within each model: The baseline version is gasoline-powered with manual transmission, while further versions are diesel-powered and/or with automatic transmission. We moreover include a set of fixed effects related to years and models to comply with the theoretical model in (2) and control for unobserved changes in consumers' taste regarding particular models or manufacturers (e.g., following 2010's massive Toyota recall) or supply-side decisions (e.g., changes in the distribution

⁴ Fuel intensity is a ratio of units of fuel per given distance (usually $\frac{\text{L}}{100\text{km}}$ in European units) and corresponds to the inverse of fuel efficiency. In this analysis, we decompose this standard measure of fuel intensity (in $\frac{\text{L}}{100\text{km}}$) in two dimensions: (i) engine's fuel intensity (in $\frac{\text{L}}{100\text{km} \times 1,000\text{kg}}$), i.e., the amount of fuel needed to move a given mass over a given distance and (ii) car's weight (in 1000 kg). This decomposition highlights that an equivalent fuel consumption decrease could be achieved either through technical improvements related to a car's engine or by lowering the car's weight.

⁵ For instance, a 1% improvement in fuel efficiency at low levels of fuel efficiency is worth more in terms of fuel savings than a 1% improvement in fuel efficiency at high levels of fuel efficiency.

⁶ Centered variables take the value zero for the median car effectively bought in 2006–2015.

network). These fixed effects will also capture possible variations in the test cycles conducted to determine fuel consumption.⁷

The estimated equation hence can be written as:

$$\begin{aligned} \ln(s_{imt}) = & \alpha + \beta \ln(p_{it}) + \gamma_1 \ln(efi_{it}) + \gamma_2 \ln(efi_{it})^2 \\ & + \delta_1 \ln(w_{it}) + \delta_2 \ln(w_{it})^2 + \phi_1 \ln(hp_{it}) + \phi_2 \ln(hp_{it})^2 \\ & + \lambda \ln(efi_{it}) \times \ln(hp_{it}) \\ & + \theta_1 ga_{it} + \theta_2 dm_{it} + \theta_3 da_{it} \\ & + \tau_t + \mu_i + \varepsilon_{it} \end{aligned} \quad (3)$$

where s_{imt} is market share of model i produced by manufacturer m in year t , p_{it} is price, efi_{it} is engine fuel intensity, w_{it} is weight, hp_{it} is horsepower, $ga_{it}/dm_{it}/da_{it}$ are “technical diversity dummies”, i.e., binary variables indicating whether gasoline-automatic/diesel-manual/diesel-automatic versions of model i exist, τ_t are year fixed effects, μ_i are model fixed effects, and ε_{it} is an idiosyncratic error term.⁸ In order to investigate possible evolutions in the preferences, we will also run alternative specifications in which we interact the car attributes with year dummies.

Given the functional form in (3), the coefficients should be interpreted as elasticities of market shares, or equivalently as elasticities of sales, with respect to their corresponding variables. For instance, β indicates the percentage change in the market share (or in sales) of model i following a 1% change of its price.

Additionally, we can also derive willingness-to-pay (WTP) for an attribute as the ratio of this attribute's coefficient to the price coefficient. WTP for engine fuel efficiency, weight and horsepower are respectively given by $WTP^{efe} = -WTP^{efi} = \frac{\gamma_1}{\beta}$, $WTP^w = -\frac{\delta_1}{\beta}$, and $WTP^{hp} = -\frac{\phi_1}{\beta}$ (since the variables are centered on their median, γ_2 , δ_2 , ϕ_2 and λ do not affect the WTP for this particular value). In the literature, WTP is usually expressed in monetary terms, i.e., how much consumers are willing to pay for a marginal change in a given attribute. However, in our framework with variables in logarithm, WTP are obtained in relative terms, i.e., what percentage increase of price are consumers willing to pay for a 1% increase of the given attribute. For instance, WTP^{efe} indicates the percentage price increase a consumer is ready to pay for a 1% improvement of engine fuel efficiency, everything else being constant.⁹

Since our framework is derived from the standard logit formulation, the independence from irrelevant alternatives (IIA) property might be of concern. To assess the reliability of our results, we carry out robustness checks by running models with random effects, thus equivalent to mixed logit models that do not exhibit the IIA property (McFadden, 1986).

3. Data

The data used in this paper come from two different sources.

⁷ It is for instance well-known that the gap between official consumption and actual consumption is widening (e.g., Tietge et al., 2015).

⁸ Note that a single interaction term between car attributes (i.e., engine fuel intensity and power) is included in our estimations, while other interactions are excluded because they create collinearity issues, due to a tight connection between weight and power (see Fig. 2 below). The interaction between weight and power had to be removed from our estimations based on extremely large variance inflating factors (VIFs). Finally, the selection of the interaction between engine fuel intensity and weight versus the interaction between engine fuel intensity and power is based on a series of likelihood ratio tests, which clearly show that estimations containing the former are superior to those containing the latter.

⁹ To allow for the calculation of WTPs, model fixed effects will be replaced by manufacturer fixed effects or manufacturer-year fixed effects in the estimations. Because prices display less variation over time for each model, the price coefficient is unlikely to be precisely estimated in specifications encompassing model fixed effects.

Numbers of new car sales were obtained from Auto-Schweiz website.¹⁰ From 2006 to 2015, figures are available by manufacturer and model. These data allow us to compute market shares for each model and each year.

Technical characteristics of cars available for purchase in Switzerland between 2006 and 2015 were provided by Touring Club Switzerland (TCS). These data correspond to what is reported in yearly consumption books (e.g., TCS, 2015) and include a wide range of technical information on each version of all models. Among others, recorded characteristics include manufacturer, body type, number of doors, price in CHF (currency roughly equivalent to USD), displacement (cm^3), power (kW and HP), transmission (automatic or manual), weight (kg), fuel consumption (L/100 km), CO₂ emissions (g/km), and energy label (A - G). Some of these technical variables are left out because they correlate very strongly with others.

