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How to accelerate the uptake of electric cars? Insights from a choice experiment

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ABSTRACT

Battery electric vehicles (BEV) are widely regarded as crucial to decarbonising the transport sector and achieving the Paris Agreement goals. Yet, there is much political controversy over how to accelerate the uptake of BEVs, which is currently still rather slow in most countries. The most important controversy concerns the extent to which consumer-oriented policy measures, such as purchase price subsidies, tax breaks and subsidised charging infrastructure are needed. Based on a large-scale (n = 1′021) choice experiment, we examined the relevance of a broad set of potential obstacles and drivers of BEV uptake from a consumer perspective. Obstacles include purchase price, energy costs, maintenance costs, warranty, and range. Potential policy measures for overcoming such obstacles include, e.g., free public transportation tickets and car exchanges, government subsidies, warranty periods, and charging infrastructure. Our main finding is that current key obstacles to BEV uptake are primarily economic and technical. It implies that disruptive measures such as banning fossil-fuel cars as well as supply-side policy interventions could help push the car industry into rapid technological innovation, and that economies of scale in BEV production may be more effective than governmental measures aimed at incentivising BEV uptake.

1. Introduction

Mitigating climate change requires rapid and large scale societal action at all levels, from global to individual, if the 2 °C target is to be met within the next few decades (Elmqvist et al., 2019; IPCC, 2021). One of the focal points in mitigation efforts is the transportation sector, which is responsible for one third of total CO_2 emissions globally (IPCC, 2021; Lamb et al., 2021; Nejat et al., 2015). Motorised private transport accounts for almost half of this emission share (IPCC, 2021). Switzerland, on which we focus empirically in this paper, is representative of this global pattern (Federal Office for the Environment (FOEN), 2020). Besides their substantial impact on global climate change (Creutzig et al., 2015, 2018; Howey, 2011; Lamb et al., 2021; Lelieveld et al., 2015), transport-related emissions also have severe local impacts on human health and the environment (Nieuwenhuijsen, 2018; Victor et al., 2019).

Transitioning from internal combustion engine vehicles (ICEVs) to battery electric vehicles (BEVs) can significantly reduce transport-related energy use and, especially if BEVs are charged with electricity from renewable energy sources, their emissions (Creutzig et al., 2018; Koppelaar and Middelkoop, 2017; Zhang and Fujimori, 2020). While BEV technology has made rapid progress over the past few years, its uptake has been very modest in most countries (Almeida Neves et al., 2019; Javid and Nejat, 2017). For example, the share of BEVs in new passenger car registrations in Switzerland was only around 13% as of 2021, and the total percentage of BEVs in the Swiss car fleet was around 1.5% (Swiss Federal Statistical Office (SFSO), 2022). Globally, the International Energy Agency (IEA) targets a vehicles market share of 30% for electric vehicles in 2030 (IEA, 2020), whereas the current share is only around 3% worldwide (Krishna, 2021).

Various policy interventions are being considered and/or implemented in efforts to address obstacles to current BEV uptake, such as high purchase prices, few charging opportunities, and limited vehicle ranges. Political controversy in this respect has focused mainly on whether governments should intervene by steering individual behaviour in this area at all or whether this should be left to market forces as BEVs are becoming cheaper due to technical innovation and economies of scale. The ongoing debate has also focused on how, if at all, governments should approach this challenge from a policy tools perspective. This concerns, for instance, whether policymakers should enact push or pull measures. Push measures seek to make non-BEVs less attractive and pull measures seek to make BEVs more attractive. Existing research suggests

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that pull policies, e.g. policies to reduce purchase prices or offer more charging opportunities, tend to attract more public support than push policies and may thus contribute to higher BEV adoption rates (Brückmann and Bernauer, 2020; Hardman, 2019; Rietmann and Lieven, 2019; Wicki et al., 2019). But whether such measures suffice depends on consumer behaviour. Conversely, more intrusive push policies, such as banning fossil-fuel cars, might in principle be more effective in accelerating BEV uptake but have been shown to face more public opposition.

Our paper adds to existing research by identifying potential (joint) causal effects of political, technical, and financial factors on attitudes and purchasing intentions with respect to BEVs. Existing studies on consumer attitudes and behaviour towards BEVs have focused primarily on individual determinants of such attitudes, such as factors related to costs, experiences, technologies, and contexts – mostly based on correlational study designs (Wicki et al., 2022). The main research gap our paper thus addresses is that the lack of experimental (and thus causal inference, rather than correlational) studies to jointly assesses the main barriers and drivers concerning attitudes and purchasing intentions with regards to BEVs, including BEV characteristics and contextual factors.

In our experiment, study participants encountered sets of two BEV proposals, shown side-by-side, and were asked to compare the two offers and then systematically express what car they prefer to acquire. We presented the BEV proposals in terms of ten particular properties (attributes) of BEVs that can be affected by the car industry or policymakers and that are widely regarded as relevant to attitudes towards BEVs in the existing literature.

We implemented the conjoint experiment with a representative (random) sample of N = 1′021 residents from the Canton of Zurich, Switzerland, the most populated Swiss state. Switzerland is particularly interesting for our study for several reasons. Firstly, Switzerland is among the worst performers in Europe regarding vehicle emissions (European Environment Agency, 2017). Secondly, it also has a high vehicle density as well as very high external costs (in the order of 8 billion Swiss Francs per year[1]) of road-based transportation (Federal Office for Spatial Development, 2019). Thirdly, currently low BEV adoption rates are puzzling, given high income levels in the country. Most daily trips are within comfortable reach for most currently sold BEVs (Melliger et al., 2018). Finally, the excellent public transport (P.T.) network allows substituting the car for a combination of local and long distance trains (Petersen, 2016).

