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Hybrid Electric Vehicles: Some Theoretical Considerations on Consumption Behaviour

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Abstract: Solving the problem of the lack of environmental sustainability in transport activities requires the involvement of new technologies, particularly in populated cities where mobility activities play a major role in generating externalities. The move from cars powered by conventional internal combustion engines to cars powered by alternative energies can make an important contribution to reducing emissions and achieving a more sustainable transport system. Unfortunately, green car market development still remains uncertain because of the higher production costs of batteries and engines. In this context, surprisingly little attention has been devoted to analysing the economic factors affecting consumers' behaviour in the choice of hybrid electric vehicles. To fill this gap, the diffusion process of hybrid technology as well as intrinsic and extrinsic motivations and the crowding-out effect on consumers' purchasing decisions are taken under consideration. Finally, some policy recommendations are provided.

Keywords: transport sustainability; hybrid vehicles; technological innovation; consumer behaviour

1. Introduction

Environmental literature highlights that the impact of fossil fuel-based energy on the environment, particularly in terms of global climate change, has emerged as one of the biggest problems facing the planet [1].

In its last report (2014) [2] the Intergovernmental Panel on Climate Change (IPCC) concluded that "warming in the climate system is unequivocal, with many of the observed changes unprecedented over decades to millennia: warming of the atmosphere and the ocean, diminishing snow and ice, rising sea levels and increasing concentrations of greenhouse gases".

Despite the fact that a number of sceptics still continue to debate these propositions, and independently of their reliability, it is undeniable that this way of thinking has increased consumers' concern for environmental problems, slowly changing their efforts to save energy and pushing technological innovation to the top of the policy agenda of many countries' governments.

Environmental quality is a key issue, particularly in developed countries, due to the high value of natural resources as perceived by the population.

The sustainability of transport activities plays a key role for many cities and countries across the globe, because mobility activities generate relevant negative externalities for natural environments [1].

Moreover, agents lack economic incentives to adopt new "green" technologies that would reduce pollution levels as, in many cases, these agents are unmotivated to protect public goods such as the environment. Therefore, public intervention in the form of policies is needed to stimulate the adoption of environmentally-friendly innovations.

Nowadays, the increases in miles driven and the growth in the number of vehicles on the road offset the progress made towards cleaner engines.

In this context, alternative fuel vehicles play a key role in reducing greenhouse gas emissions. Still, market share still remains limited because of the production costs of the batteries and engines required by these vehicles [3].

In Europe in 2016, the percentage of new alternative vehicles (Liquified Petroleum Gas (LPG), natural gas, and Ethanol E85 fuels) was only 1.3%, whereas the share of diesel and petrol engines was 49.5% and 45.8%, respectively. The percentage of electric cars bought increased from the preceding year, going from 1.7% in 2015 to 2.1% in 2016 for hybrid electric vehicles (HEV) and from 1.4% to 1.5% for electrically chargeable vehicles (ECV). Thus, overall, a reduction in consumers' preference for traditional fuel cars and an increase in electric cars purchased was registered in 2016 (Figure 1).

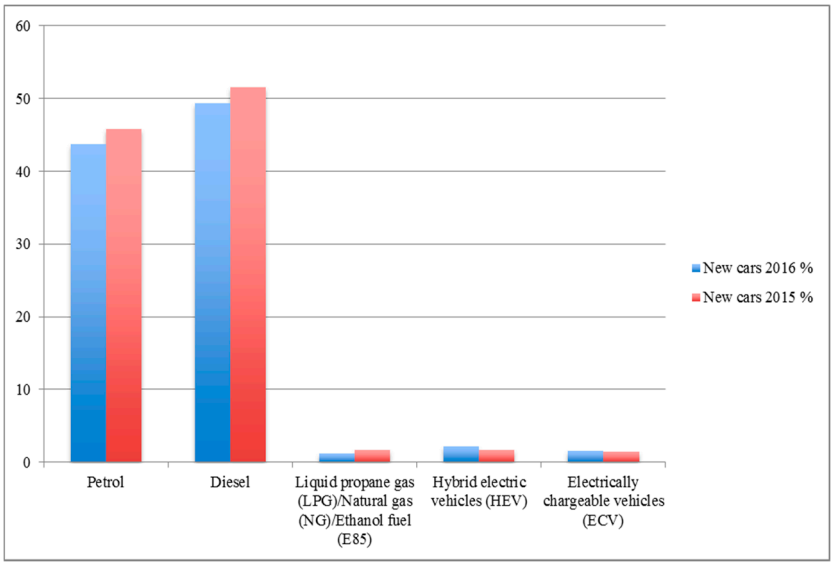

Figure 1. Distribution of cars by fuel type in European Union (EU) 28 (Years 2015 and 2016). Source: Our elaboration on Eurostat data.