Combining data from the two different sources is not straightforward because of differences in granularity. Auto-Schweiz data contain sales at the model level while TCS reports technical characteristics at the (more disaggregated) version level. For instance, the VW Golf model is available in many different versions, such as 1.2 TSI Trendline, 1.6 TDI BlueMotion Comfortline, 2.0 TSI GTI, asf., but only one sale figure encompassing all versions is provided by Auto-Schweiz. Our strategy to combine the two datasets is therefore as follows. First, we separate the versions of a model on the basis of fuel (gasoline or diesel) and transmission (manual or automatic) and create “submodels” by averaging the characteristics of all versions with similar fuel and transmission.¹¹ Then, we retain only models where a gasoline-powered submodel with manual transmission (i.e., the most common fuel-transmission combination) is available. All sales of a model are allocated to this gasoline-manual submodel and dummy variables are used in the estimations to account for the presence or absence of alternative submodels. We refrain from trying to distribute the reported sales between different submodels or even different versions because that would require critical assumptions.¹²

Our final sample contains almost 90% of all car sales and is composed of 1998 gasoline-manual model-years, totaling almost 2.6 million sales over the 10 years that constitute our observation period. Table 1 provides further descriptive statistics and shows that all variables are right-skewed, which is a further reason for taking their logarithm in the estimations. We observe that gasoline-automatic and diesel-manual versions are available for most models, while diesel-automatic versions are less frequently offered.

Fig. 1 shows the evolution of the main car attributes in our sample over 2006–2015. It is well-known that new cars are getting more fuel efficient over time, and panel A shows this is the case for new cars

¹⁰ <http://www.auto-schweiz.ch/>. Strictly speaking, these figures correspond to new car registrations, which are not necessarily equivalent to sales. However, comparisons with accurate sales data provided directly by Toyota's Sales Planning department over 2006–2013 show that the difference between the two is negligible, so that we simply assimilate new registrations to sales.

¹¹ Because alternative fuel vehicles (electrical, hybrid, gas, and ethanol) are still an emergent technology counting for a negligible part of the Swiss car market, this paper focuses on conventional (gasoline and diesel) cars only. The number of versions used to create the generic submodels ranges from 1 to 67, with an average of 7.0. Within submodels constructed by averaging several versions, all versions are quite similar: The average standard deviations of the main characteristics are 0.21 $\frac{\text{L}}{100\text{km} \times 1.000\text{kg}}$ (engine fuel intensity), 31.4 kg (weight), 13.9 kW (power), and 4308 CHF (price), which are small compared to the average values of these variables (see Table 1).

¹² Sales data obtained from Toyota's Sales Planning department allow us to compute the evolution of shares by fuel and transmission type, which is not possible at the manufacturer level in Auto-Schweiz data. Comparing Toyota's sales with market sales prove that important differences exist across the shares of gasoline/diesel and manual/automatic cars from different manufacturers. A strategy disaggregating manufacturers' sales by replicating market-level sales is therefore to be avoided.

Table 1
Descriptive statistics for the final sample.

Variable	Mean	SD	Min	Max
Market share (%)	0.436	0.520	0.001	4.758
Price [1000 CHF of 2006]	32.943	16.518	9.097	659.800
Engine fuel intensity $\left[\frac{\text{L}}{100\text{km} \times 1,000\text{kg}}\right]$	4.889	0.696	2.970	12.597
Curb weight [1000 kg]	1.389	0.233	0.809	2.672
Horsepower [1000 kW]	0.102	0.036	0.040	0.478
Gasoline-automatic available	0.867	0.340	0.000	1.000
Diesel-manual available	0.889	0.314	0.000	1.000
Diesel-automatic available	0.575	0.494	0.000	1.000
# model-year	1,998			
# models	361			
# sales	2,597,401			

Note: all variables (except market shares) are weighted by sales.

Horsepower (panel D) also remained relatively stable. One should note that most outliers in fuel intensity and power dimensions are luxury cars with prices more than twice the average price.¹⁴

A strong argument to justify why we disaggregate (standard) fuel intensity is provided by Fig. 2. In panel A, fuel intensity is plotted against car weight, and we observe as expected a strong positive correlation between the two. Panel B, however, shows that engine fuel intensity is almost orthogonal to weight. Panels C and D provide similar observations regarding the relationship between fuel intensity and power. Therefore, using engine fuel intensity as an alternative to (standard) fuel intensity appears as highly relevant. It will allow us to clearly disentangle the effects of the different components.¹⁵ Panel E of Fig. 2 displays the relationship between horsepower and weight. As expected, these two variables are strongly correlated, which means that consumers cannot make independent choices for these two dimensions. In our estimations, we therefore do not include any interaction for these

