Subsidy, Battery-Swapping Station, and Green Purchase: Evidence from Electric Motorcycles in Taiwan

Yu-Tung Hsieh* and Chih-Hai Yang**

Abstract

This study investigates the influences of government subsidies and battery-swapping stations (BSSs) on the demand for battery electric motorcycles (BEMs) in Taiwan. In addition, we explore whether BSSs in neighboring regions, a network effect, influence BEM purchase. Based on a county-level panel dataset spanning from 2018 to 2022 in Taiwan, our empirical findings highlight the significant role of government subsidies, particularly the "out with the old and in with the new" subsidy, in facilitating BEM adoption. Furthermore, the presence of technological infrastructure, BSSs, positively influences BEM sales. However, our study does not find a robust network effect associated with BSSs in neighboring regions. A battery of robustness checks confirm the above findings.

Keywords: Electric Motorcycle, Subsidy, Battery-swapping Station, Network Effect

JEL Classifications: R41, R42, R48

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I. Introduction

Reducing carbon dioxide (CO2) emissions to combat global warming is a worldwide consensus. Transport CO2 emissions are recognized as one of the main emission sources. The introduction of electric vehicles (EVs), a green product without tailpipe emissions of exhaust gas, could be a feasible strategy to combat worsening air pollution and climate change (Needell et al., 2016), as well as an option for securing ecological balance (Khatua et al., 2023), thereby promoting environmental sustainability. This sustainable transport technology, EVs, also helps reduce petroleum dependence for countries lacking natural resources. Underpinned by the institutional pillars, many countries have adopted a variety of policies and measures to support the development of EV-related industries and the adoption of EVs, mainly subsidy, taxation, technology support, and others (e.g., Chakraborty et al., 2021; Khatua et al., 2023; Zimm, 2021).

Along with the growing popularity of EVs, an emerging and rapidly growing body of literature has investigated the effectiveness of policy schemes in promoting EV adoption, one kind of green purchases,[1] while most existing studies focus on electric cars (E-cars) rather than

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[1] Green purchase is also named as "environmentally preferable purchase". According to the definition of U.S. Department of Health & Human Service, "*it is the affirmative selection and acquisition of products and services that most effectively minimize negative*

electric motorcycles. Theoretically, the subsidy policy can facilitate the adoption of EVs and segment vehicle market among consumers (Chen et al., 2018). Evidence from advanced countries overall finds that subsidies can lower purchase costs and then facilitate EV purchase (intentions), e.g., Norway (Springel, 2021), the UK (Santos and Rembalski, 2021), and the US (Breetz and Salon, 2018). However, Hirte and Tscharaktschiew (2013) argued that EVs should not be subsidized but taxed in Germany. Evidence from China (the most prominent country using and producing EVs) is mixed, exhibiting either positive (Kong et al., 2020; Sheldon and Dua, 2020) or insignificant (Dong et al., 2020; Qiu et al., 2019) results. Although subsidy can reduce consumers' purchase costs, EVs' high purchase price, the high replacement cost of their battery, and rapid depreciation may outweigh fuel savings, making the subsidy incentive ineffective.

Charging infrastructure plays a pivotal role in the widespread adoption of EVs because a well-established charging infrastructure can reduce the range anxiety which is a potential barrier to the widespread adoption of EVs (Egbue and Long, 2012). Drivers of EVs care whether there are sufficient charging stations in close proximity and charging times, which can alleviate range anxiety, thereby facilitating EV purchases (Sonar et al., 2023). Some studies support that the increasing availability of public charging infrastructure drives EV adoption, e.g., Anjos et al. (2020), Illmann and Kluge (2020), Liu et al. (2021), and Schulz and Rode (2022). However, charging speed as well as the number and location of charging stations, are more relevant to consumers' purchase intention (Yu et al., 2018).[2]

Notably, EVs include various types, mainly battery and plug-in hybrid electric vehicles, hydrogen fuel cell electric vehicles, battery electric motorcycles (BEMs), and plug-in hybrid electric scooters. Indeed, BEMs are more crucial than E-cars in metropolitan cities, especially

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environmental impacts over their life cycle of manufacturing, transportation, use and recycling or disposal."

