Transport Policy 68 (2018) 107–117

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Estimation of vehicle home parking availability in China and quantification of its potential impacts on plug-in electric vehicle ownership cost☆

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ARTICLE INFO

Keywords:
China's vehicle market
Home parking availability
Data mining
Vehicle ownership cost
Monte carlo simulation
Electric vehicle charging

ABSTRACT

China has become the world's largest plug-in electric vehicle (PEV) market. One major barrier to greater consumer acceptance of PEVs is the lack of home parking spaces for charging outlets. This study developed a methodology to estimate the residential parking ratios (parking spaces vs household numbers) and project the residential community-weighted parking availabilities (home parking availabilities) in China, by area and by province, through data mining from several major real estate trading network platforms. The results show that the home parking availabilities from 2015 to 2050 vary by geographic areas and building life expectancy. A method was developed to quantify the shadow values of home parking impacting on PEV ownership costs and combined with Monte Carlo simulation to address estimation uncertainty. Depending on the PEV type and all-electric range, the value of home parking space to a PEV owner, measured by the reduced vehicle ownership cost, ranges from $2399 USD to $10,802 USD. The total incremental shadow value, relative to the 2015 situation, of the home parking availability for PEV owners increases over time due to both improvement in home parking availability and increase in the PEV population, and is estimated to reach over $2.51 billion USD by 2025 (U.S. dollars in 2015 level).

1. Introduction

China has become the world's largest market in both all vehicles and the plug-in electric vehicles (PEVs) (Ou et al., 2017). According to the China Automotive Technology and Research Center (CATARC), the total vehicle stock in China reached over 151 million in 2015, and the passenger vehicle population increased to around 130 million units, most of which were sold in the urban areas (CATARC, 2018). Studies anticipate that, by 2050, the vehicle stock in China will reach to 400–700 million (Huo et al., 2007; Huo and Wang, 2012). The explosive growth of the vehicle market in China has inevitably raised issues in the economic, energy security, air pollution, and urban planning (Ou et al., 2017; Wang et al., 2011). Therefore, the PEVs, including both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), are viewed as a solution for national energy security and air pollution problems in highly congested urban areas (Zheng et al., 2012). After implementation of a range of favorable policies, in 2015, China became the world's largest light-duty PEV market with annual sales of 191,000 units (Ou et al., 2017).

As urbanization and motorization develop in China, the availability of vehicle parking becomes an increasingly severe problem in neighborhoods and communities in urban areas. Vehicle owners fret to find empty parking spots while pedestrians and cyclists are annoyed by streets congested with vehicles (The Economist, 2016). Meanwhile, more people are moving into cities: the urbanization rate in China has reached 55.61% by the end of 2015 with a 3.05% annual rate of change (2010–2015 estimation) (The World Bank, 2015). The conflict between urbanization and motorization constantly intensifies. According to the Ministry of Housing and Urban-Rural Development of China, the ratio of the parking spaces to vehicles is about 0.8 in the megacities, and is just 0.5 in small cities (Information Office of the State Council, 2015). The government reckons China has a shortage of roughly 50 million parking spaces, and its target is 1.3 parking spaces per vehicle (including both public and home parking) (Information Office of the State Council, 2015).

Insufficient parking space for electric vehicle charging

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https://doi.org/10.1016/j.tranpol.2018.04.014
Received 4 October 2017; Received in revised form 16 April 2018; Accepted 17 April 2018
Available online 03 May 2018
0967-070X/

infrastructure has become a critical bottleneck to the large-scale adoption of PEVs (Franke and Krems, 2013). Specially, as found by Smart. et al., in 2012, during early adoption of PEVs, most vehicle charging took place at homes using residential PEV charging equipment (Smart and Schey, 2012), demonstrating the importance of home parking spaces for promoting PEV acceptance by consumers. In the meantime, because of the generous government subsidies and vehicle purchase privilege for PEVs, most PEV sales occur in highly congested metropolitan areas such as Beijing and Shanghai (Ou et al., 2017). This brings a critical problem to some PEV owners: no home parking spaces for vehicle home-charging.

The Chinese government has stated commitments to investing more in residential and public parking lots for urban residents to meet the parking and charging demands. In the *2016 Report on the Work of the Government*, the premier of the State Council promised to speed up construction of urban parking lots and PEV charging infrastructure (Li, 2016). The *Guiding Opinions on Accelerating the Construction of Urban Parking Infrastructure* issued by the National Development and Reform Commission in 2015 requires all new residential parking lots to provide the infrastructure for PEV charging facility installation (General Office of the State Council, 2015).