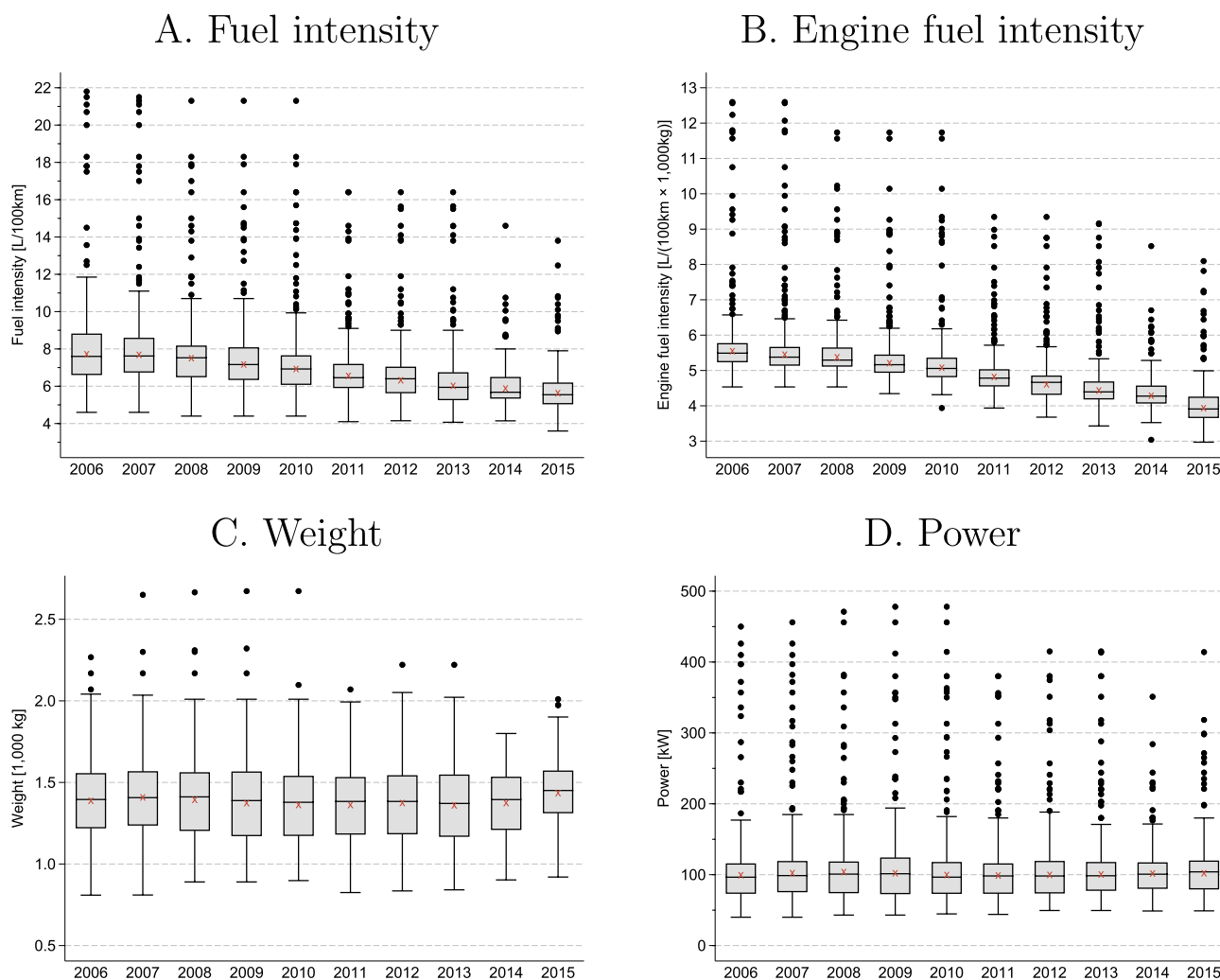


Fig. 1. Evolution of fuel intensity, engine fuel intensity, and weightNotes: x = means. Statistics weighted by sales.

registered in Switzerland. Decomposing the standard measure of fuel intensity into engine fuel intensity (panel B) and car weight (panel C) however reveals that efficiency improvements originate exclusively from engines' improvements over our observation period, while the distribution of new cars' weight shows no particular trend.¹³

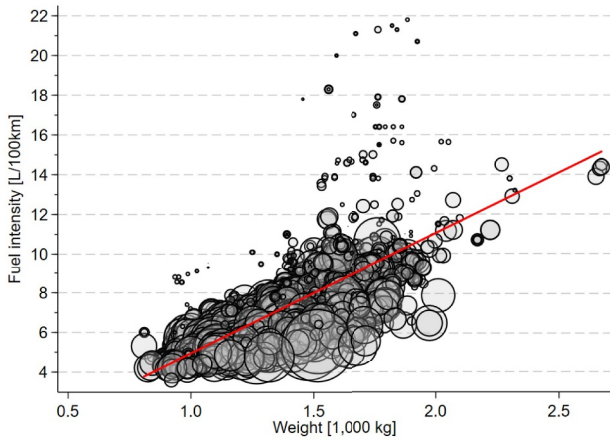
(footnote continued)

evidence tends to indicate that car manufacturers are starting to work on decreasing weight. Some examples are provided by newspaper articles published under the titles (translated from the French by the author) “Beautiful bodies on a diet” (*Swissquote Magazine*, March 2014) and “The ultra-low consumption, new automotive grail” (*L'Hebdo*, October 16, 2014).

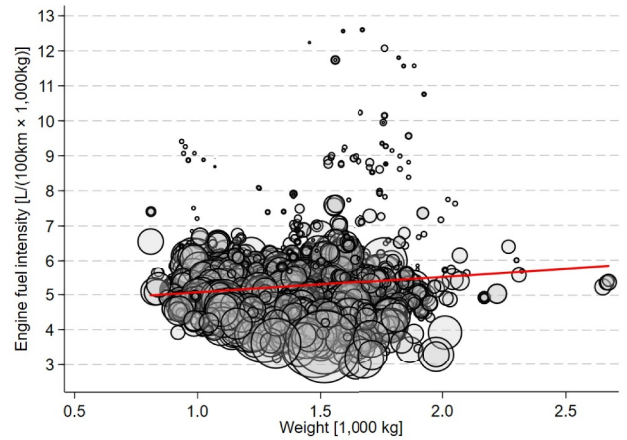
¹⁴ As robustness checks, we have conducted the empirical analysis excluding