The remainder of the paper is structured as follows. We start by discussing the existing literature and present a set of arguments to be evaluated empirically. We then outline the empirical case and present our study design and the data collection process. This section is followed by a presentation and discussion of the empirical findings and a concluding section.

2. Literature review and theoretical expectations

To assess the pool of existing knowledge on factors affecting BEV uptake, we carried out a literature review to identify key challenges and barriers of BEV uptake. Specifically, we focused on consumer attitudes and behaviour when purchasing BEVs. Key aspects driving individual decision behaviour and purchasing intentions that were robust across different study settings are predominantly BEV-specific characteristics or policies. However, to the best of our knowledge, they have not been addressed collectively as also recent meta-analytical evidence shows (Wicki et al., 2022). In the following, we derive theoretical expectations on both aspects based on existing literature to study how BEV-specific characteristics, such as costs, and policies that aim to foster BEV adoption jointly affect consumer attitudes and behaviour.

When consumers decide whether or not to purchase BEVs given specific market offerings and policies, their attitudes on BEVs tend to be the most important factor (Wang et al., 2021). Several reviews and meta-studies have looked into the effects attitudes, concerning BEVs, are likely to have in this regard (Coffman et al., 2017; Daramy-Williams et al., 2019; Hardman et al., 2018; Li et al., 2017; Liao et al., 2017; Rezvani et al., 2015; Wicki et al., 2022). These attitudes are formed based on BEV-specific and context specific factors (Wicki et al., 2022). BEV-specific factors can be both of a technical or cost-related nature. Existing research has looked at several drivers of BEV adoption, such as (1) costs, (2) charging infrastructure, or (3) driving range.

(1) Both purchasing and operational costs are among the most discussed factors in the existing literature on BEV purchasing intentions and behaviour. First, a higher purchase price negatively affects the willingness to pay for, or buy, a BEV (Austmann and Vigne, 2021; Berkeley et al., 2018; Brückmann et al., 2021b; Carley et al., 2019; Rezvani et al., 2015). The relatively higher purchase price is one of the key obstacles among current users of fossil-fuelled cars (Haustein and Jensen, 2018; Nielsen and Haustein, 2018). Second, most studies also identified a negative relationship between higher operational costs (primarily measured in energy costs, e.g. per distance or fuel prices) and BEV acceptance (DellaValle and Zubaryeva, 2019; Liao et al., 2017; Singh et al., 2020). Previous findings show that these operational costs, as they do for ICEVs, predominantly negatively affect BEV acceptance. Some studies also examined the effects of maintenance costs, e.g. energy costs and costs per distance (Mabit and Fosgerau, 2011). Besides, Jensen et al. (2013) found that BEVs' fuel costs appear significantly more critical than fuel costs of conventional vehicles. However, consumers' attitudes might be irrationally informed as research shows that the total cost of ownership (TCO) for BEVs is likely lower than for conventional vehicles (Hagman et al., 2016).

(2) Longer charging time is predominantly negatively associated with BEV attitudes (Hackbarth and Madlener, 2016; Higueras-Castillo et al., 2020; Kim et al., 2020; Ščasný et al., 2018). While only few studies explicitly distinguish between slow and fast charging, when they do, results indicate that fast-charging stations play a more important role in shaping attitudes (Bockarjova and Steg, 2014; Helveston et al., 2015). Similarly, the availability of charging infrastructure has a predominantly positive effect on attitudes towards BEVs (Danielis et al., 2020). Several authors conclude that more public charging infrastructure is needed to alleviate concerns about the BEV range and promote BEV adoption (Brückmann et al., 2021b; Brückmann and Bernauer, 2020; Sommer and Vance, 2021). Similarly, the availability of charging infrastructure has a predominantly positive effect on attitudes towards BEVs (Coffman et al., 2017; Danielis et al., 2020; Liao et al., 2017; Nazari et al., 2019).

(3) Another highly studied determinant in the existing literature is BEVs' (perceived) driving range. Recent studies from various countries find a positive association between a higher driving range and pro-BEV attitudes, indicating that the perception of driving range of BEVs is seen as a disadvantage compared to conventional vehicles (Lim et al., 2015; Melliger et al., 2018; Pevec et al., 2020; Rommel and Sagebiel, 2021; Schneidereit et al., 2015; Tarei et al., 2021).

Policy measures affecting BEV purchasing intentions may vary and usually promote BEV uptake by helping to overcome higher up-front purchase prices, range anxiety and long charging times. Existing studies have examined government financial support (subsidies) to lower vehicle purchase prices and policies to increase public charging infrastructure (Brückmann and Bernauer, 2020; Coffman et al., 2017; Egbue and Long, 2012). More generally, the existing literature often categorises policy interventions in this and other policy areas into push

[1] As of March 2022, 8 billion Swiss Francs equal 7.8 billion Euros and 8.5 billion U.S. Dollars.

and pull measures (Brückmann and Bernauer, 2020; Cools et al., 2012; Eriksson et al., 2008; Gärling et al., 2002; Piatkowski et al., 2017; Thorpe et al., 2000; Wicki et al., 2019). Push measures are those that impose costs or other inconveniences on undesirable behaviour (in our case owning and using a conventional motorised vehicle). Examples include higher fuel or vehicle taxes, or restrictions on vehicle access to city centres. Pull measures seek to make BEV adoption more attractive. Examples include purchase price subsidies, or more and cheaper charging infrastructure. Various studies show that push policies tend to receive less public support than pull policies (Brückmann and Bernauer, 2020; Huber and Wicki, 2021; Wicki et al., 2019).

