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MODELLING AND EVALUATION OF THE DIFFUSION OF ELECTRIC VEHICLES: EXISTING MODELS, RESULTS AND PROPOSAL FOR A NEW MODEL

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Abstract:

In this paper we review the available methods, models and results about the diffusion of electric vehicles and the evaluation of related policy. We show that existing models often relate to contexts that are not relevant for the design of policies that could take place in Europe. We also find that many models rely on exogenous diffusion assumption and are not intended to simulate the effects of alternative policy packages, which can significantly limit their scope. Moreover we find that only a few of the studies presenting themselves as costs-benefit analysis really perform what they claim. We also draw some conclusions on the features of models that would be needed to derive recommendations relevant in the European policy framework.

1. Introduction

Electric cars as an alternative to conventional internal combustion engines are becoming increasingly popular among policy makers as well as the general public since they supposedly appear as a way to address environmental issues as well as the rising prices of fossil fuels. In this context, a number of countries are considering ambitious policies in order to foster the diffusion of such technologies. It is however unclear how such policies can represent a welfare improvement i.e. if their social benefits are larger than their costs. This is already apparent considering the high costs of some measures decided in given countries (consider a 5000 € premium proposed in numerous European countries) and the high targets of this policy (consider the target of 1 million vehicles in 2020 set by the German government). Such high targets and heavy costs should not, in themselves, be a sufficient rationale for rejecting these policies but they strongly suggest that they should be submitted to rigorous assessment.

In order to assess the validity of these policy packages, one needs to establish a consistent evaluation framework based on a realistic representation of the mechanisms leading to the diffusion of electric vehicles and a comprehensive representation of the costs and benefits that accrue to the different actors.

In this paper, we present the main existing models for the simulation of diffusion and for the evaluation of electric cars together with the main findings of Cost Benefit Analysis. In a conclusive section we propose a number of guidelines for future developments.

2. Existing models and results

The literature regarding the diffusion of electric vehicles consists of several types of material: diffusion forecast (which typically provide the foreseen development of electric vehicles in a given context), models (that allow for large scale simulation of various policy scenarios), and evaluations (which provide results about the costs and benefits of policies). While these different materials should theoretically be interlaced, it is often found that they are quite distinct which makes it possible to proceed with our examination using this categorization.

Diffusion forecast

As far diffusion forecast is concerned, the available material mainly consists of simplified market penetration forecasts based, mainly, on the Bass diffusion theory (a methodology defined in Bass (1969, 2004) and used recently for instance in Becker *et al* (2009)) or ad hoc Stated Preferences surveys (Achtnicht, 2008; Dagsvik et al., 2002; Mabit and Fosgerau, 2011). Some other studies (mainly carried out in a professional rather than a scientific context) rely on the concept of Total Cost of Ownership (TCO), an approach that, sometimes with some more extra complications, substantially assigns the demand to the most economical technology (for a critic of cost driven decision process see Turrentine and Kurani (2006)).

Bass diffusion models are a way to model mathematically the speed at which the potential market of a given technology is achieved based on two types of behaviors: *innovation* and *imitation*. Stated Preferences surveys, as far as they are concerned, are based on surveys that propose to consumers hypothetical products (for instance a gasoline car with a given range and fuel costs, together with an electric car with different performances) and obtain information on how much consumer preferences are sensitive to the different features (for instance: range, fuel cost). This information is then used to simulate consumer purchase behavior when products with given characteristics are introduced in the market.

Forecast and evaluation models

Another important body of literature relates to models. **Errore. L'origine riferimento non è stata trovata.** indicates the most relevant models available to forecast and evaluate the diffusion of electric vehicles. Such models can prominently be illustrated by the U.S. project Transition toward Alternative Fuel Vehicles (TAFV: (Greene, 2001)) and its successor (AVID, (Santini and Vyas, 2005a)).