[2] Along with the development of EV battery and charging technologies, the range anxiety and charging speed problems can be mitigated gradually.

in developing countries. However, quantitative research on the aforementioned issues on BEMs is limited. The traffic congestion due to urbanization has caused a need of fast mobile method in cities. Traditional fuel-powered motorcycle is the most popular mode of transportation or vehicle in many emerging Asian economies, such as Indonesia, Malaysia, Thailand, and Vietnam, while gasoline-powered motorcycles may contribute to air pollution and worsen air quality. However, the gasoline motorcycle has the advantages of a low price, high fuel efficiency, and a well-functioned second-hand market. For instance, the average price of 125cc scooters were US$2,333 in Taiwan in 2017 and such a scooter possesses a fuel efficiency of 45-50 km/liter gasoline.[3] Moreover, owners of BEMs have to sign up for different types of subscription packages for replacing empty batteries. This expense is probably higher than gasoline expenditure if they do not ride BEMs for a long riding range per month.

Although the introduction of BEMs provides a cleaner alternative to gasoline-powered motorcycles and helps alleviate air pollution, raising the penetration rate of BEMs may hinge on the effects of government subsidy and technological infrastructure, as discussed in the EVs literature, e.g., Breetz and Salon (2018), Egbue and Long (2012), Santos and Rembalski (2021), Springel (2021), and Sonar et al. (2023). Whether the government subsidy provides sufficient incentives for spurring BEMs purchases? This research question remains less examined because the slower development and lower popularity of BEMs compared with E-cars in most countries.

E-cars require charging-power through converter connecting grid to a fast DC charge in charging stations, whereas BEMs' charging-power demand is fulfilled through battery swapping in battery-swapping stations (BSSs). Unlike EVs require a certain waiting period from the fully discharged state until fully charged, BSSs provide fully charged batteries to replace the used one quickly (one minute). This charging type is a feasible and successful one of different battery charging methods in several countries (Chutima and Tiewmapobsuk, 2021).

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[3] The price and energy efficiency information are obtained from https://autos.yahoo.com.tw/ and the Bureau of Energy, Ministry of Economic Affairs, Taiwan.

However, the development BEMs battery technology is challenging that BEM battery generally possess a short range that confines BEMs to move within a certain limited distance. For instance, the driving range of a two-battery BEMs is about 110km,[4] suggesting that BEMs are incapable of cruising for a long-distance journey.

The distinct features of BEMs battery and charging type inspire a crucial and topical issues: does a widespread establishment of BSSs stimulates more green purchase? Although several studies have examined the determinants of adopting electric motorcycles (Eccarius and Lu, 2020), in-depth quantitative analyses on the influence of BSS on BEMs remain scarce. Notably, do BSSs in neighboring regions generate a network effect that enables BEMs to raise cruising ability, facilitating BEMs sales? Understanding the network effect is helpful for initiating more effective policies to promote BEMs diffusion. The aforementioned issues regarding BEMs diffusion are particularly relevant to developing countries which require cleaner and cheaper transportation vehicles.

The study employs a county-level panel dataset from 2018 to 2022 to analyze how government subsidy and BSSs affect sales of BEMs in Taiwan, aiming to provide several new aspects to the literature. First, even though some studies have examined determinants of EMs (BEMs) purchase (see literature review on section 2), they focus on consumers' purchase intention rather than actual EM sales. Taiwan provides an excellent example because its development of BEMs (e.g., small e-scooters) and battery-swapping systems are globally renowned. Its experience can set an example for countries that would like to promote the use of BEMs and provide policy implications. Second, we provide one of first evidence on the influence of technology infrastructure, BSS, on demand of BEMs. Specifically, both numbers of BSSs and batteries are considered because the number of batteries contained in a BSS varies