Accordingly, Brückmann and Bernauer (2020) find strong public support for installing public charging stations, which could also help in accelerating BEV uptake (Coffman et al., 2017). Wang et al. (2017) find the most substantial effects for policies such as high occupancy vehicle lane access for BEVs or dedicated parking spaces and no restrictions from the even-and odd-numbered license plates scheme in their study with interested people in China. Further issues emerge with resale value and the so-called mobility guarantees (Liao et al., 2019; Lim et al., 2015). Perceived risks in resale value could be reduced, for example, through buy-back guarantees or some kind of insurance against the risk of unexpectedly high depreciation to bring BEV depreciation rates in line with those of conventional cars.

Many studies also emphasise the importance of other mobility tools as well as policies targeting alternative mobility modes in order to make BEVs more desirable, such as multiple cars (Brückmann et al., 2021b; Fevang et al., 2021) and carsharing memberships (Brückmann et al., 2021b). However, the results are mixed, as carsharing at the moment seems unable to meet the demand for vehicles (Sprei and Ginnebaugh, 2018).

Existing research on various factors affecting BEV uptake is rather extensive. The overview provided here only addresses a fraction of these studies (for more detailed reviews on different drivers of BEV uptake, see (Coffman et al., 2017; Daramy-Williams et al., 2019; Hardman et al., 2018; Li et al., 2017; Liao et al., 2017; Rezvani et al., 2015; Wicki et al., 2022). Overall, however, the existing literature does not offer a comprehensive assessment of the extent to which a wide range of BEV-specific characteristics and policies jointly and causally affect attitudes and purchasing intentions towards BEVs. In this paper, we contribute to filling this gap by relying on a conjoint experiment that jointly assesses the main barriers and drivers for BEV uptake. To the best of our knowledge, this study is the first assessing the causal effects of a wide range of both BEV-specific features and consumer-oriented policy measures on attitudes and purchase intentions for BEVs.

3. Method

3.1. Research methodology

Our empirical research relies on a study design based on a conjoint experiment implemented within an online survey (Hainmueller et al., 2014). In conjoint analysis, survey participants are given two or more options to choose from that have different characteristics. These options then have to be compared, whereby several product features (also called attributes), that differ in their characteristics (i.e., their associated attribute levels) are weighed against each other simultaneously, and one has to decide on a product in the end. A statistical evaluation is then used to calculate the part-worth of the individual product features and the price.

In our conjoint experiment, survey participants are asked to compare different BEV purchase offers, each consisting of varying BEV-specific attributes and contextual factors. Conjoint experiments are useful for studying the causal effects of multiple variables (in our characteristics of BEV purchase conditions) in decision-making processes (Hainmueller et al., 2014). In our conjoint experiment, respondents were asked to compare and choose between sets of two BEV purchase offers that are characterised by ten BEV-specific features and contextual conditions. The order in which the ten attributes (the equivalent of explanatory variables, each of which can have a range of values) were presented to respondents was randomly assigned. So were the values on each attribute (for more details, see below). In this study design, the preference for one or the other BEV purchase offer, as expressed by respondents in response to the BEV offers, they look at and compare, is the outcome variable to be explained. The attributes of the offer constitute the explanatory variables. The experimental nature of the study design stems from the fact that the ten attributes of BEV purchase offers and the specific values or expressions on each are not empirically observed but are experimentally manipulated and randomly assigned. This approach allows us to draw causal inferences about how each attribute individually, relative to the other attributes, and how all attributes jointly affect BEV attitudes and purchase intentions.

While there is no fixed rule for conjoint experiment iterations, about 4–8 iterations are common in current literature. By iteration we mean the number of times study participants are asked to compare a set of two BEV purchase offers. Hainmueller et al. (2014), for example, used six iterations. Wicki et al. (2020) used five iterations. Generally, research has shown that a substantially larger number of iterations would still not change the results (Bansak et al., 2021). Therefore, we choose four iterations with the response burden and total survey duration in mind.

The statistical power calculation for conjoint experiments relies on the following considerations: Following Stefanelli and Lukac (2020), a conjoint design with four tasks, an estimated effect size of 0.05 and up to five possible values a variable could take would require at least 1000 respondents to achieve a predicted statistical power of 88%, a 0% probability of estimating a coefficients incorrect sign (Type S error), and an exaggeration ratio of 1.24 (Type M error). Overall, we thus aimed for a realised sample of above 1000 respondents, but since each participant engages in four comparisons of two BEV proposals, there will be 8000 units of analysis.

To analyse the main results of our experimental design, we examine our theoretical expectations using marginal means, following Leeper et al. (2019), as conjoint experiment results are sensitive to baseline categories. This approach is especially important for testing hypotheses that involve experimental interactions and heterogeneous treatment effects. The quantity of interest can then be interpreted as the difference in the probability of a study participant choosing BEV offers that include a particular attribute level (i.e., value of the particular explanatory variable), marginalising across all other attributes. We also calculate Average Marginal Component Effects (AMCE), which depicts the marginal effect of a given attribute on the choice probability over all other attributes' joint distribution. In practice, AMCEs are calculated by regressing a dummy variable indicating whether a respondent preferred a particular scenario when the respective attributes were present or not. This approach also uses cluster-robust standard errors to account for within-respondent clustering.

3.2. Attributes in the survey experiment

Starting with the literature above, we selected ten attributes for our survey experiment, as summarised in Table 1, including BEV-specific factors (cost-related and technical, coloured in white) and policy measures (coloured in grey). BEV-specific characteristics were the purchase price, energy and maintenance costs, warranty, and range. To test for possible policies that could be implemented, the following measures were investigated with the offered BEVs: an additional day pass for P.T., the possibility of temporarily exchanging the BEV for a diesel or petrol car, charging guarantee, and a subsidy at the time of purchase (see details in Table 1). The respondents had to compare these BEV proposals in pairs and express which one they preferred.