Table 1 – main existing models for the forecast and evaluation of electric car diffusion[1]

Model	**Country - Time frame**	**Type of model**	**Market diffusion approach**	**Observation**
TAFV (Greene, 2001) (and AVID), (Santini and Vyas, 2005b)	USA	Micro economic welfare maximization model	Discrete choice model. Coefficients derived from microeconomics and, partly, economic data	High level of resolution among technologies and fuel types
VISION (Singh *et al.*, 2003) (see also VISION CA)	USA- until 2050	Spreadsheet model	Exogenous market penetration assumption for different technologies	Diffusion pattern is strongly driven by numerous exogenous assumptions
Smart Garage (RMI)	USA 2010-2030	Spreadsheet model	Bass diffusion with exogenous 50 % potential	Strong focus on time pattern of battery reload
AECOM (AECOM Australia, 2009)	Australia Until 2040	Market penetration forecast	Synthetic Utility Function	
CalCars (Kavalec, 1996)	California 1994-2015	Market and policy simulation model	Nested multinomial logit for ownership and technology choice based on RP and SP data	
IPTS transport technologies model (Christidis et al., 2003)	20 developed countries: up to 2020	System dynamics	Weibull distribution based on costs, + Wood algorithm to take into account capacity constraints	Implemented in Vensim
Vector21 (Mock *et al.*, 2009)	Germany Until 2030	Extended TCO approach	TCO+wtp for “advanced vehicles”	Model includes 9 technologies and 900 customer types. BEV diffusion is exogenously limited (for instance to 50 % for small cars) to reflect range limitation
ASTRA (IWW *et al.*, 2000)	EU 27: until 2050	System dynamics model integrating macroeconomic transport and environment	Discrete choice model. MNL	Implemented in Vensim. Discrete choice calibrated on diesel/gasoline competition 1990-2006

[1] Other existing transport models were not considered in this table (for instance Transtools. Tremove) as they offer limited knowledge about.

Apart from these models, which concentrate on the market penetration, the literature also proposed a number of studies labeled as "cost benefit analysis" of electric vehicles. Most of the studies falling into this category actually use this terminology improperly, at least to our view, as they consider the costs and benefits to car users only (Simpson, 2006), or alternatively, the industry, or government agency (Kosub 2010), or sometimes omitting the externality component of the COBA (Draper *et al.*, 2008) negating the intrinsic holistic view of cost benefit analysis that should consider costs and benefits to society as a whole.

Some studies however take a broader view on the topic. Kazimi investigates the effect of electric and alternative fuel vehicles on air quality in the Los Angeles area and provides the $ value of the related benefits (Kazimi, 1997a; Kazimi, 1997b). This analysis does not, however, compare benefits against costs. Funk and Rabl analyses the private and social (= private + external) km costs of electric against gasoline and diesel vehicles in France (Funk and Rabl, 1999; Rabl, 2002). Their findings indicate that while the total costs of EV are higher than diesel, they are not generally lower than gasoline cars. Carlson and Johansonn-Stenman analyze the social costs and benefits of the introduction of Hybrid technology among small cars in Swedish towns (Carlsson and Johansson-Stenman, 2003). Their main finding is that, due to the difference in taxation between electricity and fuel, the development of EV will cost more to society than it will benefit (through the reduced environmental externality). Such results can however be found controversial. While their assumption of no burden cost of taxation is supported by solid arguments, their other crucial assumption that reduced tax revenues is a cost to society is controversial and not aligned with the standards of Cost Benefit Analysis as it constitute a mere transfer between economic agents[2]. Keefe, Griffin and Graham examined the private as well as the total (private + externalities) costs and benefits of new fuels in the US (Keefe *et al.*, 2007). The scope of their research for the current policy process is however limited in that they

[2] In a personal communication, the authors provide some arguments on why there approach would be valid even considering that taxation is fundamentally a transfer between agents.

consider hybrid vehicles (parallel to "advanced diesel", and E85) as the only electrified technology. Interestingly, their analysis aims at integrating novel elements in a Cost Benefit Analysis framework like: the impact of reduced oil consumption on US energy security, the rebound effect (increase in vehicle miles travelled when cheaper travelling technologies are made available). Their finding is that "*measured by NPV, the diesel is the most promising alternative*" a statement that would seem provocative in a number of contexts (as, typically, in European ones) but whose scope is limited for the current policy discussion due to the limited set of technologies considered and to the specificity of the Californian context.

PriceWaterhouseCoopers also produced Costs Benefit Analysis of EV fleet deployment in Austria (PriceWaterhouseCoopers, 2009). This study takes into account changes in taxation, imports, energy consumption, and infrastructure investments (charging stations, energy plants). While this study provides interesting insights (for instance showing that, in what can be understood as a no policy scenario, the effect of EV diffusion on public budget is substantially neutral), it fails to recognize the fact that COBA should treat as generally neutral transfers between agents[3] and erroneously associate costs and benefits to decrease/increase in general taxation.