The high price of green cars and the lack of refuelling/charging infrastructure, as well as long refuelling times and restricted driving ranges compared to conventional vehicles are, among others, some of the important factors that slow the development of the market for green cars [4].

The presence of network externalities can also cause inertia in the development and diffusion of green cars. Consumers are reluctant to switch to a new vehicle if refuelling/charging infrastructures are not widely available and, of course, will prefer conventional technologies if refuelling stations are abundant [5].

Nonetheless, new technological progress and innovative business models are emerging and many environmentally conscious consumers increasingly choose to purchase green cars and, in particular, electric hybrid vehicles.

One of the simplest ways to extend the range of an electric car is to carry fuel and an efficient combustion engine on-board to generate extra electricity when needed. Hybrid vehicles run on a conventional internal combustion engine and are equipped with an electric propulsion system. These cars also use regenerative brakes in order to charge the battery, converting kinetic energy to electrical energy. Hybrid electric technology also generates less pollution because a hybrid gasoline engine is usually smaller than a pure gasoline one.

This paper is organized into six sections, the first being this introduction. The next section gives an overview of the relevant literature related to the choice of alternative fuel vehicles. In Section 3, we discuss the possible determining factors of consumers' willingness to pay for hybrid electric

vehicles. In the fourth and fifth sections the theory of diffusion of innovation and the different types of consumer purchasing motivation are described and adapted to the hybrid vehicle case. Section 6 concludes with some important policy recommendations.

2. Methodology Used in Literature Analysis

In the last 10 years, many studies devoted to analysing consumer preferences in adopting electric vehicles have been produced. These can be divided into two main groups. The first one is mainly focused on analysis related to defining which experimental design and modelling techniques are more suitable in predicting consumer behaviour [3,6,7]. The second group is focused on defining which attributes mainly affect consumers' preferences when they choose among different vehicle propulsion systems (fuel, gasoline, gas, hybrid, etc.) [8–11].

From the methodological point of view, almost all of the authors use the stated preference (SP) model to analyse and predict the behaviour of consumers when they face a choice between traditional and electric vehicles [12–14].

Another group of studies is mainly focused on the analysis of variables that influence consumer choices. These studies generally include different kinds of variables considering technical aspects of the power system used by a car [5,15], financial aspects such as vehicle costs [3,16], savings in operating costs, etc. [8,17], and the availability of infrastructure to recharge the cars [10,18].

In this paper, differing from other literature, we deal with some socioeconomic considerations of consumer behaviour related to the purchase of a hybrid vehicle. So, in order to give an idea of the relevant literature on this specific topic, we carried out a systematic literature review of the Scopus database using the Boolean search parameters "hybrid + vehicle + demand OR hybrid + vehicle + consumer+ behavior". Through this search, we sought to find the literature concerning two different kinds of problems in the adoption of hybrid vehicles. The first problem concerned the identification of papers that apply traditional literature from the field of technological diffusion to the hybrid vehicle sector. The second concerned understanding which variables affect consumers' behaviour when facing the purchasing choice of an expensive durable good. In this regard, it should be noted that hybrid vehicles incorporate a new technology with many uncertain endpoints regarding its quality and future maintenance costs.

The literature review returned a huge number of documents, 3335 in total. To narrow down the documents to be analysed we introduced two more parameters: the language, "English", and the document source, "journals"; in this way we reduced the number of documents to 1482. Since this number of documents was still too large to analyse, we concentrated our research on the title, abstract, and keywords, in this way obtaining 30 documents containing the words "hybrid + vehicle + demand OR hybrid + vehicle + consumer + behaviour".

Analysing the contents of the 30 documents, we found that only 27 of them were economic papers that analysed consumer demand for alternative-fuel vehicles. In Table 1, we report the most significant papers that have a Scopus index and that are classified as papers published in journals. Moreover, we grouped in the table the considered papers according to the model used and summarised the type of research performed (empirical, theoretical, and so on) and the year of issue in order to present a clear idea of how the research in this field has evolved in the last decade as well as the different directions that it has followed.