Table 1
Conjoint experiment attributes and their sets of attribute levels. Note: The attributes are coloured as either BEV-specific characteristics (white) or policy measures (grey). All attributes were shown to every participant in all choice tasks, and attribute levels were randomly assigned for each choice task. CHF = Swiss Francs; at the time of the study, CHF 1 is equal to around USD 1.10.

Attribute	Description	Attribute levels
Purchase price	Purchase price of the BEV	CHF 20′000; CHF 40′000; CHF 60′000; CHF 80′000; CHF 100′000
Energy costs	Energy costs per 100 km (electricity)	CHF 2; CHF 5; CHF 10; CHF 20; CHF 30
P.T. day pass	The electric car can be exchanged for CHF … per day for a 2nd class SBB day ticket	CHF 0; CHF 25; CHF 75; CHF 150
Car exchange	The electric car can be exchanged for CHF … per day for a petrol or diesel car	CHF 0; CHF 50; CHF 100; CHF 150
Government subsidy	Government subsidy for car purchase (purchase premium)	CHF 0; CHF 500; CHF 2000; CHF 4000; CHF 6000
Charging time	Charging the battery from 0 to 80% takes	15 min; 30 min; 45 min; 60 min; 75 min; 90 min
Maintenance costs	Annual maintenance costs (insurance, service, spare parts, repairs)	CHF 500; CHF 2′000; CHF 4′000; CHF 6′000
Warranty period	The warranty period for (free replacement) of the battery if its capacity falls below 80% of the original capacity	2 years; 4 years; 6 years; 8 years; 10 years
Driving range	Range with a fully charged battery	100 km; 300 km; 500 km; 1000 km
Charging guarantee	Guaranteed charging at a public charging station within a radius of your household of …	0.5 km; 1 km; 2 km; 10 km

3.3. Experiment

Conjoint analysis is a method mainly used to analyse attitudes. While we follow a conventional approach and ask respondents (before the experimental part) what their most important BEV obstacles are, this paper aims to examine purchasing intention in more depth. To this end, we conducted a purchase decision experiment employing conjoint analysis with a sample of n = 1′021. In our conjoint experiment, participants expressed their attitudes concerning BEV purchase options consisting of car and policy characteristics (called attributes) whose sets of attribute levels are randomly assigned. For this purpose, the respondents were presented repeatedly with descriptions of two potential BEV proposals, each of which had randomly assigned sets of attribute levels. The cars shown are each characterised by ten features, as depicted in Table 1.

To ascertain internal validity, we described all the attributes present in the experiment beforehand. At the beginning of our conjoint experiment, we provide basic information on each of the included measures (attributes) and continue with instructions to complete the conjoint experiment. The first part of the conjoint experiment consists of tables showing various BEV proposals' features (attributes and possible sets of attribute levels). The attributes included are listed and described in Table 1. The attributes were displayed in every conjoint task, but we randomly varied each attribute's level.

After the ten attributes and their possible attribute levels were shown to the respondents, they each had to compare sets of two proposals, shown side-by-side. Our survey confronted study participants with four such pairs of different proposals. They were asked to decide which proposal they prefer within each pair, both in a forced-choice mode and a purchasing decision question (see Fig. 1 for an example). The attribute levels on each attribute are inserted randomly into the tables. Since all attribute levels are randomly assigned, we can estimate the average marginal component effect and the marginal means for each attribute level (Hainmueller et al., 2014; Leeper et al., 2019).

After being confronted with a pair of proposals, respondents are asked to express which one they prefer (binary choice task: "If you had to choose one car, which car would you buy?"). Consequently, they have to decide for each proposal whether they would buy or not buy such a BEV package ("Would you buy car A/B?"). The unit of observation in the resulting dataset is defined by the response variable, i.e., the response to each proposal. This approach generates two observations for each choice task and eight observations per participant from the four choice tasks. For our sample of 1′021 participants, the number of observations is thus 8′168. The data analysis is based on linear mixed-effects regressions to estimate the average marginal component effect (AMCE) (Hainmueller et al., 2014; Leeper et al., 2019).

3.4. Survey process

The data was collected through an online survey. For this purpose, we sent out a postal invitation letter in August 2020 to a random sample of 10,000 residents of the Canton of Zurich to participate in the online survey. The address data was randomly drawn from the population register of the Canton of Zurich Statistics Office. All respondents were 18 years or older because the minimum age for obtaining a driver's licence for passenger cars in Switzerland is 18 years (which also defines the group of potential buyers of BEVs). The survey was to last about 20 min. Two weeks after the first invitation, a reminder letter was sent to those persons who had not yet taken part in the survey or had not communicated their intention not to participate by that time. All letters were sent out by the Statistical Office of the Canton of Zurich.

The survey also consists of questions regarding attitudes, knowledge, and acceptance of electric cars. For example, respondents were asked to state their most significant obstacles when buying a BEV. Then, the sample was split before participants were confronted with various survey experiments to not overstretch the response time. One half of respondents answered a conjoint experiment on decision-making behaviour when buying electric cars. The second half received experiments on resale value and regulations for charging stations in residential and office buildings and blue zones, which is not included in this study.

Further questions were asked about socio-demographics, mobility behaviour, general political attitudes and world views, technology and environmental attitudes, and the acceptance of different policy measures. Then, survey participants were introduced to the herein described purchasing experiment. After the conjoint experiment, the survey concluded with some final questions, e.g., about respondents' income.

