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Exploring critical factors influencing the diffusion of electric vehicles in China: A multi-stakeholder perspective

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ABSTRACT

Electric vehicles (EVs) have received significant global attention due to the high energy efficiency and low pollutant emissions. In recent years, the Chinese government has allocated considerable funding and taken a number of legislative and regulatory steps for promoting the deployment of EVs. However, the increasing trend of EV adoption is not satisfying. In this paper, we investigate the factors that influence the diffusion of EVs in China from a multi-stakeholder perspective. Considering that decision makers' evaluation information is often imprecise and there can be significant dependence and feedback among influencing factors, a three-phase framework based on 2-tuple linguistic method and decision making trial and evaluation laboratory (DEMATEL) is proposed. First, a set of specific influencing factors is identified through a literature review and expert interviews. Second, direct relations of the influencing factors are evaluated using the 2-tuple linguistic method. Third, the critical factors influencing the diffusion of EVs in China are determined via the DEMATEL technique. According to the results of an empirical case study, 'technological level', 'policies and regulations', 'consumer acceptance and expectation', 'price and models', and 'market structure and competition' are critical factors influencing the diffusion of EVs in the Chinese market, which should be emphasized by the government and automakers for the benefits of EV development.

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1. Introduction

Over the past decades, vehicle population in China has been increasing dramatically with the growth of resident income and the acceleration of urbanization driven by fast growing economy. The production of automobiles in China reached 23.7 million in 2014, ranking first in the world (Yuan, Li, Gou, & Dong, 2015). By 2020, the vehicle population will likely exceed 280 million in China (Wan, Sperling, & Wang, 2015). This significantly growth in vehicles leads to a considerable increase in oil consumption, vehicle emission, traffic congestion and air pollution in China. For example, China's greenhouse gas (GHG) emissions accounted for 26% of total world carbon dioxide emissions in 2012 (Zhao, Doering, & Tyner, 2015). Future regulations for the automotive industry will require a sharp decline in car emissions within the next decade. By the year 2030, China will have to cut the carbon intensity of its economy by 60–65% below 2005 level according to the Paris Agreement. Automobiles (excluding natural gas vehicles) are responsible for a large share of GHG emissions of the road transport sector. Therefore, to address the concerns of high oil prices, air pollution and GHG emissions, policymakers and the automobile industry in China are seeking alternative energy sources for new vehicles. The development of electric vehicles (EVs), which include both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), is widely viewed as a promising solution. Compared with the conventional internal combustion engine vehicles (ICEVs), EVs have many advantages in terms of improving energy security,

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promoting economic growth and minimizing tailpipe emissions (Mohamed, Higgins, Ferguson, & Kanaroglou, 2016; Vergis & Chen, 2015; Wu, Freese, Cabrera, & Kitch, 2015). The performance of EVs is better than ICEVs because of the usage of more efficient power trains and electric motors (Burke & Zhu, 2015; Langbroek, Franklin, & Susilo, 2016; Lu, Liu, Tao, Rong, & Hsieh, 2017; Yong, Ramachandaramurthy, Tan, & Mithulananthan, 2015).

To foster the development of EV market in China, different initiatives, policies and programs were introduced by the central government (Wang & Yan, 2016; Xue, You, Liang, & Liu, 2016a; Zhao et al., 2015). For example, in 2009, the Chinese government launched a pilot program for EV adoption in 13 cities and plan to manufacture 0.5 million alternative fuel vehicles by 2012. In 2012, the Chinese government subsequently put forward a plan that aims for cumulative production and sales of 0.5 million BEVs and PHEVs by 2015 and 5 million by 2020. In 2015, the national government is providing a subsidy up to 54, 000 RMB ($8502) per vehicle to the EV consumers. Besides, many provinces have committed themselves to wider EV uptake. For example, Shanghai has taken a number of local policies and regulations to promote the adoption of EVs into market, such as provision of free private license plates and rebate for purchasing EVs. However, the market development of EVs in China is relatively slow given that there were only around 108, 392 BEVs and PHEVs sold in 2015.

Many researchers investigated the EV adoption and deployment in various countries, but the current studies limited their focus to specific issues (such as policy measures, consumer preferences and public acceptance) and the impact of EV uptake. No study has explored the factors influencing EV diffusion in the Chinese context, particularly from a multiple stakeholder perspective. Hence, this paper aims to propose a formal modelling methodology to investigate the EV marketing determinants in China with three different perspectives. Because decision makers' evaluation information is often imprecise and there can be significant dependence and feedback between different influencing factors, the decision-making trial and evaluation laboratory (DEMATEL) method (Gabus & Fontela, 1972), an effective multi-criteria decision making (MCDM) tool for complex problems, is integrated with 2-tuple linguistic method to determine key factors in the diffusion of EVs. Besides, stakeholder cooperation is highly needed to promote the development of EVs in China. Thus, multi-stakeholder perspectives (i.e., the government, automotive manufacturers and research institutions) are taken into account in this paper, which differentiates this study from other existing literature.