¹³ Even though statistics do not display anything in this direction, anecdotal

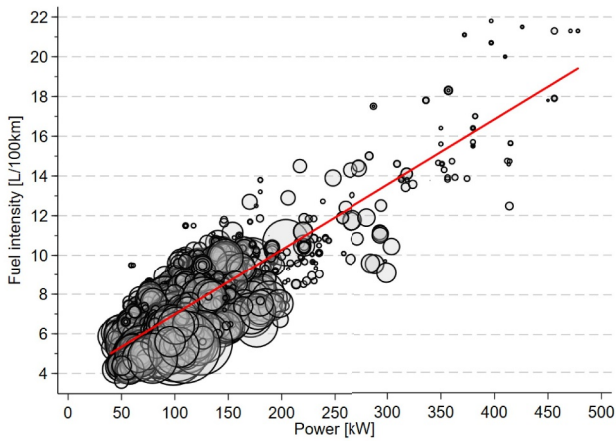
A. Fuel intensity - Weight



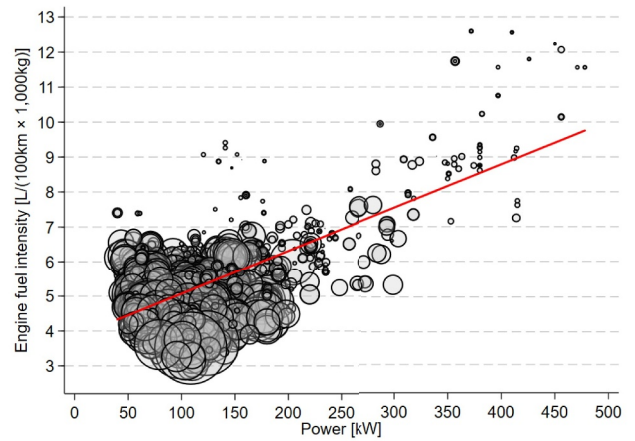
B. Engine fuel intensity - Weight



C. Fuel intensity - Power



D. Engine fuel intensity - Power



E. Power - Weight

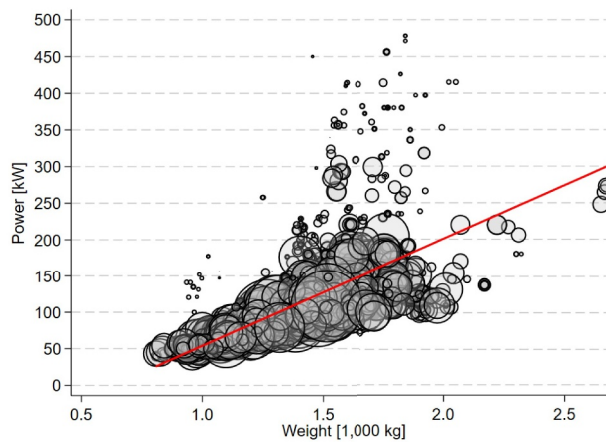


Fig. 2. Relationships between fuel intensity, weight, and power. Notes: marker size proportional to number of sales. Plain lines depict the predictions of simple OLS estimations.

(footnote continued)

luxury cars (defined as those with a price above CHF 70,000) and/or excluding models with extremely low sales, which could be due to supply-side decisions and would in this case not be explained by consumers' preferences. The results of these alternative analyzes (available on request) provide results that are very

(footnote continued)

similar to the ones presented in the paper.

¹⁵ Moreover, from an econometric point of view, our model would be strictly equivalent if we included standard fuel intensity and weight instead of engine fuel intensity and weight. Our argument is that the effect of weight will be

Table 2
Estimation results: determinants of market shares.

	(1)	(2)	(3)	(4)	(5)	(6)
ln(price)	−0.007 (0.216)	−0.202 (0.162)	−1.336*** (0.215)	−0.966*** (0.191)	−1.548*** (0.244)	−0.554* (0.290)
ln(engine fi)	−2.348*** (0.231)	−2.572*** (0.220)	−2.594*** (0.292)	−2.800*** (0.290)	−2.889*** (0.345)	−2.386*** (0.599)
ln(engine fi) ²	−1.251** (0.493)	−2.132*** (0.433)	−0.239 (0.603)	−0.636 (0.591)	−0.160 (0.792)	−3.593*** (0.775)
ln(weight)	−3.463*** (0.423)	−2.761*** (0.329)	−1.650*** (0.294)	−2.057*** (0.277)	−1.581*** (0.322)	−2.398*** (0.536)
ln(weight) ²	−0.111 (0.899)	−0.298 (0.750)	1.395** (0.629)	1.107* (0.613)	1.511** (0.696)	−0.837 (0.840)
ln(power)	0.901*** (0.212)	0.900*** (0.195)	1.245*** (0.219)	1.063*** (0.213)	1.363*** (0.243)	1.585*** (0.405)
ln(power) ²	−0.219 (0.174)	−0.267* (0.156)	−0.036 (0.178)	0.047 (0.174)	−0.043 (0.212)	0.139 (0.211)
ln(engine fi) × ln(power)	1.093*** (0.344)	0.857*** (0.323)	0.859** (0.433)	0.943** (0.429)	0.979* (0.524)	0.772 (0.549)
Gas-auto available	0.147*** (0.044)	0.178*** (0.043)	0.390*** (0.063)	0.402*** (0.063)	0.442*** (0.072)	0.023 (0.099)
Dsl-man available	0.301*** (0.053)	0.417*** (0.051)	0.901*** (0.073)	0.945*** (0.073)	0.923*** (0.081)	0.399*** (0.108)
Dsl-auto available	0.068 (0.044)	0.120*** (0.043)	0.303*** (0.064)	0.315*** (0.064)	0.333*** (0.071)	−0.078 (0.117)
Constant	−5.681*** (0.083)	−5.951*** (0.095)	−6.465*** (0.117)	−6.700*** (0.138)	−7.181*** (0.097)	−5.772*** (0.176)
Year FE	Yes	Yes	Yes	Yes	No	Yes
Model FE	Yes	No	No	No	No	No
Model RE	No	Yes	No	No	No	Yes
Manufacturer FE	No	No	Yes	No	No	No
Manufacturer RE	No	No	No	Yes	No	No
Manufacturer-Year FE	No	No	No	No	Yes	No
Year × linear terms interactions	No	No	No	No	No	Yes
# obs (model-year)	1,998	1,998	1,998	1,998	1,998	1,998
# models	361	361	361	361	361	361
# sales represented	2,597,401	2,597,401	2,597,401	2,597,401	2,597,401	2,597,401
R ² within	0.222	0.212	0.279	0.277	0.306	0.266
R ² between	0.202	0.320	0.578	0.640	0.462	0.328
R ² overall	0.217	0.328	0.352	0.368	0.305	0.344

Notes: Standard errors in parentheses. ***/**/*: significant at the 1/5/10% level. Price, engine fuel intensity, weight and power are centered on their median weighted by sales. In estimation (6), all linear terms (price, engine fuel intensity, weight, horsepower, and the availability dummies) have been interacted with year dummies. The coefficients reported in estimation (6) apply to 2006. Coefficients for years 2006–2015 related to engine fuel intensity, weight and horsepower are displayed in Fig. 4.

two variables, as this would raise collinearity issues.

