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A probabilistic total cost of ownership model to evaluate the current and future prospects of electric cars uptake in Italy

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ABSTRACT

In order to evaluate the current and future prospects of electric cars' in Italy, we develop a probabilistic total cost of ownership (TCO) model, which includes stochastic and non-stochastic variables, vehicle usage and contextual assumptions. We find that electric cars are currently not cost-competitive in Italy with the conventional petrol or diesel cars. However, they are cost-competitive with the hybrid electric cars when more than 10,000 km are annually traveled. With incentivizing policies (a €5,000 subsidy and a €400 parking and access fee annual savings), currently in place in a limited number of Italian Regions and cities, electric cars perform in monetary terms better than hybrid electric cars and some diesel cars, especially if they are charged at home. However, electric cars are expected to gain market share in the year 2025 if fuel prices follow past trends, even without subsidies. The driving force could be a drop in their retail price, thanks to declining battery pack costs, and a possible revision of the taxes on diesel.

1. Introduction

Italy is one of the countries with the lowest uptake of electric cars (BEVs)[1] in Europe, equal in 2017 to 0.01% of the total new car sales, while in neighboring countries, such as Austria, France, Switzerland or Germany, BEVs have a market share ranging from 1.5% to 3%, and growing. Many factors play a role in the consumers' car purchase decision (Coffman et al., 2017; Berkeley et al., 2017; Liao et al., 2017; Biresselioglu et al., 2018). They are both monetary (e.g., purchase price, excise taxes, operational costs, parking fees) and non-monetary (e.g., driving range, car size and segment, brand, attitudes,[2] charging time and charging infrastructure). The former group of costs are captured by the *total cost of ownership* (henceforth, TCO) concept. TCO is defined both as a purchasing tool and a philosophy, aimed at understanding the true financial cost of buying a specific good such as a car (Ellram, 1995). This paper develops and applies a probabilistic TCO model to evaluate the prospects for BEVs' diffusion in Italy.

Using the terminology proposed by Letmathe and Suares (2017), TCO can be divided into two cost components: the consumer-oriented TCO, including all the cost born by the car user, and the society-oriented TCO. This paper focuses on the former, whereas Danielis and Giansoldati (2017) deal with both types of TCO.[3]

Estimating the TCO of a car presents difficult computational challenges. Nonetheless, TCO provides a useful information for consumers, fleet managers, original equipment manufacturers (OEMs) and policy makers. As argued by Hagman et al. (2016), the informational tools available to consumers have so far been limited. Consequently, one might suspect that private consumers (and to a lesser extent fleet managers) have limited knowledge on the TCO metric and its components, potentially leading to economically irrational purchase decisions.[4] OEMs could use this information to develop more focused BEVs' marketing strategies and transport policy decision makers might tailor spatially and temporally their policies, eventually targeting specific market segments without risking an excessive or insufficient use of public resources.

The construction and implementation of a TCO model requires the

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[1] Hereafter, we shall use the conventional acronym BEVs, battery electric vehicles, although we will restrict our analysis to cars without considering light- and heavy-duty vehicles, two- or three-wheelers, pick-up trucks and vans. In addition, in our paper BEVs refers only to pure battery electric cars and do not include plug-in cars.

[2] Zhang (2007) stresses the importance of the "familiarity" in car adoption. As suggested by the reviewer, in Italy BEV uptake might be helped by the large presence of e-car sharing schemes (about 30% of the share cars) that allow for a personal experience of electric car by a population orders of magnitude larger than actual current purchasers.

[3] A recent evaluation of the CO_2 emission of the different propulsion systems for all European countries is presented by Cavallaro et al. (forthcoming).

[4] Gillingham and Palmer (2013) argue that consumers might suffer from the "energy-efficiency paradox" because of imperfect information, bounded rationality, and limited mathematical skills. One strategy to address consumers' misconception is to supply information on the TCO. Dumortier et al. (2015) find that providing such information would affect the stated preferences of consumers to purchase more energy efficient cars. Kaenzig and Wüstenhagen (2010) find similar results regarding eco-innovations.

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identification of the multiple private and social cost components. Some of them have uncertain values (i.e. real consumption in real driving conditions, preventive maintenance, residual value), some have a subjective nature (e.g. insurance premiums, driving styles), or vary over time (e.g. fuel or electricity cost). Some others are scientifically controversial (e.g. external costs of environmental or noise pollution), or stem from political decisions (e.g. monetary or non-monetary incentives, fees for parking or accessing reserved areas). Moreover, the estimation requires to take into account the driving habits (e.g., annual distance driven, the percentage of urban/suburban trips), the ownership period (with implications for the residual value), and the appropriate discount rates.

In order to deal with parameters' uncertainty, this paper develops a probabilistic TCO model along the lines suggested by Wu et al. (2015). The model is used to evaluate the current and future prospects of a BEV's diffusion in Italy in different scenarios, assuming that there is a relationship among the monetary cost of a car and the consumers' buying decision, although we acknowledge that non-monetary variables play also a relevant role.