Table 1. Economic papers related to consumer demand for vehicles with alternative fuel grouped according to the employed models.

Number of Paper	References	Year	Type of Research
Stated Preferences			
1	[4]	2018	Empirical
1	[6]	2017	Empirical
2	[8,19]	2016	Empirical
1	[15]	2015	Empirical
1	[9]	2014	Empirical
3	[10,20,21]	2013	Empirical
2	[18,22]	2011	Empirical
1	[11]	2010	Empirical
1	[17]	2008	Empirical
1	[12]	2007	Empirical
1	[16]	2005	Empirical
1	[7]	2004	Empirical
1	[23]	2002	Empirical
Results Comparison among Different Kinds of Models			
1	[3]	2015	Empirical
Regression Analysis			
1	[24]	2018	Empirical
1	[25]	2011	Empirical
1	[13]	2007	Empirical
Ownership Cost Model			
1	[26]	2013	Empirical
Nested Logit			
1	[27]	2012	Empirical
Microsimulation			
1	[5]	2016	Empirical
1	[28]	2014	Empirical
Environmental Propensity Framework			
1	[14]	2010	Empirical
Paper Description			
1	[29]	2017	Review
1	[30]	2016	Review
1	[31]	2013	Review
Meta data analysis			
1	[32]	2013	Review

Table 1 clearly shows that almost all of the analysed economic literature related to consumer behaviour when purchasing an alternative fuel vehicle is focused on empirical work, and that the main techniques used are stated preferences or a discrete choice analysis. This literature gap generates an incomplete empirical model to explain the effective process that causes a consumer to choose a hybrid vehicle. In a similar situation, it is hard to answer questions such as: is it possible to treat hybrid vehicles as public goods so that we can hope that public intervention will favour its diffusion? What kind of public intervention can guarantee a higher diffusion rate of hybrid vehicles? Should governments implement better policies to reduce consumer information asymmetries? Or, is it better to undertake measures to encourage hybrids through tax benefits? And so on. On the other hand, the producer may have different alternatives to foster the sale of hybrid cars. For example, they may rely on advertising and, in more general terms, on marketing to increase the consumer information about the advantage of hybrids or increase the after-sales assistance to reduce the risk involved

in acquiring a durable good that incorporates a new technology with a high degree of uncertainty about quality.

In the following sections, we attempt to describe, from a theoretical point of view, the major factors that influence consumers' willingness to pay for hybrid vehicles in order to gain a better understanding of what may be the most appropriate policies for encouraging their diffusion.

3. Hybrid Electric Vehicles: An Alternative

Cars are infrequently bought and are considered expensive durable goods. Therefore, considering that it may cost a lot to rectify a wrong choice, consumer choice is a high-involvement process. Consumers will ponder different factors and dimensions, such as price, running costs, performance, aesthetics, fuel economy, and emissions [33].

Many studies on purchasing decisions regarding green cars have primarily focused on fuel cost and public incentives. Caulfield et al. (2010) [11], for example, found that one of the main reasons behind the decision to buy these vehicles is the reduction in fuel costs, whereas Ozaki and Sevastyanova (2011) [18] reported that financial incentives are the key motivating factor in purchasing. In the same paper, using a survey of drivers of hybrid vehicles, the authors found that car performance attributes (such as quietness and comfort of driving) are also important factors influencing consumers' choices. In the evaluation process, the probability of adopting a car crucially depends on these characteristics, and will be relatively higher when they address the well-established decision parameters of a consumer.

It might be useful to describe this concept using the standard microeconomic theory of utility maximization. For this purpose, let us indicate the consumer facing the choice problem by i and the set of alternatives she faces by Ω_i. Let us denote the vector of all relevant characteristics of vehicle x as faced by consumer i with the symbol $\omega_{i,x}$.

In addition, the utility of purchasing a car also depends on a vector θ_i which describes the personal characteristics of the decision-maker, such as income, age, education, family size and household composition, type of personality (conformist or innovative), personal attitudes toward environmental problems, and so on. It seems obvious to expect that an innovative environmentalist will have a higher willingness to pay for a hybrid vehicle than a conformist non-environmentalist consumer [13].

Knez [9] and Carley [10], among others, found that the higher the age, the education, and/or the income of the consumer, the higher the probability of a hybrid purchase.