The remainder of this paper is structured as follows: In Section 2, we review the prominent research previously conducted on this paper's central objective. In Section 3, we briefly introduce the basic theories which will be applied in this paper. Section 4 develops a model framework to recognize critical factors influencing the industrialization of EVs in China. Application of the proposed framework is illustrated with an empirical case study in Section 5. The obtained results are discussed and the critical influencing factors are figured out in Section 6. Finally, this paper is concluded in Section 7 with possible directions for future research.

2. Literature review

2.1. The impact of EV uptake

In recent years, extensive research efforts have been conducted to analyze the impact of EV uptake, with focus on economic, environment and technical issues. From the economic aspect, Riesz, Sotiriadis, Ambach, and Donovan (2016) used the Australian car fleet as a case study to explore the financial costs of a rapid national transition to EVs in comparison to continuing use of ICEVs. They suggested that a rapid transition towards EV technologies for urban car travel may offer a cost-effective second-best climate change mitigation strategy. Zhao et al. (2015) examined the economic competitiveness and emissions of BEVs in the Chinese market by comparing with ICEVs from the perspectives of consumers, society and GHG emissions. The results showed that BEVs are not economically competitive compared with ICEVs in the current Chinese vehicle market with government subsidies. Seixas et al. (2015) used a partial equilibrium model that minimizes total energy system costs to assess the cost-effectiveness of EVs in European countries, and found that BEVs are cost-effective in the European Union by 2030 if their costs are 30% lower than expected costs. Lin (2014) proposed a framework for optimizing the driving range for drivers of United States by minimizing the sum of battery price, electricity cost, and range limitation cost as a measurement of range anxiety. The quantitative results suggested that short ranges are likely to be more popular for a long period of time and battery cost reduction significantly drives BEV demand toward longer ranges, whereas reducing battery cost is expected to drive BEV demand toward longer ranges.

From the environment point, Weldon, Morrissey, and O'Mahony (2016) analyzed the environmental impacts of varying EV user behaviors in the Irish context and compared them to ICEV usage. The results showed that the environmental impacts of EVs are highly influenced by the charging behaviors of individual users, and EVs are a more environmentally friendly choice of vehicle than ICEVs under a wide majority of scenarios. Shi, Wang, Yang, and Sun (2016) compared the environmental impacts of the transition from gasoline vehicles to EVs in Beijing based on a full life cycle assessment, and indicated that EVs could play a significant role in decreasing the potential of global warming, abiotic depletion and ozone layer depletion. Yuan et al. (2015) built an EV model based on a prototype BEV and proposed an analytical model to determine the impact of driving patterns on energy consumption. As a result, short driving range and low driving speed were suggested to reduce the energy and environmental impacts of BEVs in China. Huo, Cai, Zhang, Liu, and He (2015) made a life-cycle assessment of GHG emissions and air pollutants of EVs in China and the United States, and indicated that EV fuel-cycle emissions depend largely on the carbon intensity and cleanness of the electricity mix and vary considerably across the selected regions.

As for the technical aspect, Lim, Jahromi, Anderson, and Tudorie (2015) evaluated and compared the technological advancement of hybrid electric vehicles (HEVs) observed in different market segments, and showed that the diversification of midsize HEVs is posing a threat to the two-seaters and compact HEV segments while an sport utility vehicle (SUV) segment shows a fast adoption with a significant performance growth. Sohnen, Fan, Ogden, and Yang (2015) created a network-based electricity dispatch model to estimate the spatial and temporal effects of plug-in electric vehicle (PEV) charging on the existing power grid infrastructure system and showed that comparing with gasoline hybrids, California's electricity is a clean transportation fuel when used in EVs. Wu et al. (2015) developed an EV data collection system and used it to analyze both EV performance and driver behaviors. The analysis showed that EVs are more efficient when driving on in-city routes than freeway routes. In addition, Yong et al. (2015) conducted a comprehensive review concerning current EV status, the latest development in EV technologies, impacts of EV roll out and future opportunities brought by EV field.

2.2. The market introduction of EVs

On the other hand, many studies were carried out to explore factors affecting the market introduction of EVs by applying

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