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Effect of electricity generation mix on battery electric vehicle adoption and its environmental impact

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ABSTRACT

Battery electric vehicles (BEVs) are gaining much attention as the next technology paradigm in the transport sector because it can mitigate the environmental problems, such as greenhouse gas (GHG) emissions, of conventional internal combustion engine vehicles. Many countries are attempting to promote the consumer adoption of BEVs in this sense by providing subsidies and expanding their related infrastructure. The expected environmental effect of BEVs is an important factor in increasing the consumer adoption of BEVs, and the environmental impact of BEVs is directly related to the electricity generation mix. In this study, we analyze how the consumer adoption behavior of BEVs and their environmental impact can be changed by improving the environmental performance of BEVs based on the electricity generation mix. To this end, we estimate consumer preferences in vehicles by using a discrete choice experiment survey and a mixed logit model. Then, on the basis of the estimation results, we simulate changes in consumers' vehicle adoption behavior according to various electricity generation mixes and measure the environmental impact of these changes. Analysis results show changing the electricity generation mix to renewable-oriented mix can promote BEV's market share up to 10% and reduce GHG emissions up to 5% by 2026.

1. Introduction

Climate change is an actual and/or potential cause of disastrous climate events such as the rise in sea level, hurricanes, heat waves, droughts, and floods, which can result in serious adverse economic, social, cultural, and health changes globally Stabinsky and Hoffmaister (2015); van der Geest and Warner (2015); Dinan (2017); Mann and Gleick (2015); Hauser et al. (2016); Arnell and Gosling (2016)). One can no longer neglect the problem of climate change, and countries around the world are joining forces to resolve this problem. At the Paris climate conference (COP21) in December 2015, the first legally binding agreement was signed by 195 countries, which together account for about 90% of the global greenhouse gas (GHG) emissions. In this situation, many countries are independently setting up objectives to reduce GHG emissions and designing various policies to accomplish these targets.

Among various energy-consuming sectors, the global CO_2 emissions from the road transport sector increased by 71% during 1990–2014 and as of 2014, this rate is 17% (IEA, 2016). Consequently, environment-friendly vehicles, particularly battery electric vehicles (BEVs),[1] have been receiving considerable attention as the next technological paradigm to alleviate the environmental problems of conventional internal combustion engine vehicles (ICEVs). Certain studies have even identified BEVs as an effective option to alleviate GHG emissions by ICEVs in the road transport sector (Faria et al., 2013; Hawkins et al., 2013; Woo et al., 2017a; Doucette and McCulloch, 2011). On the other hand, many studies have highlighted the obstacles in increasing consumer adoption of BEVs, including high purchase price, low max range on a full charge, prolonged charging time, and lack of related infrastructure (Sierzchula et al., 2014; Bockarjova and Steg, 2014; Junquera et al., 2016; Plötz et al., 2014; Rezvani et al., 2015; Sang and Bekhet, 2015; Larminie and Lowry, 2003; Nilsson, 2011; Bishop et al., 2014; Wikström et al., 2014; Donateo et al., 2015; Neubauer and Wood, 2014; Li et al., 2017; Neaimeh et al., 2017; Yu et al., 2016). As a result, the BEV share in most consumer automobile markets remain negligible. Nevertheless, some countries have managed to successfully promote BEVs. China and the United States sold over 250,000 and 80,000 BEVs in 2016, respectively, and the annual market share of BEVs in Norway was 15% in 2016 (IEA,

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[1] A battery electric vehicle (BEV) is a type of electric vehicle that uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers instead of internal combustion engines for propulsion.

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Table 1
Descriptive statistics of the sample.

		Response	Percentage
Total		1002	100%
Gender	Male	528	52.7%
	Female	474	47.3%
Age	20–29	183	18.3%
	30–39	209	20.9%
	40–49	247	24.7%
	50–59	246	24.6%
	60–64	117	11.7%
Monthly income	Less than KRW 3 million	280	27.9%
	KRW 3 million–4 million	272	27.1%
	KRW 4 million–5 million	213	21.3%
	More than KRW 5 million	237	23.7%

2017). A key factor driving the success in these countries is the strong government promotion policies including subsidies; tax exemptions to cope with high purchase prices; expansion of related infrastructure in response to the shortage of related infrastructure; and other benefits offered to BEV drivers, such as free parking, discounted/free toll, and use of high-occupancy-vehicle (HOV) lanes (Sierzchula et al., 2014; Langbroek et al., 2016; Bjerkan et al., 2016; Hao et al., 2014; Zhang et al., 2013; Hardman et al., 2017; DeShazo et al., 2017; IEA, 2017).