Moreover, since there is asymmetric information and a lack of product knowledge about hybrid cars, a risk adverse individual will be less likely to adopt this new technology [14].

Given the fact that a hybrid vehicle is perceived as a risky durable good, the consumer's objective is to maximize the expected discounted value of the utility level gained over the years of the product's life expectancy. Of course, a consumer will ponder the purchase of an alternative only if this discounted utility net price level is positive (i.e., the consumer surplus). It seems, therefore, also appropriate to incorporate in this evaluation process a vector λ_x of financial incentives and policy instruments related to vehicle x. Incentives and policy instruments are developed to encourage the adoption of alternative vehicles. We can distinguish between monetary incentives (for example, a purchase bonus and subsidies, or the reduction or exemption of certain taxes, such as registration and circulation taxes) and non-monetary incentives (road toll exemptions, free parking, free public charging) [12,25].

Therefore, the utility level of consumer i of purchasing alternative x can be written as a function of these relevant sets of factors as follows:

$$U_{i,x} = U(\omega_{i,x}\ ,\ \theta_i, \lambda_x) \tag{1}$$

Given the price of alternative x, p_x, we can then assume that driver i will certainly choose automobile x in Ω_i if and only if:

$$U(\omega_{i,x}\ ,\ \theta_i, \lambda_x) - p_x \geq U(\omega_{i,y}\ ,\ \theta_i, \lambda_y) - p_y \tag{2}$$

for all x and y in Ω_i. In other words, a consumer will choose an alternative only if its discounted utility level net price is the highest, compared with the other available alternatives.

Based on the previous relation (Equation (2)), we can derive the aggregated demand function for hybrid electric cars for a given market. Denoting the hybrid electric alternative with the letter h, for a given population, the aggregating demand for alternative h is defined as:

$$D_h = \#\{i : (U_{i,h} - p_h) > (U_{i,x} - p_x)\} \quad (3)$$

where the aggregating demand, D_h, is equal to the cardinality of the set, which is the sum of all the consumers that have the highest surplus in purchasing a hybrid alternative.

Given this reasoning, we can further investigate the determinants of the market share of hybrid electric vehicles:

$$S_h = f(\omega_h,\ p_h,\ \lambda_h,\ \overline{\theta}) \quad (4)$$

where the hybrid market share, S_h, is still a function of the attributes, price, and financial policy instruments of the hybrid vehicle, but the consumer's preferences and socioeconomic characteristics are now replaced by the characteristics of the overall population of the country/market being analysed, and so the vector $\overline{\theta}$ will list the average income, the average education level, the average environmental sensibility, and so on.

It is clear that all of the factors that positively or negatively influence individual demand for hybrids will also have the same kind of effect on both aggregate demand and market share.

To date, car consumers have not been truly satisfied by the performance of hybrid vehicles regarding speed, acceleration, and cruising range. Even though there is an evident environmental awareness, the market share of hybrid vehicles is still limited because of the small demand segment [16] that considers gas emissions and fuel efficiency as the main characteristics of the cars. However, the improvement of new models accelerates market penetration and will probably make the take-off of this technology possible [28].

If the rate of diffusion of hybrid vehicles increases, the technology could make a difference in terms of emissions and energy consumption [6].

At the moment, hybrid cars are a small but growing share of the vehicle fleet. In order to increase this share, it is necessary to know what characteristics are influencing consumers' decisions when they choose to buy hybrids rather than conventional vehicles. Why do people buy hybrid cars? Even though some network effects still remain (as an example of network externality, higher hybrid penetration may lead to more mechanics able to service hybrids, which would lower their cost and increase adoptions), the crucial factors that really make the difference in the relation (Equation (2)), and thus in market share, are costs (including purchase price and running costs) and personal attitude towards the environment [34].

Generally, hybrid cars are more expensive than conventional vehicles. Moreover, energy cost savings can hardly offset the price difference. Hence, according to a rational behaviour decision-making process, a consumer should not buy a hybrid car and economic theory should predict little interest for this market. On the contrary, hybrid demand is very high compared with other green cars, giving reason to assume that, in the near future, market share will experience further growth, as more models are offered and production costs are expected to decline due to learning and scale benefits. For these reasons, analysts are confident that hybrid technology will surely play a key role in determining an environmentally sustainable transport solution.

Because hybrids are a newer pro-environmental technology, we briefly introduce the theory of diffusion of innovation below. In addition, two important types of consumer motivations are described.