4. Empirical results

This section presents our main empirical findings. The section starts with the response behaviour in the survey. We then present results regarding a general description of stated obstacles. Following this short discussion, we present the main results from the conjoint experiment displaying AMCEs and Marginal Means.

4.1. Response behaviour

Fig. 2 shows the process of the survey, following section 3.4. We initially contacted a randomly selected sample of 10′000 residents of the Canton of Zurich between 18 and 80. Of the initial population sample contacted, 132 people were not reached or were unavailable for a reason such as illness. Of the remaining sample, 190 persons did not consent on the consent page within the survey or contacted us to inform us of their non-participation. Of the remaining people invited by letter, 2′344 started the survey, and 2′075 completed it in full (defined as at least 90% of the questions completed). Two hundred sixty-nine (269) respondents partially completed the survey. The complete responses sample was then randomly split in half for the experimental parts of the survey. Half of the respondents were assigned randomly to fill out the conjoint design. 1′021 conducted the conjoint choice experiment presented in this paper, Comparison X of 4

	Car A	Car B
Purchase price	*CHF 80'000*	*CHF 80'000*
Energy costs	*CHF 5*	*CHF 10*
P.T. day pass	*CHF 25*	*CHF 75*
Car exchange	*CHF 150*	*CHF 50*
Government subsidy	*CHF 2'000*	*CHF 6'000*
Charging time	*15 min*	*30 min*
Maintenance costs	*CHF 4'000*	*CHF 6'000*
Warranty period	*10 years*	*10 years*
Driving range	*500 km*	*100 km*
Charging guarantee	*2 km*	*2 km*

If you had to choose one car, which car would you buy?

O Car A

O Car B

Would you buy Car A?

O Yes

O No

Would you buy Car B?

O Yes

O No

Fig. 1. Conjoint task example. Note: Translated from German, all attributes appear in every choice task; the attribute levels in italic are randomly shown and only serve as an illustrative example here. Source: Author's own illustration of the survey experiment.

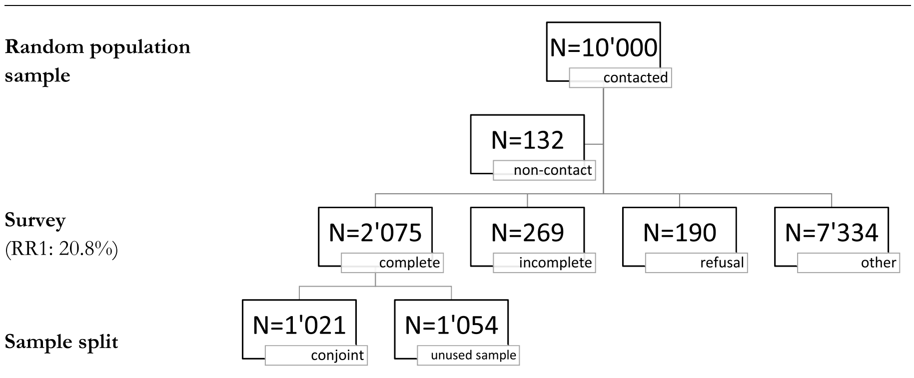

Fig. 2. Survey stages and participation. Note: Definitions based on The American Association for Public Opinion Research (2016). "Other" summarises all contacts that were successfully contacted but did not (partially) complete, refuse, or break off the questionnaire. Source: Author's own conception.

while the rest of the sample conducted unrelated vignette experiments.

The participants were between 18 and 75 years old, with an average age of 48.1 years. 50.2% were male. The surveyed sample represents the actual population well – both in terms of gender and age groups, although people between 40 and 65 are slightly overrepresented. The respondents have a slightly higher average education level than the Canton of Zurich population but are still representative (see Figure A2 in the Appendix). The respondents were around 44.2% with the highest educational achievement in tertiary education, with either a university or an applied sciences degree. At the same time, around 27.2% reported a vocational school diploma or an apprenticeship as their highest educational qualification. Another 17.2% also have a higher technical or vocational qualification. Around 72.4% stated that they were currently in employment.

4.2. *Stated BEV purchasing obstacles*

Before the experimental part, respondents were first asked to name the most significant obstacles from their perspective when buying a BEV. Fig. 3 displays these biggest obstacles to the purchase of BEVs. The

