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Technological growth of fuel efficiency in european automobile market 1975–2015

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HIGHLIGHTS

- We evaluated fuel efficiency technological growth trends in European cars.
- We quantified trade-offs between vehicle attributes and fuel consumption using statistical methods.
- Technology development was offset by upsizing and upgrading of cars in 1975–2006.
- Technology development and downsizing enabled large improvements in efficiency in 2006–2015.
- Maintaining historical trend of efficiency improvement is not enough to achieve EU 2021 target.

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ABSTRACT

This paper looks at the technological growth of new car fleet fuel efficiency in the European Union between 1975 and 2015. According to the analysis results, from1975 to 2006 the fuel efficiency technology improvements were largely offset by vehicles' increased weight, engine size, and consumer amenities such as acceleration capacity. After 2006, downsizing in weight and engine capacity was observed in new car fleet, while fuel consumption decreased by 32% between 2006 and 2015. We adopt a statistical method and find that from 1975 to 2015, a 1% increase in weight would result in 0.3 to 0.5% increments in fuel consumption per 100 km, and a 1% reduction in 0–100 km/h acceleration time would increase fuel consumption by about 0.3%. Impacts of other attributes on fuel consumption are also assessed. To meet the European Union's 2021 fuel consumption target, downsizing of cars, as well as at least maintaining fuel efficiency technology growth trend observed between 2005 and 2015, are needed. Government policies on controlling improvement in acceleration performance or promoting alternative fuel vehicles are also important to achieve European Union 2021 target.

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1. Introduction

The transportation sector is a major energy consumer and one of the largest Greenhouse Gas (GHG) emission contributors. Governments around the world are taking steps to address the energy and GHG emission problems caused by transportation (CARB, 2009; US DOE, 2009; EU, 2011; Chen and Fan, 2013; Zhang et al., in press; Chen, et al., 2015). In 2009, the European Union (EU) government finalized setting emission performance standards for new passenger cars as part of the EU Community's integrated approach to reduce carbon dioxide (CO_2) emissions from light-duty vehicles (EU, 2009). This regulation sets the average CO_2 emissions for new passenger cars at 130 g CO_2/km (equivalent to 5.6 l per 100 km of gasoline or 4.9 l per 100 km of diesel) by end of 2015, and 95 g CO_2/km (equivalent to 4.1 l per 100 km of gasoline or 3.6 l per 100 km of diesel) by 2021.

According to European Environment Agency (EEA), the average fuel efficiency level of a new car sold in 2014 was 5.3 l per 100 km, which was already below the 2015 target of 5.6 (EEA, 2015). Although manufacturers have made considerable technological progress, they still have to do more in order to meet 4.1 l per 100 km by 2021. For policymakers and researchers, it is important to know whether the 2021 target is achievable and to be aware of whether the candidate polices can help smoothing the process.

Generally, influencing factors of vehicle fuel efficiency, usually expressed as fuel consumption (FC) per distance of vehicle travel, can be put into three categories, i.e. vehicle system inputs (e.g. vehicle weight, engine attributes, body shape), vehicle system outputs or consumer amenities (e.g. acceleration performance, all-wheel drive feature), and technological progress in vehicle fuel

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efficiency. Here, the technological progress is a measure of innovations that help vehicles achieve better fuel efficiency without changing any vehicle system input and output parameters. Otherwise, without technological improvement, the only way to achieve a lower fuel consumption rate is through downsizing vehicle system input parameters, or limiting consumer amenities. Furthermore, the three factors interact with each other. For example, engine size (vehicle system input) influences acceleration performance (vehicle system output), and these two are both impacted by technological development because with advanced technology, vehicles can achieve better acceleration performance without changing engine size. Therefore, in order to predict the fuel efficiency of future cars, we need to 1) quantify relationships between vehicle input / output parameters and fuel efficiency, 2) understand the historical technological improvement in fuel efficiency of cars.

As summarized by MacKenzie and Heywood (2015), there are two major views of evaluating fuel efficiency in vehicles, the bottom-up and top-down view. The bottom-up view focuses on the relationship between vehicle system inputs (such as engine attributes, weight, etc.) and fuel consumption, while the top-down view focuses on vehicle system outputs (performances perceived by consumers, such as acceleration time).

Extensive studies were devoted to utilize the bottom-up approach (Kwon, 2006; Van den Brink and Van Wee, 2001; Knittel, 2011). Kwon (2006) investigated the quantitative relationship between engine capacity and fuel consumption rate in the UK between 1979 and 2000. It was found that technological improvements during that period were mainly used to offset increased average engine capacity in the 1980s Van den Brink and Van Wee (2001) quantified impacts of weight, cylinder capacity on Dutch new car-fleet fuel consumption using the bottom-up approach. Similar to the findings of Kwon (2006), it was concluded that the unchanged new car-fleet fuel consumption between 1985 and 1997 was mainly due to the fact that the benefits of technological improvement were used to offset increased engine capacity and weight. Knittel (2011) adopted a similar bottom-up approach to study trade-offs between engine power, vehicle weight, and fuel economy in the US. It was found that technological progress that occurred between 1980 and 2006 had the potential to increase fuel economy by 65%. However, due to increase in vehicle weight and engine power, the actual increase in fuel economy was only 18%, only one fourth of the potential.