4. Results

Empirical estimations of equation (3) are reported in Table 2. Recall that all continuous variables are centered on their median weighted by sales. Hence, linear terms can be directly interpreted as marginal effects on market shares (elasticities) for a car with the median characteristics. Quadratic terms and the interaction between engine fuel intensity and power indeed fall to zero for the median values of the variables.

In order to comply with equation (3), all estimations contain year fixed effects. In addition, estimations (1) and (2) contain respectively model fixed and random effects, so that coefficients are estimated from the variations within models over time. It is thus not surprising that the price coefficient is insignificant in these two estimations. There are indeed few changes in the price of a model from one year to another. As noted before, there is more variation in engine fuel intensity and (to a lesser extent) weight and power, so that significant coefficients can be identified for these variables. Considering that random effects relieve

(footnote continued)

correctly estimated if we use engine fuel intensity while it would not if we included standard fuel intensity because some of the effect of weight would then run through fuel intensity.

the potential issue of independence of irrelevant alternatives faced by fixed effects models, estimation (2) is our preferred specification, and most of our comments are based on this one.

We find that consumers are willing to pay for fuel efficient and lighter cars, but at the same time they assign a larger value to more powerful cars. For the median car, the elasticity of market shares to engine fuel intensity is around −2.5, implying that a 1% improvement in fuel efficiency leads to a market share increase of 2.5% everything else being constant (and in particular weight and power). We then obtain that a 1% decrease in weight would improve market shares by around 3%. Finally, a 1% improvement in power implies a 0.9% increase in market shares. The quadratic terms of weight and power are small and at best weakly significant. The quadratic term for engine fuel intensity, however, is negative and highly significant, indicating a decreasing marginal utility for this characteristic. Hence, consumers place value on fuel efficiency, but at a diminishing rate, which is consistent with the fact that efficiency improvements at low levels of efficiency bring larger gains than similar improvements at higher levels of efficiency.

The interaction between engine fuel intensity and power is strongly positive. This finding reveals important heterogeneity in the effect of fuel efficiency, which appears to vary greatly at different levels of power.¹⁶ Fig. 3 displays the elasticity to engine fuel intensity along the power distribution, and shows that among the least powerful cars a

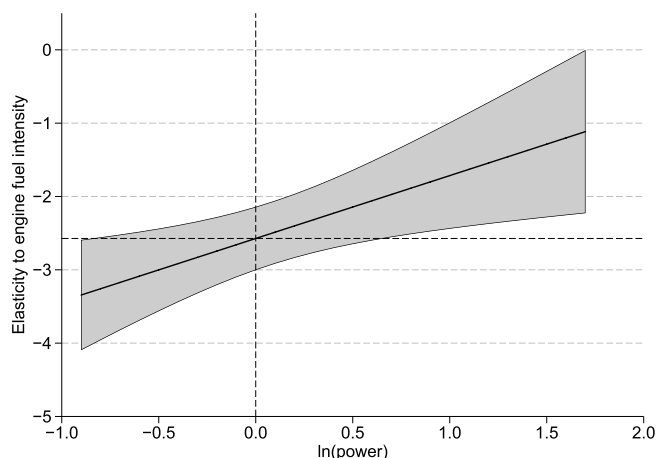


Fig. 3. Elasticity of market shares to engine fuel intensity. Notes: this figure is based on estimation (2) in Table 2. Shaded area indicates 95% confidence interval. Dashed lines show that the coefficient of $\ln(\text{efi})$ (-2.572) applies to median power (i.e., $\ln(\text{power}) = 0$) because this variable is centered on its median. In our sample, $\ln(\text{power})$ centered ranges from -0.9 to 1.7 .

marginal increase of fuel intensity has a much greater negative impact on market shares than at the power's median, all other things being equal. For the most powerful cars in our sample, this elasticity becomes negligible.¹⁷

This result hence reveals heterogeneous consumers' taste and indicates the existence of market segments across which consumers' valuation of fuel efficiency varies. For instance, buyers of light sub-compact cars might pay close attention to fuel consumption, while buyers of upper-end cars are much less sensitive to this criterion or might even indirectly consider it a desirable attribute (fuel consumption being, for instance, closely correlated with more powerful engines). Such heterogeneity in the valuation of fuel consumption has also been put forward by Gramlich (2010), who finds that, conditional on segment of purchase, luxury vehicles purchasers are the least sensitive to fuel economy, while (counter-intuitively) purchasers of Utility Vehicles (CUVs and SUVs) are the most sensitive. To explain these results, he states that “despite, and perhaps even because of, UVs being inefficient compared to other segments, competition within the segment is quite sensitive to fuel efficiency”.

Also, the dummy variables indicating presence of alternative sub-models are all positive and significant, which implies a larger market share for models available in different versions. For example, models for which a gasoline automatic version is sold in addition to a gasoline manual version obtain a market share almost 20% larger.

Estimations (3) and (4) repeat similar regressions, but including fixed or random effects at the manufacturer level instead of model effects. In estimation (5), manufacturer and year fixed effects are replaced by manufacturer-year fixed effects. All these specification allow identification of coefficients based on variation within manufacturers but across models. The coefficient of price therefore becomes significant at

¹⁶ Replacing the interaction between engine fuel intensity and power by an interaction between engine fuel intensity and weight leads to very close estimates. As explained earlier, both of these interactions cannot be included simultaneously because of collinearity issues. The choice of the former interaction term is driven by likelihood ratio tests comparing the estimated models against models without interaction terms and against models containing both interaction terms. In all cases, the model with a single interaction term between engine fuel intensity and power is favored.

¹⁷ Extending our predictions to the set of cars available in the market but that were discarded from our sample because no sales data was available shows that the elasticity to fuel efficiency becomes nil or even slightly negative (i.e., there would be a positive WTP for fuel intensity) for the most powerful cars.

the 1% level, with estimates between $(-1.0$ and $-1.5)$, making it possible to calculate willingness-to-pay for the other car attributes. At the same time, note that the coefficients for all other attributes remain stable.