4. Theory of Diffusion of Innovations

According to a seminal paper by Rogers (1962) [35], the diffusion of innovations is a social process in which individuals create and share information through communication. In other words, through

diffusion, an idea or an object perceived as new is disseminated over time among the members of a social system. Moreover, different social systems have different innovation values and beliefs, which will influence the costs and benefits of innovations. Innovations are adopted in a sequence and actors can be distinguished in terms of time of adoption. The degree to which an individual is relatively earlier in adopting new ideas compared to other members of a system is defined as "innovativeness". Rogers (1962) [35] categorized the adopting population into five classes: innovators, early adopters, early majority, late majority, and laggards.

Typically, "innovators" are a small fraction of highly educated, risk-loving individuals who can easily embrace new ideas. The "early adopters" are opinion leaders, disseminating information for a larger social network. These two groups generally have a great concern for environmental issues. Once they have received information from their peers, the categories of "early" and "late majority" take more time over the decision-making process. Finally, "laggards" are rather risk-adverse in their consumption behaviour, with low financial resources and/or with very limited social interactions and a very slow decision-making process.

The communication process is the core element of the diffusion process related to information concerning hybrid vehicle characteristics and quality. Once opinion leaders are informed via the mass media, they then inform and persuade the masses. For technology to diffuse throughout society as a whole, in this context, social networks are of central importance. As shown in the approaches used in traditional literature, innovation and former technologies are compared to alternatives and the relative advantage of a new technology is a crucial factor influencing its adoption, encompassing characteristics such as social status and market price, thus increasing its probability of adoption.

However, consumers are heterogeneous in terms of motivational states and attitude towards environmental problems; in this respect, Rogers' model falls short. Assuming a normal distribution of individual thresholds to adoption and normally distributed intrinsic motivation intensity towards environmental issues, the diffusion process will typically show an S-shaped curve.

An important issue concerning the adoption of environmentally-friendly behaviour regarding consumption is related to the incentives that drive the consumption decisions of leading consumers. To investigate this, we next introduce two different types of motivation: intrinsic and extrinsic motivation.

5. Intrinsic, Extrinsic Motivations and the Crowding-Out Effect

Intrinsic motivation appears to be an important reason why environmentally-minded consumers adopt eco-friendlier products [36,37]. Strictly following Deci's definition, "to be intrinsically motivated means to engage in an activity because the activity itself is interesting and enjoyable" [38], i.e., an individual is moved towards making a choice for behavioural motives coming from the inner person (inner feelings, morality), rather than because of external reward or financial incentives. If actors are strictly concerned about the environment, consumer behaviour can be driven by environmental morality even if it means an increase in cost. Moreover, the literature highlights that the use of communication supporting and reinforcing environmental morality can amplify intrinsic motivation [39].

Extrinsic motivation is related to the type of behaviour described in standard economic theory. Consumers are assumed to base their decisions on expected payoffs and, in this sense, a choice is made in order to attain some separable outcome. It is also possible that extrinsic rewards such as popularity, image, or social status may be a more relevant reason for some consumers to adopt environmentally friendly products, e.g., Griskevicius et al. (2010) [33], Jansson et al. (2009) [40], Clark (2003) [41]. This is not to say that these consumers do not possess intrinsic motivations, but that extrinsic reasons appear to play a more powerful role in their decision-making process. Financial measures, such us subsidies that lower the relative cost of a pro-environment product, can induce individuals to adopt green technologies. Polluting behaviour can be corrected through the threat of deterrence even though, as previously stated in Section 3, age, education, and income greatly affect the probability of a hybrid purchase [9,10].

One of the main problems with this system of extrinsic incentives is that actors may start to base their behaviour on the belief that they have the "right" to pollute if they bear the associated financial cost. The crowding-out effect may then intervene since any intrinsic motivation to protect the environment could be "crowded out" by a strictly monetary logic.

Moreover, environmental issues may then not be the only reasons to switch to an energy-efficient car, whereas a subsidy may push a consumer to purchase an energy-efficient car. Even if, in the short term, consumers attribute their behavioural changes to either incentives or to intrinsic motivation, in the long term other effects may arise. If consumers chose a car in order to obtain a financial reward or avoid a punishment, they will probably stop this behaviour if the financial incentive is removed. For instance, if people purchase a green car in order to get a subsidy, they are not likely to purchase another energy-efficient product without a subsidy. On the other hand, if consumers purchase a green car in order to save the environment, they are more likely to purchase other energy-efficient products for the same reason.