In Australia, AECOM performed a simplified Cost Benefit Analysis of various policy scenarios in New South Wales (AECOM Australia, 2009). Costs relate to purchase and operating costs of the vehicles. Benefits relate to Green House Gas and mostly, air pollution. The three scenario policies that are considered can strongly increase the net benefits of electric vehicles diffusion. Such a result however constitutes a remote prospect as the Net Present Value of policies usually becomes positive only in years after 2030.

As can be observed from this synopsis of previous studies, the number of available analysis is quite reduced when considering the policy relevance of the issues and the number of countries which actually are considering Electric Vehicles policy. Apart from the general need of keeping up with the pace of technological development and to generate results in other contexts than the few investigated areas (Paris, Swedish towns, California,

[3] With a provision for second order effects as reflected for instance opportunity costs of public costs.

New South Wales, Austria, Australia) the existing results need to be complemented with further investigations.

First, one needs to take into account the linkages of Electric Vehicles development with further economic impacts, and with related (acknowledgedly speculative) employment effects. Policy makers have a strong focus on the so-called “indirect effects” and employment effects. In the absence of sound, micro-founded analysis, the policy making process can easily be occupied by fuzzy, policy driven, lobby produced figures which call for more rigorous analysis.

Second, there are some other issues on how “*global*” benefits like CO_2 emissions should be accounted for in a Cost Benefit Analysis with national scope.

Third, more fundamentally, few of these models (Aecom is an exception, Keefe as well but with the narrow perspective of the costs and benefits to a public agency) are really policy valuation tools that would compare the outcomes of policy scenarios with a properly defined reference scenario. Most of them concentrate on examining the impact of an (often exogenous) EV diffusion. So they evaluate the benefits of some (undefined) technology development while arguably, what is relevant is not what is the cost/benefit of the apparition of a new technology, but how a policy can improve welfare by influencing this development. What is needed is a tool that simulates the effects of policy packages based on a set of incentives consistent with the policy currently considered by policy makers (Kley et al., 2010).

3. Conclusion

In this paper, we have reviewed the existing models and results for the forecast of electric and alternative fuel vehicles and the evaluation of related policies. We have found that a number of models are available. They basically relate to three paradigms: TCO, SP surveys and Bass diffusions models with a limited number of additional, heterodox, approaches.

We found that most of the models available for the diffusion of Electric Vehicles relate to the North American context and/or provide limited insights into the relevant policy issues for European countries. Eventually we found that the Cost Benefit Analysis of Electric Vehicle policy is still incipient as, to our best knowledge, notwithstanding the quality and relevance of the works we have quoted in this article none of them constitute a satisfactory and comprehensive evaluation framework for EV policies in European countries.

This picture suggests that the community of applied economists should dedicate efforts to the extension of existing models focusing on a few features. Apart from the need to develop relevant and consistent evaluation tools, one can propose a number of modeling features that should be considered in order to make the diffusion mechanisms, and correspondingly, the policy recommendations, more realistic.

First, there is a general need to develop adequate modeling and evaluation tools for the European context: many of the existing models have been developed for an American context and provide little insights about the evolution that can take place in Europe.

Second, we find that a stronger focus should be made in the model development about market diffusion mechanisms. In many of the existing models, diffusion is exogenous, which makes it virtually impossible to make policy assessment. In other models, we find that the adequacy of the behavioral parameters is questionable: whether it is based on a given SP survey that can prove very idiosyncratic, or whether it is calibrated on a very limited set of data (like diesel/gasoline market shares). Additionally, one should consider how the diffusion theory insights should be integrated together with discrete choice models. There is a wide discrepancy between the meaning that marketing science gives to SP based market shares estimates and the meaning given to these estimates by transport scientists. How these two diverging approaches should be reconciled is still on the agenda of transport modelers and marketing scientists.

Third, one should consider that most of the existing models present limited interactions with the energy sector, while this sector will certainly be impacted by the development of EV and reversely some policy measures will probably be implemented through the energy sector (consider refueling stations). Similarly to energy sector, we also reckon that more attention should be dedicated to car industry and to the CO_2 emissions standard that this industry will have to face due to EU/443 regulation. Such a change in the regulatory setting is felt to be a major change in the car market and may constitute a strong input to EV diffusion. In this context it is fair to state that the modeling of EV diffusion should explicitly take into account the effects of this regulation on the car industry and indirectly on car market.

It is our view that, taking into account these indications, evaluation models could become a relevant tool for the definition of EV development policies in European countries.

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