Among various policy options that government can use, this study specifically focuses on analyzing the impact of the electricity generation mix[2] on BEV consumer adoption and its subsequent environmental impact. While subsidies and the expansion of infrastructure are useful options, choosing appropriate electricity generation mix can also be an important contributor to the promotion of BEVs. Studies have found that consumers do consider a vehicle's environmental performance at the time of purchase (Degirmenci and Breitner, 2017; Bockarjova and Steg, 2014; Plötz et al., 2014; Sang and Bekhet, 2015). Degirmenci and Breitner (2017), for example, found that the effects of this consideration are stronger for electric vehicles than for traditional ICEVs. Since electricity generation mix is directly related to BEVs' environmental performance, a change in the mix could impact consumer's choice to purchase a BEV. However, the effect of electricity generation mix on vehicle adoption can be complicated since consumers also have differing preferences towards different power sources (Huh et al., 2015; Shin et al., 2014). That is, even though certain power sources may report lower GHG emissions during their electricity generation process, the public may not prefer these sources because of related risks and possible damages by these sources. Therefore, the choice of the electricity generation mix compositely affects GHG emissions from the road transport sector through varying promotion effects on BEV adoption and amounts of GHG emitted during the electricity generation process.

According to previous studies, the environmental impact of BEVs, such as GHG emissions, is contingent on the extent to which electricity used by the vehicles is produced in an environment-friendly manner. If the electricity is produced mainly using fossil fuels, BEVs may report higher GHG emissions than ICEVs (Faria et al., 2013; Freire and Marques, 2012; Doucette and McCulloch, 2011; Tomic and Kempton, 2007; Huo et al., 2009, 2015; Wu et al., 2007; Granvskii et al., 2006; Helms et al., 2010; Varga, 2013; Nichols et al., 2015; Bickert et al., 2015; Rangaraju et al., 2015; Tamayao et al., 2015; Jochem et al., 2016; Woo et al., 2017a). This study—the first of its kind, to our knowledge—aims to quantitatively analyze changes in consumer adoption behavior toward BEVs in response to a specific electricity generation mix and its resultant effect on the level of GHG emissions. To meet this objective, we model consumer adoption behavior toward vehicles using a discrete choice experiment survey and a mixed logit model. We then simulate changes in the consumer adoption of BEVs according to various electricity generation mixes and measure the environmental impact of these changes while accounting for GHG emissions by each electricity generation mix. Our findings offer implications for energy policies on national electricity generation mixes and their effect on the consumer adoption behavior of BEVs and GHG emissions in the road transport sector.

The remainder of this paper is organized as follows. Section 2 presents the survey data and discrete choice model used in this study. Section 3 discusses the estimation results and scenario analysis. Section 5 concluded and offers key implications.

2. Methodology and data

2.1. Choice experiment survey

We collected data on consumers' stated preferences for vehicles using a choice experiment survey. In addition, face-to-face interview were conducted with 1002 respondents in South Korea by Gallup Korea, a professional survey company, during September 19–26, 2016. The respondents were proportionally sampled on the basis of gender, region, and age to represent actual new car buyers. Respondents were recruited from the Seoul metropolitan area (Seoul and Gyeonggi-do) and six metropolitan cities (Incheon, Busan, Daegu, Gwangju, Daejeon, and Ulsan) in South Korea, which account for 70% of South Korea's population. We focused on respondents aged 20–59 years, who according to the Korea Automobile Manufacturers Association (Korea Automobile Manufactureres Association, 2017), accounted for about 89% of new vehicle registrations in 2016. Table 1 presents the descriptive statistics of the sample.

To administer the survey effectively, we conducted an online pilot test of the survey among 400 respondents and checked for modifications needed. We then designed a manual and trained interviewers to provide detailed survey information to the respondents prior to the main survey. The information covered the study's purpose and setting, appropriate ways to answer the questionnaire, the attributes and levels available for the choice experiment (using a format similar to that of Table 2), and key assumptions such as independence between each attribute and other attributes that are not presented in the choice set remains the same across all alternatives. The main survey was administered in the form of an offline, face-to-face interview in an enclosed space. If respondents found questions to be difficult or complex, interviewers were trained to help them without imposing or introducing any bias to the respondent's answer. More details about the interview protocol and survey questionnaire are presented in Appendix A.

To design an appropriate discrete choice experiment for vehicles, it is important to identify their core attributes and accordingly, assign their levels (Louviere et al., 2000). However, the core attributes affecting vehicle adoption behavior may vary by vehicle class (e.g., subcompact, compact, mid-sized, and sports utility vehicle) and covering all vehicle classes can be difficult when using a single discrete choice experiment. However, previous literature suggests that consumers' vehicle choice is effected by the vehicle class being considered (Higgins et al., 2017). Thus, we attempted to set a vehicle class that is representative of the Korean auto market. We chose the mid-sized sedan class because it reports a steady and high market share in the Korean auto market and include vehicles of various fuel types (i.e., gasoline, diesel, and hybrid). Moreover, with the expected entry of BEVs in the mid-sized sedan market in the near future, forecasting the market can have useful implications.

Table 2 presents the four defined attributes and their levels that may influence consumer adoption behavior toward BEVs. Other potential attributes not included in Table 2 are assumed to be the same level across all alternatives. We carefully selected the four attributes in line with this study's objective by drawing on previous research to consider factors influencing EV adoption. First, the 'fuel type and operating

[2] Electricity generation mix refers to the combination of different power sources (such as coal, natural gas, and nuclear power) used to produce electricity.