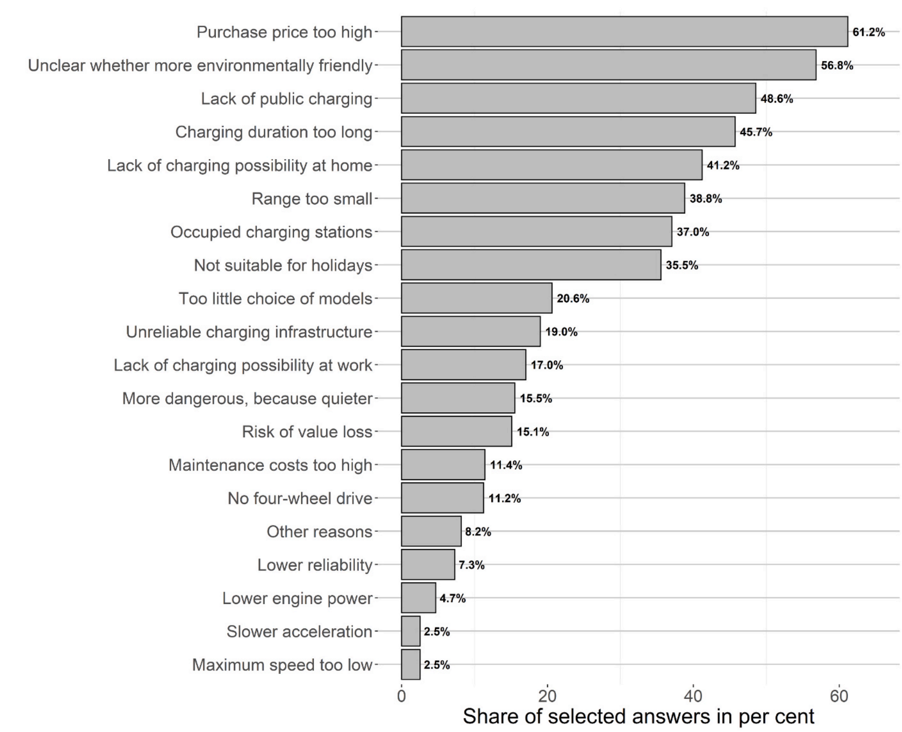

Fig. 3. Stated barriers to purchase BEVs. Notes: Answer to the question "Below are some potential barriers to switching from petrol or diesel cars to electric cars. Please select from them the five most important reasons for you personally". The percentage per barrier indicates how often the respondents selected this barrier compared to all other selected barriers. Thus, a single reason can take up a maximum of 100% if all participants consistently named it. N = 2′107. Source: Author's own conception, based on R software (R Core Team, 2013).

respondents selected a maximum of five obstacles from a longer list of potential reasons. The percentage per obstacle indicates how often the respondents selected this obstacle compared to all other selected obstacles. Thus, a single reason could assume a maximum of 100% if all participants always named it. They also had the option of listing further points ("Other reasons"). The results show that in this survey, too, the well-known obstacles were mentioned most frequently. Accordingly, more than half of the participants named the price and uncertainty about whether a BEV is more environmentally friendly or not as the main obstacles. Additionally, essential barriers are long charging times, low driving ranges, and the sparse availability of charging stations - whether at home, on the road, or because they are already occupied. It also seems essential that BEVs are considered impractical during holidays: presumably, because there is still uncertainty about the availability of charging stations abroad, and holiday trips are by far exceeding everyday travel distances.

4.3. Conjoint results

Moving away from descriptive results to the experimental findings, Fig. 4 displays the marginal means for the choice task and purchase decision (for AMCEs, see Figure A1 in the Appendix). The results indicate the average willingness to purchase a BEV with the specific attribute level for the purchase decision. However, the results for both questions differ only minimally from each other. Average marginal effects display the rate at which the dependent variable changes concerning the respective predictor while holding other predictor variables constant[37]. For the choice task, the marginal means thus indicate the average probability a BEV package was chosen when the respective attribute level was present.

Overall, the results indicate that the purchase decision is mainly driven by the purchase price, the maintenance costs, and the driving range. It is clear from the results that the purchase price is the most critical decision feature. Compared to the reference category of CHF 20,000, the most expensive variant of CHF 100,000 was accepted almost 30% less often for the purchase. The likelihood of choosing the most expensive variant is also reduced by more than 25%. In addition, the purchase decision results indicate the willingness to buy respective BEV packages, which on average, is at around 30% (0.3). However, this value varies from around 18% for the highest purchase price of CHF 100′000 to around 45% for BEVs with purchase prices of CHF 20′000. Unsurprisingly, the cheapest option of CHF 500 is preferred over the others for the maintenance costs.

The results regarding range show that the reference range of 100 km is less accepted by the participants than 300 km, 500 km, and 1000 km. No statistical effects can be observed for the rest of the attributes, and one can only interpret tendencies. For example, a longer charging time is generally less accepted and negatively affects purchasing decisions.

5. Discussion

This paper examines the main barriers to individuals' BEV uptake and how particular policies could alleviate them. We test our theoretical arguments with data from a representative population sample, including a choice experiment with 1′021 consumers. The empirical findings provide insights into the biggest hurdles in BEV purchasing intentions.

The purchase decision experiment results clearly show that the most critical decision criterion was the purchase price. The purchasing intention seems primarily dominated by techno-economic considerations. Thus, primarily cost factors, including warranty and technical factors of the vehicle such as the range and, to a certain extent, the charging time, significantly affect the purchase decision. Compared to the reference category of CHF 20,000, the most expensive offer of CHF 100,000 was preferred almost 30% less often on average. These results are in line with existing literature (e.g., Austmann and Vigne, 2021; Berkeley et al., 2018; Brückmann et al., 2021b; Carley et al., 2019; Rezvani et al., 2015).

The results are similar for maintenance costs, where the cheapest option of CHF 500 was preferred over the others. In line with existing literature, these results show that operational costs predominantly