Finally, policy-makers would benefit from considering both intrinsic and extrinsic factors in environmental policy. Policy intervention should crowd out the intrinsic motivation controlling them or giving the impression that they have acknowledged the problem [24]. Moreover, if people participate in decision-making, intrinsic motivation also increases. This suggests that legal and financial tools should be as "democratic" as possible.

6. Conclusion and Policy Recommendations

The diffusion of full electric vehicles may play a major role in reducing environmental pollution and neutralizing the impacts of fossil fuel-based energy, particularly in urban areas.

From a pro-environmental point of view, people consider full electric vehicles to be more sustainable than hybrid vehicles, given that the latter still create some air-polluting emissions while driving [34]. Around the world, policy-makers implement new strategies in order to increase the market share of green cars. Nevertheless, the purchase price and other costs over the ownership period and the limited range of battery are, among others, major factors that inhibit the market diffusion of full electric cars. Moreover, economic and technical attributes have a major impact on consumers' choice.

As reported above, the main techniques used to analyse consumer behaviour for alternative fuel vehicle purchasing are stated preferences or a discrete choice analysis.

It is also unquestionable that hybrid electric cars are, in turn, a superior pro-environmental alternative to traditional cars and could play an important role in the transition to a more sustainable transportation system.

Currently, we believe that a transportation system based on hybrid technology could be, in the midterm, even more sustainable than a transportation system based only on full electric vehicles. First of all, a relatively rapid massive diffusion of full electric vehicles in our society would likely create extra demand for additional electric power generation, far beyond what the electric power generating industry can provide with its current generating capacity. Second, if in the meantime the current electric power generating industry fails to switch to more sustainable energy sources and continues with the prevalent use of fossil fuels, such a transition would result in much more adverse environmental consequences. In this sense, the diffusion of hybrid electric vehicles can be seen as an intermediate step towards the full sustainability of both the transportation and electric power systems [42].

Now, the crucial question is: are hybrid cars destined to be a niche market, adopted by only a small fraction of the environmentally conscious population, or will they, sooner or later, become the standard?

To date, in many countries—with the only exception being Japan, which has the world's highest market penetration—the process of adoption of new hybrid technology is still the preserve of the first two groups of "innovators" and "early adopters". At this stage, the best policy to encourage hybrid car market penetration should be based on enhancing awareness of and social concern about the threat

of climate change combined with clever marketing and communication campaigns to promote hybrid vehicles as a possible mitigation of that problem. It is important to highlight that the knowledge of consumer preferences should contribute to making policy strategies more effective and efficient.

The transition from "innovators" to "early adopters" (often called "crossing the chasm") status is a key stage that can determine the success or the failure of a new technology. Unlike monetary tools, information policies do not run the risk of crowding out intrinsic pro-environmental motivation, so at this key stage of the diffusion process, governments should provide information to foster intrinsic motivation and limit the use of tax credits and subsidies in order to partially mitigate the higher initial purchase prices of hybrids. As time passes and the diffusion of hybrid cars reaches the "early" and the "late majority", it will be possible to introduce strong financial incentives. At this point, given that the intensity of consumers' intrinsic motivations decreases, it is unlikely that a crowding-out effect will occur. In this stage, governments should combine information policies and financial incentives to finally help hybrid technology take off. Finally, given that all intrinsically motivated green consumers have already "democratically" switched to hybrid technology, the government can surely also use legal devices, such as taxing the use of conventional vehicles or punishments to persuade "laggards", or, as many governments are now planning, drastically banning the production and sale of vehicles powered only by fossil fuels.

As it has previously been pointed out, the few analyses that have been performed on this topic do not provide a clear-cut answer to questions about the benefits of public intervention in order to promote the diffusion of hybrid vehicles.

In light of the findings reported in this study, we conclude that, nowadays, hybrid cars have a growing share of the market. In order to increase the market penetration of these cars, it is necessary to analyse consumers' behaviour in their choice to buy hybrids rather than conventional vehicles. Our results show that the crucial factors making the difference are total costs, comprising purchase price and running costs, while personal attitude towards the environment plays a secondary role. However, the issue needs to be further investigated in order to better inform policy-makers.

Finally, our prospective study will concentrate on further analysing the findings generated in this manuscript by undertaking cross-country comparative research.

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