The planning and management of the vehicle parking is a challenge in other places as well. In some developed countries/regions, such as Europe, parking space is a scarce resource in urban context; this situation is intensified when electric vehicle charging facilities are needed in the parking spaces. For example, Faria et al. constructed a methodology to quantify the economic feasibility of deploying the electric vehicle parking spaces in urbans (Faria et al., 2014). Vehicle parking still needs a strategic planning even in areas with a low population density, such as the U.S. The urban planners set minimum parking requirements to satisfy the peak demand for free parking, which might increase the implicit cost to vehicle owners and bring unnecessary expenses (Guo, 2013; McDonnell et al., 2011; Shoup, 1999). In the developing countries, the insufficient home parking availability aggregates the extra economic burden to vehicle buyers (Liu, 2002; Wang, 2011). Because of its influences on the PEV charging infrastructure and street congestion (Liu, 2002), the insufficient residential parking substantially affects the commuter behaviors, vehicle kilometers traveled (VKT), and emissions (Weinberger et al., 2009). However, few published studies have investigated current situations of residential parking availability in China or quantified its potential impacts on the PEV ownership.

This study quantifies the residential community-weighted average parking availabilities by province/region and by urban type in China from 2005 to 2050, explores the relationship of the residential community-weighted average parking availability with other exogenous variables such as economic level, geographic position, urban planning etc., and built a method to estimate the impacts of the home parking on PEV ownership with Monto Carlo simulation by @Risk®. The term - "home parking availability" - will be used for describing the residential community-weighted average parking availability in following context. Admittedly, the policies pursuing the high parking availability to meet the demands by the rapid vehicle ownership growth might bring some traffic and urban design problems (Manville and Shoup, 2005), but the evaluation of the parking policies or PEV promotion policies is out of this study scope. Nevertheless, the methods and results achieved in this study can supply the policy makers and researchers a reference for their policy evaluation.

The vehicle residential parking ratio (γ) is defined as the ratio of the vehicle residential parking spaces to the households in the residential communities. The number of "households" in this study means the number of houses or apartments in a residential community. The home parking availability (R) is a weighted average value calculated from the parking ratios (γ) of the residential communities, and it is used for evaluating the residential parking conditions in the urban areas in China.

The following questions are raised and addressed:

- What are the home parking availabilities in first-tier, second tier, third-tier cities respectively by province?
- What will the home parking availability be like in the future in China?
- What is the relationship between the home parking availability with economic level, geographic position, urban planning etc.?
- What is the invisible cost of the residential parking space on the PEV ownership?

This paper consists of five sections. The first section presents the motivations and objectives, and it reviews the related background and literature. The second section presents the processing of the data analysis and assumptions for the home parking availability model. The third section clarifies the methodology and equations. Section four focuses on the analyses of the home parking availabilities and quantifies its influences on the PEV ownership. The last section presents the conclusions. The yearly average currency exchange rate of $ 1.0 USD = 6.489 CNY in 2015 is used (U.S. Internal Revenue Service, 2017), and money is at 2015 level.

2. Data

To investigate the residential parking circumstances in different levels of urban areas by province, three tiers of areas are classified (Tier 1, Tier 2, Tier 3) in 31 provincial regions in mainland China (excluding Taiwan, Hong Kong, and Macao) based on their administrative partitions by the Chinese government. As shown in Table 1, Tier 1 areas include the urban areas in the direct-controlled municipalities (Beijing, Chongqing, Shanghai, and Tianjin), the capitals of the provinces (e.g., Changsha, Nanchang), and the sub-provincial municipalities (e.g., Dalian, Qingdao). Tier 2 refers to the suburban areas in the direct-controlled municipalities and the prefectural level cities in provinces. Tier 3 includes the urban areas in the county or township levels in each province.

To achieve the parking ratios, accurate and comprehensive information is vital. Information on both household and residential parking spaces are rarely collected by the authorities. However, the dramatic development of real estate transactions in China spurs Chinese real estate transaction platforms to glean abundant information of pre-owned and new residential communities and present them online to the customers. Through data mining, this study collected residential community information from the largest real estate transaction internet platforms (fang.com, lianjia.com, anjuke.com) in China. Fig. 1 shows the information structure of the data obtained. Totally, 852 samples of residential community information, covering over 100 cities across 31 provinces, are collected. Recognizing the potential limitation of the collected data, the following assumptions are made:

- Only the residential parking in the urban areas is studied, and it

Table 1
Classification of the area type in China.

Classification	Area types (n)	Example
Tier 1	The urban areas in the direct-controlled municipalities	Haidian, Beijing
	The provincial capitals	Nanjing, Jiangsu
	Sub-provincial municipalities	Qingdao, Shandong
Tier 2	The suburban areas in the direct-controlled municipalities	Baoshan, Shanghai
	The prefectural level cities	Yueyang, Hunan
Tier 3	The urban areas in the county or township levels	Weng'an, Guizhou