Based on our results, WTP for engine fuel efficiency can be estimated as the (negative of the) ratio of the fuel intensity coefficient to the price coefficient. Intuitively, this ratio indicates how the two variables must change so as to keep market shares constant. We obtain a WTP between 1.9 (in estimations (3) and (5)) and 2.9 (in estimation (4)), implying that consumers are ready to accept an increase up to 2.9% in the price of a car for a 1% decrease in engine fuel intensity. A back-of-the-envelope calculation indicates that such a WTP implies that consumers overestimate future financial savings attributable to improved fuel efficiency.¹⁸ Similarly, we estimate a WTP from -1.0 to -2.1 for weight and from 0.9 to 1.1 for power, indicating the price percentage variations consumers are willing to pay for a decrease in car's weight or for an increase in horsepower. All these WTP estimates are significantly different from zero albeit their confidence intervals are wide.

Finally, we investigate possible evolutions of the market responses in estimation (6), and let the effects of price, engine fuel intensity, weight, power, and the availability dummies vary over time by interacting all these variables with year dummies. For the sake of space, only the 2006 coefficients are displayed in Table 2, but all coefficients for 2006–2015 are plotted in Fig. 4. Most estimates are significantly different from zero, but not necessarily different from one year to another. Still, we observe a slow but gradual decrease in the elasticity of market shares to power. The last coefficients in the observation period are in fact only weakly significant. For engine fuel intensity and weight, we find a relatively parallel but non-monotonic evolution. Elasticities increased (in absolute value) at the beginning of the observation period, then decreased, and finally increased again at the end of the period. Also, it appears that changes in the elasticity to engine fuel efficiency lag one year or so behind the elasticity to weight.

The sensitivity of consumers, in particular to fuel efficiency, might be linked to fuel prices. To investigate this possible relationship, Fig. 5 plots the evolution of unleaded gasoline prices over 2006–2015 in Switzerland. In some years (e.g., 2006–2008), it appears that elasticity grows while fuel prices increase as could be expected from a theoretical standpoint. However, in other years (e.g., 2011–2012), the same elasticity declines while fuel prices increase. No obvious pattern therefore emerges, and the relationship might be more complicated. It could for instance be the case that consumers react to fuel price variations with some lags. Elasticities could then become stronger only after sustained periods of high fuel prices (such as 2006–2008 and 2012–2014), and weaker after long spells of low fuel prices (such as 2009–2010). Such a lagged reaction would be consistent with the findings by Bonilla (2009), who shows that consumers will buy fuel efficiency in the long run, but not in the short run. Our observation period is nevertheless too short to reach a clear conclusion regarding this issue.

¹⁸ For the median car, which consumes 6.8 L/100 km, a 1% improvement in engine fuel efficiency leads to financial savings around CHF 200 over a lifetime of 15 years and 12,000 km traveled per year (see statistics from SFSO), considering an average fuel price of 1.7 CHF/L as observed over 2006–2015. A 1.9–2.9% increase in the price of the median car, which is worth around CHF 30,000, however represents CHF 600–900. For a CHF 1 decrease in future fuel costs, people would therefore be willing to pay up to 4.5 CHF up front (and accounting for discount rate would even increase the overvaluation of fuel economies). Helfand and Wolverson (2011) review studies that investigate WTP for fuel efficiency. Empirical estimates obtaining an overvaluation of fuel efficiency are almost as frequent as those obtaining an undervaluation, and some studies find much higher WTP than the ones we obtain (see e.g., Greene and Liu, 1988).

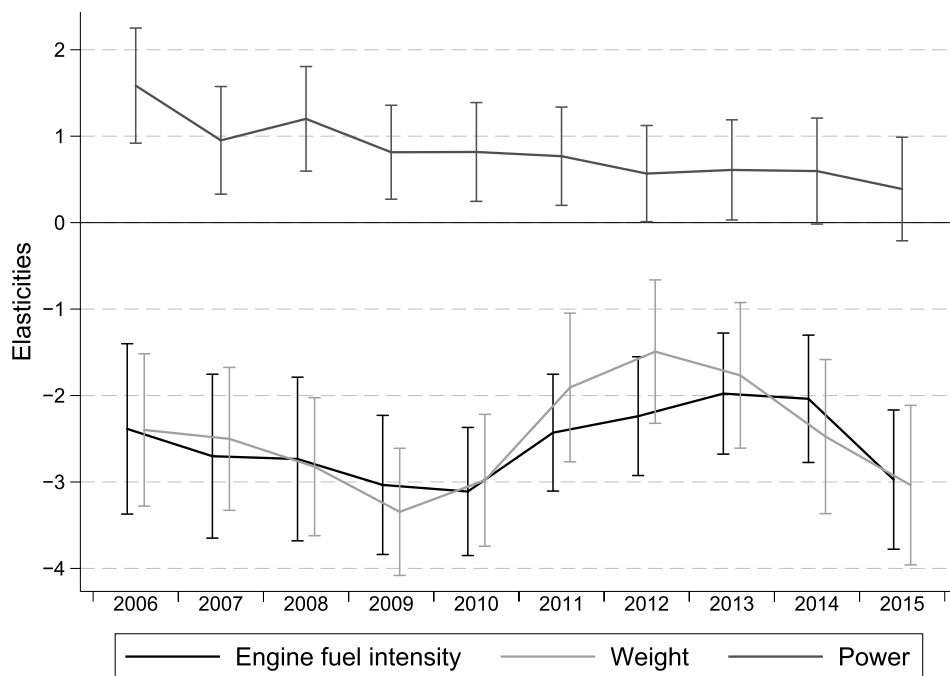


Fig. 4. Evolution of elasticities of market shares. Notes: this figure presents the results obtained in estimation (6) of Table 2, where all linear terms (price, engine fuel intensity, weight, horsepower, and the availability dummies) are interacted with year dummies. Only coefficients for 2006 are displayed in Table 2. All coefficients related to engine fuel intensity, weight and horsepower are displayed in this figure. Elasticities are plotted for the median characteristics. Whiskers indicate 90% confidence intervals.