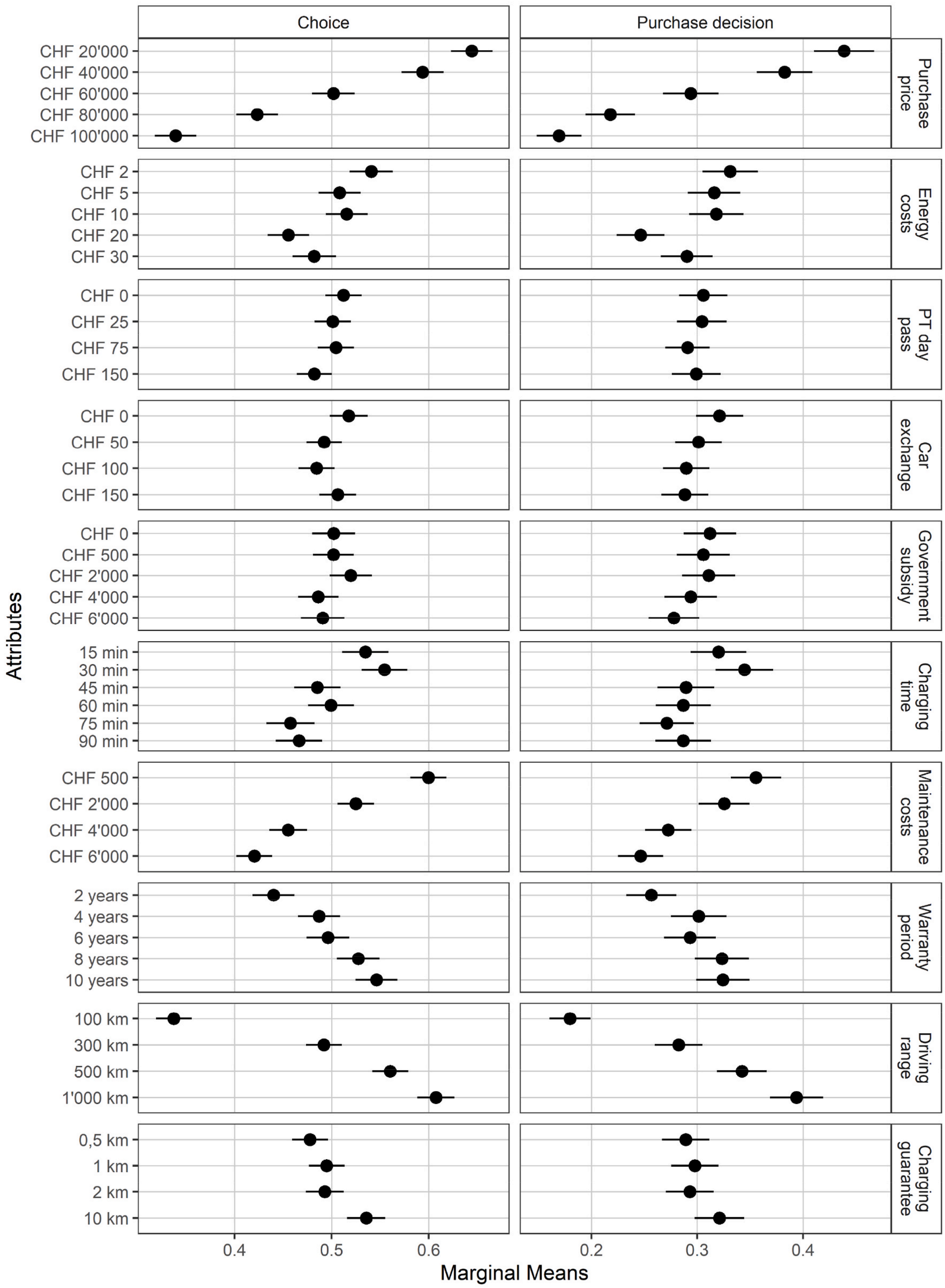

Fig. 4. Main results of the conjoint experiment displaying Marginal Means. Note: N = 1′021. Error bars display 95% confidence intervals for both choice and purchase decision tasks. The marginal mean displays the average choice probability for all proposals when the respective attribute level is present. Source: Author's own conception, based on R software, the cregg package, and the ggplot2 package (Leeper, 2020; R Core Team, 2013; Wickham, 2016).

negatively affect BEV acceptance (DellaValle and Zubaryeva, 2019; Liao et al., 2017; Singh et al., 2020). However, as current research shows, costs are generally a central factor when buying a car, regardless of the actual type of drive-train, with Andor et al. (2020) showing that running costs are systematically underestimated. This underestimation would also explain the compared to purchasing costs relatively lower importance of maintenance costs in our results (e.g., energy costs).

Regarding range, the reference category of 100 km is less accepted than 300 km or more. This finding is in line with existing literature showing that the driving range of BEVs is often perceived to be a disadvantage compared to vehicles with combustion engines (Rommel and Sagebiel, 2021; Tarei et al., 2021).

Only tendencies can be discerned for the remaining attributes and attribute levels, as results appear to be not significantly different across all attribute levels. For example, our results yield no clear results for charging time (although in tendency positively affecting purchasing decisions), which is to some extent contrary to existing studies, that are showing clearly negative connections between BEV attitudes and charging time (Hackbarth and Madlener, 2016; Higueras-Castillo et al., 2020; Kim et al., 2020; Ščasný et al., 2018).

Overall, our results regarding BEV-specific characteristics are only partly in line with existing literature, which can be explained by the dominance of technical and cost-related attributes that highly affect and dominate the stated purchasing intention. More specifically, costs (e.g., purchase price and maintenance costs) and technical factors (e.g., driving range and charging time) have the most substantial influence. In contrast, policy measures such as car exchange and daily P.T. passes only play a subordinate role in affecting stated purchase intentions.

The policy measures examined in the experiment (day pass for public transport, the possibility of temporarily exchanging the BEV for a diesel or petrol car, and a purchase price subsidy) had only a minor influence in the purchase decision experiment. This finding aligns with other research showing that policy measures may not sufficiently encourage consumers to adopt BEVs (see, for example, Hardman et al., 2020). These non-effects can be explained differently. For the case of car sharing, for example, Sprei and Ginnebaugh (2018) show that the current regime cannot meet the demands for vehicles, which is likely also to affect stated BEV purchasing intentions as respondents are aware of such issues.

