Optimal location of public charging stations in a monocentric city

○Yiming Zhou*, Kono Tatsuhito**

1. Introduction

To achieve carbon neutralization by 2050, governments around the world have set ambitious targets to reduce green-house gas (GHG) emissions. The transport sector accounted for 57% of global oil demand and produced approximately one quarter of GHG emissions, according to the United Nations Sustainable Transport Conference 2021. Transportation electrification plays an essential role in reducing GHG emissions. Sustained policies have been established across countries to support electric vehicle (EV) adoption. Transportation electrification relies heavily on the deployment of public charging infrastructure. As a substitute for home charging, the public charging stations (PCSs) help EV drivers replenish the depleted power and expand the travelling distances, relieving the driver's anxiety of insufficient battery charge to reach their destinations. Investments in sustainable charging infrastructure have expanded rapidly in recent years around the world.

In existing literature, very little is known about the economic mechanisms through which the deployment of PCSs affects the economic equilibrium of an urban-space economy. To fill the gap, this paper explores the economic mechanisms through which the location of PCSs affects the commuting costs of EV users, thereby exerting impacts on consumer's choice of vehicle types, land rents and land use patterns, and welfare in equilibrium. Moreover, we analytically solve the optimal location of PCSs under different policy scenarios, and demonstrate how a departure from the optimum affects EV adoption rate, traffic pollution, land rent revenues, and welfare in a quantitative manner.

2. Methodology and Modelling Setup

We integrate EV adoption, traffic pollution externality, and PCSs into the linear urban economic model proposed by Fujita and Ogawa (1982). Consider a monocentric city develops on a long narrow strip of homogeneous land of unit width. As in the literature, we assume that the width of the land is sufficiently small, and hence the city may be treated as a linear city, as shown by Figure 1. The residents face a trade-off by choosing EVs or conventional vehicles (CVs) as the only traffic transportation: the former have higher purchasing prices but lower per-distance fuel costs. In addition, the EV users have to visit the PCSs to charge the vehicles, which may cause additional commuting costs, depending on their residential places and the location of PCSs.

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* Department of Economics, Hiroshima University
〒730-0053, 1-1-89 Higashi-senda-machi, Naka-ku, Hiroshima, E-mail: zhou@hiroshima-u.ac.jp
** Graduate School of Information Sciences, Tohoku University

Moreover, the CVs produce traffic pollution which exerts negative externality to local residents. Each location in the city is representable by a point, x, on the line. Economic activity in the city is assumed to be generated by households and business firms. They interact in several ways: First, households supply labor to business firms, and conversely, business firms pay wages to households; Second, firms and households compete for land in a competitive land market; Third, business firms tend to cluster together to acquire agglomeration economies, but they also compete with each other in a competitive labor market.

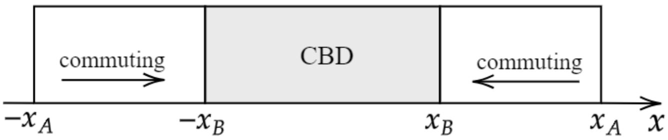

Figure 1: Spatial configuration of a monocentric city.

3. Results

In a competitive land market, our result shows that the residents who choose EVs are endogenously sorted into the suburban districts where they can exploit the advantages of lower per-distance fuel costs of EVs. Moreover, we analytically solve the optimal location of PCSs under different policy scenarios. The result indicates that, under social welfare state, the PCSs shall be located close to the central districts. If the PCSs are located too far from the center, it causes additional commuting costs for EV users and market distortion, which reduces the welfare of residents in equilibrium. However, for a utilitarian government, the optimal location of PCSs shall be at the center of the EV user residential districts, under which the workers receive higher wages and pay lower land rents, leading to maximized utility levels in equilibrium. In contrast, for a rent seeking government, the PCSs shall be located far from the center, under which all the commuters chose CVs and compete to live in the center, causing the highest land rent revenues.

4. Conclusion

By building a linear monocentric urban model with EV adoption and PCSs, this paper disentangles the economic mechanisms through which the location of PCSs affects the equilibrium of an urban-space economy. Moreover, with high analytical solvability, this model gives closed-form solutions of the optimal location of PCSs under different policy scenarios, and demonstrates how a departure from the optimum affects EV adoption rate, traffic pollution, land rent revenues, and welfare in a quantitative manner. Our results provide policy implications for the spatial deployment of PCSs that aims to achieve sustainable cities.

Reference

Fujita, M., Ogawa, H., 1982. Multiple equilibria and structural transition of non-monocentric urban configurations. Regional Science and Urban Economics 12, 161–196