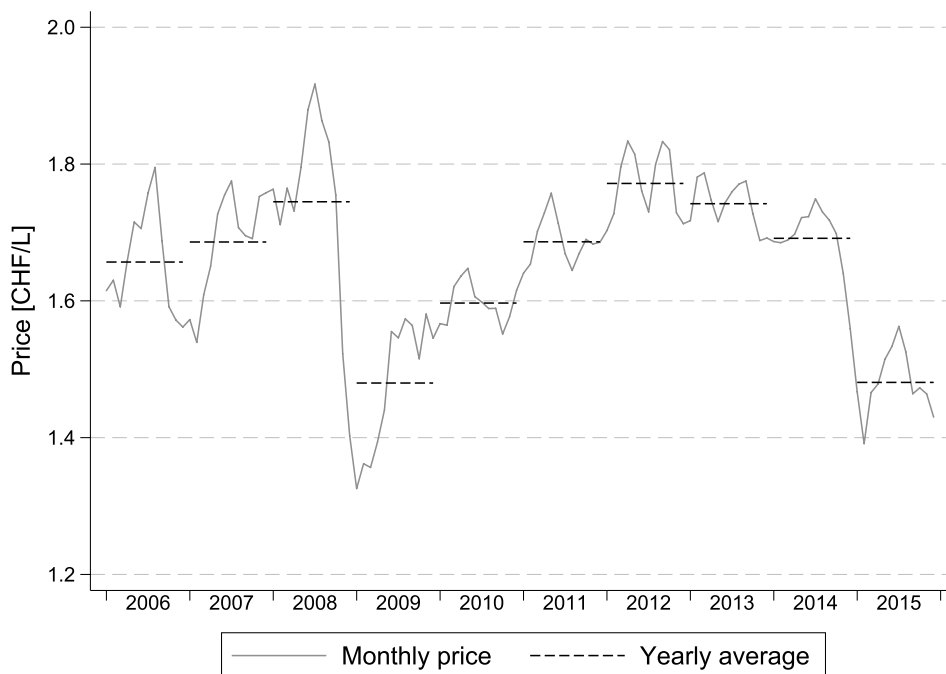


Fig. 5. Evolution of gasoline prices. Notes: Real prices (December 2015 = 100) of unleaded gasoline with 95 research octane number (RON). Unleaded gasoline with 98 RON and diesel prices follow a very similar evolution. Data source: Swiss Federal Statistical Office (SFSO).

5. Discussion

Our findings point to a recent increase in consumers' sensitivity to fuel efficiency and to a decrease in sensitivity to power. These findings are important in themselves and, providing the trend continues, implies that consumers' tastes evolve in a favorable direction from the perspective of policy makers willing to achieve ambitious fleet's fuel consumption reduction. However, we also highlight important disparities across less and more powerful car purchasers' segments. These results, showing important variations within the new car market, call for even finer analysis in future research on the topic. A better understanding of the heterogeneous segments of the market could undoubtedly be of

interest for policy makers to direct incentive schemes where they are most needed.

Our observation period encompasses important events that may explain changes in the way fuel intensity enters Swiss consumers' purchasing decisions. Between 2006 and 2015, two major economic shocks occurred: the subprime crisis in 2008–2009 (e.g., Shiller, 2008), followed by the European sovereign debt crisis in 2009–2012 (e.g., Lane, 2012). While Switzerland has been only moderately affected in comparison to other developed countries, such globalized economic melt-downs may nonetheless have had some psychological impacts, such as fear for job stability and future earnings. This could have impacted the Swiss car market, by providing an incentive to buy cars that are cheaper

to run.

Furthermore, fuel prices have been mostly growing since the early 2000s in Switzerland, let aside 2008 when prices experienced a severe peak followed by a sharp drop caused by the subprime crisis (see Fig. 5). By 2012, average yearly gasoline price was at its highest in real terms since the oil crisis of the 1970s. This increase of cars' running cost is likely to have provided a powerful incentive in favor of fuel efficiency. This effect might even have been reinforced if consumers expected the trend with respect to fuel prices to continue in the future. Such effects would be consistent with previous empirical studies, which, despite disagreements on its amplitude, show that fuel price positively impacts consumers' choice of new cars' fuel economy (Allcott and Wozny, 2014; Bonilla and Foxon, 2009; Klier and Linn, 2013; Witt, 1997).

However, as already pointed out in the literature, consumers' behavior toward fuel intensity is more complex than the usual economic assumptions of cost saving. According to Turrentine and Kurani (2007), consumers also attribute symbolic value to fuel economy (for instance based on their perception of the importance to preserve resources) and are often unable, or unwilling, to think in terms of WTP, payback period or cost saving over a car's life span. In the Swiss case, in addition to the above-mentioned economic incentives to buy more efficient cars, there are also signs that recent years were a transition period with respect to consumers' environmental concerns. Survey-based evidence shows that consumers' concern toward environment has steadily increased between 2005 and 2010, as noted by FOEN (2011). Moreover, willingness-to-act concretely through purchasing decisions seems to have increased accordingly. In 2010, 84% of respondents stated that they took into account food's production method, 88% that they looked at the energy consumption of new home appliances and 90% that they would give priority to similar products with less packaging, while in 2005 approximately 50% would have answered that way (FOEN, 2011). Unearthing the precise determinants driving this shift is beyond the scope of this paper. Still, we note that media coverage of the major environmental threats due to human activities, such as climate change, has increased sharply since 1990 (Schmidt et al., 2013), possibly having a positive impact on the extent to which consumers consider environmental variables in their purchasing decisions.¹⁹ Interestingly, the existence of a willingness-to-pay for cars with reduced CO₂ emissions has already been put forward in Germany, a country with a cultural context very close to that in Switzerland (Achtmeier, 2012).