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[4] Batteries can be classified into three generations which were introduced in 2015, 2017, and 2019. The third-generation battery increased 27% in cruising endurability, reaching approximately 59KM based on the official test of BEMs manufacturers. Alternatively, the battery of E-cars can provide a maximum driving range longer than 800 kilometers in 2023.

considerably. Considering the short range of BEMs battery, this study further examines the potential network effect brought by BSSs established in neighboring regions. EV literature (e.g., Greaker, 2021; Qian et al., 2024; Springel, 2021) claims a positive spatial network effect of infrastructure on EV adoption, while this issue is not yet examined for electric motorcycles. BEMs are widely recognized as a transportation vehicle used in metropolitans, implying that the network effect is probably less matter to BEMs purchase. If a regional network effect exists, it can facilitate BEMs to function as cars to commute across regions. Third, compared with cross-sectional analyses through consumer survey in previous studies, our panel data analysis enables us to examine the within effect rather than correlation between covariates and green purchase. As indicated in Li et al. (2017), EV adoption and charging station investment are interdependent. The panel data analysis also helps clarify the causal relation between BSSs and the demand of BEMs.

The remainder of this paper proceeds as follows. Section 2 briefly overviews the development of BEMs in Taiwan and reviews the literature. Section 3 introduces the data and empirical model. Section 4 presents and discusses estimation results about the influences of subsidies and BSSs on BEMs sales. Section 5 concludes the paper and discusses the policy and management implications of this study.

II. BEMs in Taiwan and Literature Review

A. Overview of the Development of the BEMs Industry in Taiwan

The motorcycle, known for its high mobility and affordability, in combination with climate and driving conditions, is the most popular vehicle in Taiwan. For instance, the accumulated number of motorcycles per hundred persons was 98.2 in Taiwan in 2022, Asia's highest density,[5] implying that almost everyone owns a motorcycle. Given the importance of environmental sustainability, the Taiwan government launched the program “Development of Electric Motorcycles (EMs)” in 1999 to support the development of the EM industry, hoping to reduce gasoline-powered motorcycles.[6] Six incumbent major motorcycle manufacturers organized an alliance team to develop BEMs while they remained focused on improving the fuel efficiency of gasoline engines. Although a small variety of BEMs were introduced to the market, they use valve-regulated lead–acid batteries, which are heavy and provide a very short driving range but take a long charging time. In combination with a high vehicle price, they were not widely accepted by green consumers. Therefore, the progress in promoting BEMs was slow in the 2000s.

The development and diffusion of EVs rely heavily on a range of conditions. Regarding EMs, charging patterns, charging infrastructure, and government policies could be influential factors. The government implemented “Directions of Subsidization for Electric Scooter Industry Promotion” to break the current stagnation in 2009. It subsidized not only electric motorcycle manufacturers but also the purchase of electric motorcycles. Further, the transportation authority began to issue EM-specific license plates in 2010, implying that EMs are granted a waiver for the fuel tax. Crucially, as older motorcycles have a worse energy efficiency and emission performance, replacing them with electric motorcycles contributes more to reducing total emissions than a new purchase. Thus, the “Measure of Eliminating Two-stroke Engine Motorcycle and Subsidization for Two-wheeled Electric Vehicle” was promulgated in 2015 that provided a larger amount of subsidy for ‘out with the old and in with

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[5] The corresponding number of cars per hundred persons is 36.3. Data source: https://stat.motc.gov.tw.

[6] Huang et al. (2018) argued that the subsidy policy for energy technologies of EVs should be terminated when energy technologies are well developed that enable the EV production to exhibit economies of scale.

the new' (hereafter, old-to-new) than the 'new purchase' subsidy.[7] Additionally, to further stimulate BEMs diffusion, local (city and county) governments offered the corresponding co-subsidy, depending on their fiscal conditions.