The survey does show that subsidizing BEV purchasing only has a minor influence on the purchase intention of BEVs compared to the purchase price. As subsidies are also comparably rather expensive demand-side measures from policy options that policymakers can draw on, alternatives (e.g., attractive leasing offers) should be sought to cushion the negative effect of the high purchase price when buying a BEV (in the short term). However, in the long term, prices will fall, especially since a larger second-hand market will develop in the long term (also see Brückmann et al., 2021a).

6. Conclusions

Political controversies over whether and how to accelerate BEV adoption typically focus on supply-side (such as aiming to support industry in research and development) versus demand-side measures (aiming to steer consumers' behaviour with push and pull measures). Those favouring supply-side measures usually argue that adoption rates will, quasi automatically, increase as BEVs become cheaper and better. That is, some supply-side proponents claim that market forces will solve the current BEV uptake challenge on their own. Others claim that strong government intervention (e.g., emissions rules, banning new ICEVs sometime soon) is needed to push the car industry more rapidly to develop, produce, and sell more attractive BEVs at lower costs. Those favouring demand-side measures usually claim that additional government interventions are required to make BEVs more attractive to consumers and thus incentivise the car industry to innovate more rapidly.

Consumers, however, seem to be driven mainly by the economics of switching from an ICEV to a BEV. Our empirical analysis shows that technical and price-related factors dominate the purchase intention. In other words, critical obstacles to BEV adoption are primarily economic and technical since factors such as costs (e.g., purchase price and maintenance costs) and technical factors (e.g., driving range and charging time), respectively, have the most substantial influence. The policy measures examined had only a minor effect on purchase intentions expressed in our survey experiment. From a policymaking perspective, these results suggest that supply-side policy interventions might be more effective in pushing the car industry into more rapid technological innovation than government measures that seek to incentivise BEV uptake on the consumer side. From the private sector's perspective, attractive leasing offers could help reduce the high financial barrier to entry and reduce potential fears of technology risks (e.g., strong depreciation due to the high pace of innovation in batteries). Furthermore, depending on BEVs' technology and price development, this desire for a long range could also lead to new BEVs becoming even larger and heavier - with negative effects on the environmental footprint of BEVs, energy efficiency, and space requirements (road space, parking spaces). To reduce range anxiety of potential buyers, expansion of the charging infrastructure would therefore counteract the subjective range anxiety and make it possible for other groups of people, who for example cannot charge at home, to charge and thus purchase a BEV. Whether this, together with the higher purchase price of long-range BEVs, can prevent or even reverse a trend towards (even) heavier and larger vehicles remains an open question, and additional government measures may be required here.

The policy relevance of our findings derives from the fact that they can help policymakers implement consumer-oriented policy measures to foster BEV uptake. Specifically, high acquisition costs, limited driving ranges, the lack of charging stations, and the uncertainty of charging availability appear to be the main obstacles when purchasing BEVs. Conditions to be created for accelerating BEV uptake are thus expanding charging infrastructure (especially for tenants), reducing barriers to charging system compatibility, and increasing the range of vehicles. This need is specifically important for Switzerland, where most people live in rented properties, most often apartments, which do not always offer an opportunity to charge a BEV at home. Moreover, targeted policy measures are needed for less affluent households.

Our results demonstrate that policymakers should focus on industry measures and car bans rather than demand-side policies to foster BEV adoption. We show that technical progress could be sufficient to electrify individual motorised transport, thus requiring little or no strategies and policies to pull consumers' behavioural changes. These findings also imply good news for the latest plans to effectively ban the sale of new petrol and diesel cars starting in 2035 at the E.U. level and for similar intentions from multiple other regions. Such a sharp reduction trajectory for CO2 emissions of newly registered cars essentially leads to an implicit ban on ICEVs within the next few decades, fostering R&D investments and thus technological progress.

In conclusion, we point out some limitations of our study and options for further research. To begin with, the chosen methodological approach in this paper does not allow us to draw any conclusions about comparisons of BEVs with conventional cars. This lack of comparability, for example, does not allow us to state whether the purchasing price has a more significant effect in the case of BEVs than it would have for other drive trains. Furthermore, while conjoint experiments are methodologically rigorous and allow for quite realistic choice scenarios in situations where multiple attributes matter simultaneously, they also have limitations. For example, the mere number of attributes and the experiment by nature results in high complexity, leading respondents to adapt simplification strategies to resort to the many attributes – although recent research shows that results remain generally stable and survey satisficing only increases modestly when respondents face large numbers of attributes (Bansak et al., 2021). In addition, when respondents face newly implemented categories they have never actively thought of, they tend to find it hard to articulate attitudes. As a result, they could even start to think about matters they would otherwise not. We acknowledge that the setup of the experimental approach reflects an arguably constructed setting. For example, people usually underestimate a car's running costs (Andor et al., 2020), and therefore some of their choice with all this information might not be their usual choices. In addition, attitudes measured within a survey are subject to change within different scenarios and in real-world settings (Jackson, 2005; Shove, 2004, 2010). That said, attitudes do not necessarily predict actual behaviour in real-life scenarios, although they likely do mediate such decisions (Ajzen, 1991). Still, our approach allows us to obtain robust estimates of BEV and policy-design feature effects on purchasing intentions.

Nevertheless, our results yield only rough estimations of the extent to which consumers in Switzerland are likely to react to specific BEV proposals. Options for further research are to implement such decision experiments on BEV purchasing intentions in other contexts and countries. Overall, our research presented here lays the foundations for a more extensive research effort focusing on overcoming barriers in adopting BEVs, which is urgently needed to address significant challenges humanity is facing.

CRediT authorship contribution statement

Michael Wicki: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Gracia Brückmann:** Conceptualization, Data curation, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Thomas Bernauer:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.131774.

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