Although the bottom-up approach is easy to understand and backed by continuous engineering efforts, it is hard to predict the adoption time of new technologies, which leads to the difficulty in assessing future vehicle fuel efficiency. This is because the adoption of technologies depends on consumers' choices. Therefore, recent research efforts have been shifted to utilize the top-down approach, which focuses on vehicle performances perceived by consumers.

Sprei and Karlsson (2013a, 2013b) found that until 2007, in Sweden, majority of technological development in the energy efficiency of cars was offset by continuously enhanced consumer amenities. But between 2007 and 2010, consumer amenities remained flat and, therefore, technological development resulted in actual reduction in fuel consumption. MacKenzie and Heywood (2015) adopted Knittel's (2011) econometric approach but included both vehicle system attributes and consumer amenities as independent variables. They found that per-mile fuel consumption could have been reduced by about 70% from 1975 to 2009, holding the acceleration performance and functionality of vehicles unchanged.

Although the top-down approach has the advantage of easily assessing future technological progress through consumers' amenities choices, it is also has disadvantages. Long term series of consumer amenity choice data are difficult to obtain. In addition, it is hard to predict consumers' amenities preferences. This paper takes a step in incorporating the bottom-up and top-down approaches into a methodological framework and further examines our models' interpretability in the European automobile industry.

The objectives of this paper are to 1) study the relationship between fuel consumption, vehicle attributes, and consumer amenities; 2) quantify the historical rates of fuel efficiency technology improvement in European cars, and 3) compare the improvement rates with those of US cars. The knowledge established in this study can further be used to understand whether or not, and how, the EU can achieve its fuel efficiency targets in 2021. This study distinguishes itself by its inclusion of vehicle system input parameters and consumer amenities in explaining vehicle fuel consumption rate, and the estimating of historical technological progress in one model framework.

The rest of the paper is organized as follows: methodology is presented in Section 2. The data source and summary statistics are discussed in Section 3. The results are detailed in Section 4. The conclusion and policy implications are presented in Section 5 and Section 6 respectively.

2. Methodology

There are several candidate methods that can be used for conducting analysis to achieve the objectives of this paper. Engineering-based powertrain simulation is one solution. Usually a powertrain simulation tool is built that takes vehicle design, engine control technology, and other vehicle attributes as inputs and estimates fuel efficiency of vehicles (Gao et al., 2015a, 2015b; Chen and Meier, 2016). Several publicly available tools are out there, such as FASTSim, Autonomie (Brook et al., 2015; Halbach et al., 2010; Morisson and Chen, 2011; Chen and Fan, 2014), and some previous studies were conducted using this approach (Vijayagopal and Rousseau, 2011; Moawad et al., 2014; Borken-Kleefeld and Chen, 2015; Chen and Borken-Kleefeld, 2014; Chen and Borken-Kleefeld, 2016). However, in this paper, our purposes include both studying impacts of vehicle attributes on fuel consumption and investigating technological progress trends of fuel efficiency in EU cars. The engineering simulation approach could not provide technological progress trends, which is an important aspect to predict fuel efficiency. Another approach is called econometric modeling. This is the approach chosen by Knittel (2011) and MacKenzie (2015). It has the advantage of quantitatively estimating of relationship between fuel consumption and vehicle attributes, as well as being able to utilize large volume, multi-year panel data to investigate technological progress trends of fuel efficiency. Therefore, an empirical multi-variate model, similar to the model specified in Knittel (2011) and MacKenzie and Heywood (2015), is adopted in this study. Similar to previous studies, Cobb-Douglas function form is used to model the relationship between fuel consumption and vehicle attributes. The basic setup of the econometric model is as following:

$$\ln FC_{it} = T_t + \beta_1 \ln w_{it} + \beta_2 \ln T100_{it} + \boldsymbol{X}_{it}'\boldsymbol{B} + \epsilon_{it}$$

Where FC_{it} is the fuel consumption in unit of liter per 100 km for car model i in year t. T_t is a fixed effect term trying to estimate time dependent technological improvement in our panel data.[1] w_{it} is its curb weight, and $T100_{it}$ is its 0–100 km per hour acceleration time in seconds. $\boldsymbol{X}_{\mathrm{it}}$ is a vector of other variables representing

[1] A realization of fuel efficiency technological improvement between year $t$and year t' is the difference in fuel consumption of two average cars each from year t and t', mathematically it is captured as $\frac{FC_t}{FC_{t'}} = e^{T_t - T_{t'}}$.