To the best of our knowledge, no probabilistic TCO model has been so far developed for Italy. Previous non-probabilistic TCO models with Italian data are developed by Rusich and Danielis (2015), Danielis and Giansoldati (2017) who estimate consumer- and society-oriented TCO, and Lévay et al. (2017) who publish a comparison among European countries which includes Italy. The Italian case is characterized by the lack of BEV-specific national subsidies and an insufficient charging infrastructure, a fiscal taxation favoring diesel vehicles, and poor interest on BEVs from the major Italian OEMs. Yet, air pollution level in the northern Italian towns is a serious health issue and the political interest for BEVs is growing. An additional peculiar characteristic of the Italian market is that customers buy mostly small-to-medium sized cars, which require capital investments that are quite smaller than the average current BEVs price.[5]

The TCO model proposed in this paper is useful to quantify the financial gap between BEVs and internal combustion engine vehicles (ICEVs), in the present conditions and taking into account future price and technology developments. Differently from other studies (e.g., Wu et al., 2015; Letmathe and Suares, 2017), but similarly to Lévay et al. (2017), we implement the TCO model considering the 10 best-selling cars instead of relying on conceptual car models. Four propulsion systems are considered: petrol-fueled ICEVs (P-ICEV), diesel-fueled ICEVs (D-ICEV), petrol-fueled hybrid electric vehicles (HEVs), and BEVs. The appeal of this approach is that it allows us to understand which are the actual competitors of the BEVs, as they try to gain market share.

The paper has the following structure. Section 2 introduces the related literature. Section 3 illustrates the probabilistic TCO model. Section 4 presents the main findings: a) in the current cost scenario without BEVs' incentivizing policies; b) in the current cost scenario with BEVs' incentivizing policies; c) in two future scenarios. Section 5 compares our results with those reported in previous studies and Section 6 concludes.

2. Related literature

The literature on the TCO of cars is rapidly growing as recent reviews indicate (Wu et al., 2015; Bubeck et al., 2016; Danielis and Giansoldati, 2017). Since the pioneering work by Delucchi and Lipman (2001), numerous contributions followed on the TCO of BEVs (Appendix, Table 15). Some of them deal with both consumer- and society-oriented costs, considering the costs caused by CO_2 emissions (Kromer and Heywood, 2007; Thiel et al., 2010; Element Energy, 2011; Prud'homme and Koning, 2012; Bikert et al., 2015; Liu and Santos, 2015; Bubeck et al., 2016; Falcão et al., 2017) or those caused by local pollutants and noise (Prud'homme and Koning, 2012; Tseng et al., 2013; Zhao et al., 2015; Rusich and Danielis, 2015; Mitropoulos et al., 2017; Danielis and Giansoldati, 2017). Obviously, including the social costs in the TCO model makes the task more challenging and adds uncertainty to the results, since it involves monetizing nonmarket goods and services.

All the propulsion systems available in the market have been subject to comparative evaluations: P-ICEV, D-ICEV, HEV, PHEV (Plug-in Hybrid Electric Vehicle), BEV, FCEV (Fuel Cell Electric Vehicle), LPG, methane. Some of these technologies (notably, the most recent ones such as the BEV, PHEV, FCEV) constantly evolve, changing their cost structure.

The TCO evaluations have been carried out with reference to many countries (McKinsey and Company, 2011; Lévay et al., 2017; Palmer et al., 2018). As each country is characterized by specific cost structures, due to different fuel/electricity prices (linked to different excise taxes), insurance premiums, and subsidies, results differ among countries. It has been also pointed out that the TCO greatly depends on the vehicle usage patterns. Determining factors are trip type (urban vs highway), residential density (Windisch, 2013; Wu et al., 2015), user segments, as well as whether the car is used as first or second family car (Propfe and Redelbach, 2012; Plötz et al., 2013).

TCO models include many cost components such as vehicle price, vehicle excise duty, insurance, preventive maintenance, tire substitution, car's resale value, fuel consumption, etc. BEVs pose an additional challenge connected with the need to include the cost of battery substitution, recycle or reuse (Letmathe and Suares, 2017). Such an inclusion raises difficult questions both regarding when a battery substitution is needed and on how much it would cost or what one would gain from recycling or reusing the battery. Since BEVs are a recent product, not enough experience or data exists on these issues.

Most TCO models have deterministic parameters, exception made for Element Energy (2011) and Wu et al. (2015), who develop a probabilistic simulation model which is able to account for the uncertainty in the TCO model's parameters. This paper adopts the same strategy since we are confronted with significant sources of uncertainty on both current and future variables.

The surveyed studies focus on different vehicle classes, since each of them has its own peculiarities. The selected vehicle types are conceptual models, whose characteristics are defined by the main components of a vehicle, or representative models, selected from the real world models offered in a country at a specific date. In most cases the number of selected representative models is rather small (especially for the BEVs, since only a few were available), usually choosing the most popular ones (e.g. Nissan Leaf, Zoe, BYD, depending on the country). Lévay et al. (2017), being a more recent contribution, is able to compare 10 vehicle types for each propulsion systems in 8 European countries.

For the abovementioned reasons, the prospects for BEVs' diffusion in the market are country-, vehicle class-, time-, and vehicle usage-specific. Consequently, it is no surprise that findings are not univocal. However, there appears to be an historical trend: from skepticism to moderate optimism.

The pioneering study by Kromer and Heywood (2007) shows no clear winner in the future competition among propulsion systems, unless strongly influenced by government policies. Prud'homme and Koning (2012) find that in the year 2010 in France BEVs had excess costs above €10,000, granting very small CO_2 gains. They conclude that unless massive cost and efficiency improvements are achieved, BEVs will require enormous subsidies. However, in the years 2010 and 2012 two BEVs, the Nissan Leaf and the Tesla Model S, were successfully introduced in the market.

Propfe and Redelbach (2012) argue more optimistically that the TCO gap for alternative drivetrains will decrease significantly by 2020. In a very detailed report, Plötz et al. (2013) state that BEVs' share in

[5] Thiel et al. (2015) estimate that the share of small cars (A and B segments) in the total new vehicle registrations in 2014 was 23% in Germany and 48% in Italy.