In the past decades, an increasing body of literature has shown that part of the potential energy savings from improved efficiency was lost due to the rebound effect. The rebound effect in terms of extra distance driven in the private transport sector has been widely analyzed (e.g., Frondel et al., 2012; Matiaske et al., 2012; Small and Van Dender, 2007; Su, 2012; Weber and Farsi, 2014). However, other types of rebound have received much less attention from researchers but are likely in the private transportation context. By reducing costs, fuel efficiency improvements may indeed alter driving behaviors, such as speed. Fosgerau (2005) indeed reports a positive income elasticity of speed.

According to Sorrell and Dimitropoulos (2008), the rebound effect might be decomposed into several components. In the context of transportation, technological improvements may indeed induce people to drive further, but also to buy more cars and larger cars. Sorrell and Dimitropoulos (2008) however note that because of the usual strategy used to empirically estimate the rebound effect, which focuses on the number of cars and mean distance traveled, "any increases in average vehicle weight as a result of energy efficiency improvements (e.g. more SUVs) [...] will be overlooked" (p. 639). In the same vein, Greene (2012) remarks that "decreasing the energy costs of vehicle travel can also lead to an indirect rebound effect via a shift in sales towards larger

of more powerful vehicles" (footnote 4, p. 15). In our results, consumers simultaneously penalize fuel intensity but value powerful cars, and this trade-off can be interpreted as a rebound effect. If consumers shift toward more powerful cars, realized fuel savings will be lower than expected, had consumers kept their car class unaltered (Akerlind et al., 2015; Autosmart, 2014).

A limitation of the present study is that it analyzes consumer behavior on the new cars' market only, without consideration of the second-hand market. In Switzerland, yearly sales volume of second-hand cars is approximately two and half times larger than the new car's market, making this omission a non-trivial issue. The case is made stronger by the fact that second-hand cars' purchasers are likely to have different socio-demographic characteristics (e.g., younger and with lower disposable income). A generalization of our results to the entire population cannot be directly made and a separate study of the second-hand market would be needed. Nevertheless, renewing the stock of cars (and thus improving average efficiency) necessarily runs through new purchases. In 2012, annual car sales accounted for about 7.7% of the stock of passenger cars, which, assuming a stable stock size, would imply a complete renewal time of about 13 years.

Our use of list prices could be criticized for not being equal to the effective transaction prices faced by consumers. Indeed, discounts, specific promotions or special arrangement contracts (e.g., leasing) are common practice. It has to be noted that while some price flexibility remains at the discretion of individual retailers, an important portion is defined as part of the manufacturer's importer and distribution network strategy. Such make characteristics should typically have been adequately accounted for by our year specific manufacturer fixed or random effects and we argue that list prices, which are commonly used in car market analysis (e.g., Alberini et al., 2014; Knittel, 2011; Train and Winston, 2007), are a substitute close enough to real transaction costs for the purpose of the present paper.

Finally, it has been argued in the literature (see Zachariadis, 2006, for a review) that advertised fuel consumption such as the one used in this paper, based on manufacturers' heavily optimized tests run, display a growing difference with real on-road consumption. Four main reasons have been advanced by Tietge et al. (2015) to explain this growing gap: (i) exploitation of tolerances and flexibilities in the methods for determining road load in setting up vehicle certification tests, such as tire preparation and selection of the test track; (ii) chassis dynamometer testing flexibilities, such as break-in periods for the test vehicle, tolerances regarding laboratory instruments, or the state of charge of the vehicle's battery; (iii) new technologies being deployed, such as start-stop systems and hybrid powertrains, which have more impact during the test than during real-world driving; (iv) other equipment, such as air conditioning and entertainment systems which are switched off during the tests. However, since this measure is likely to be the best and only one available to most consumers, we think that this phenomenon is of small concern for our study. Nonetheless, we acknowledge that there is room for further studies on the potential influence of heterogeneous consumers' awareness of this discrepancy on their willingness-to-pay for the advertised fuel consumption. Greene et al. (2013) opened the way on this question by showing that US consumers consider fuel economy rating as highly uncertain. If these elements create systematic biases in consumers perception, their WTP might be biased accordingly.

6. Conclusion

Considering that CO₂ emissions from the transportation sector keep increasing despite major technological improvements and important policy efforts, it appears crucial to understand consumers' preferences regarding car attributes in order to implement relevant incentives. With this objective in mind, this paper uses a combined dataset of new sales and technical characteristics to investigate the Swiss car market over the period 2006–2015. Our results reveal that consumers value engine's fuel efficiency, with a willingness-to-pay for this attribute that is

¹⁹ For example the IPCC synthesis report on climate change (IPCC, 2014) has been extensively covered and commented on by the media.

relatively large but not implausible compared to other results from the literature (see Helfand and Wolverson, 2011). The sensitivity of consumers with respect to engine's fuel efficiency seems to be rising since 2013 until the end of the observation period.

We moreover find that consumers prefer light cars over heavy ones, contrary to some former studies (e.g., Cuenot, 2009; Meyer and Wessely, 2009). The sensitivity of consumers to weight moreover appears to have increased recently. Regarding this attribute, the difference between our results and most of the literature might be explained by two elements. First, our observation period witnessed only a relatively modest increase in new cars' weight. During previous decades, which constitute the observation period of most former studies, the weight progression was much more pronounced. Second, instead of a standard fuel efficiency measure we use engine's fuel efficiency, that is precisely corrected to remove the impact of weight on fuel consumption. The third car attribute considered in our analysis is power, and our findings show a positive but slightly declining elasticity of market shares with respect to this attribute. All recent trends are thus encouraging, and should facilitate the achievement of CO₂ emission targets.

However, we also find that buyers of different car categories react very differently, with sensitivity to engine fuel efficiency being low among the most powerful cars' segment. This result highlights that policy measures should target this specific segment of the market: For a given amount of driving, consumers who buy the most powerful cars are likely to be responsible for higher emissions, because more powerful cars tend to be less fuel efficient. Hence, competitive manufacturers cannot diminish the power of their vehicles without risking losing some consumers, so that this issue can only be improved via government interventions.

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