On the supply side, Gogoro Inc., a unique BEMs-specialized firm, was established in 2011; it emphasized developing the lithium-ion (Li-Ion) battery along with the advances in fuel battery technologies.[8] Given the importance of charging infrastructure in facilitating sales, this company began constructing BSSs GoStation (Figure 1).[9] The number of stations increased from 110 in 2015 to 2,419 in 2022. Benefiting from the government subsidy for both BEMs manufacturers and buyers and increasingly widespread BSSs, this company dominated the BEMs market, reaching a market share of approximately 90% in 2018. The traditional motorcycle brands also tried to develop Li-Ion EMs, and most of them joined Gogoro's BSS network, the Powered by Gogoro Network (PBGN).[10] In 2021, BEMs sold by the members of PBGN accounted for 94.3% (Gogoro, 79.1%).

As depicted in Figure 2, the annual number of licensed EMs slightly decreased in

[7] Although the subsidy for replacing two-stroke engine motorcycles by BEMs was terminated in 2019, the old-to-new subsidy continued to be implemented for replacing older motorcycles.

[8] Gogoro Inc. was initial public offering and listed on Nasdaq in 2022. The stock market code for the company is GGR.

[9] Figure 1 shows that there are 40 batteries in this BSS. Indeed, the number of battery swapping sets (one set contains 8 batteries) in a station depends on its location (urban or rural) and space.

[10] Among the seven EM brands, six firms joined the PBGN. The exceptional one, Kymco, which is a large traditional brand, established another BSS network, Ionex. There are also charging-battery EMs sold in Taiwan, but the market is extremely small. Gogoro has promoted the PBGN system to other countries and there are 9 countries adopting this system in 2023.

2012-2014 and has increased since 2015. Because the BEMs subsidy was promulgated in 2015, presumably this policy facilitated green purchase and this hypothesis will be tested. This number peaked at 168,537 in 2019 and slightly decreased due to the COVID-19 pandemic. The ratio of licensed BEMs in total licensed motorcycles increased from 0.76% in 2015 to 18.68% in 2019 and remained stable, hovering 11%. This trend could be attributed to various causes. The subsidy measure was reviewed and revised every few years and it might affect the demand of BEMs. Moreover, the government announced to postpone the 2035 goal of stopping sales of fossil-powered motorcycles in 2019, implying that green purchase is probably not an urgent need.

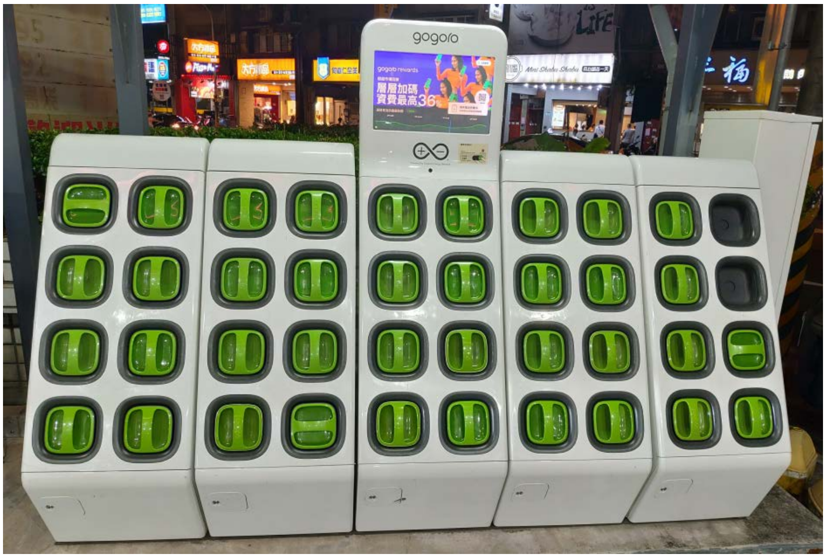

Figure 1　Battery-swapping stations, GoStation

Source: photographed by one of authors. A BSS located in a gasoline station.

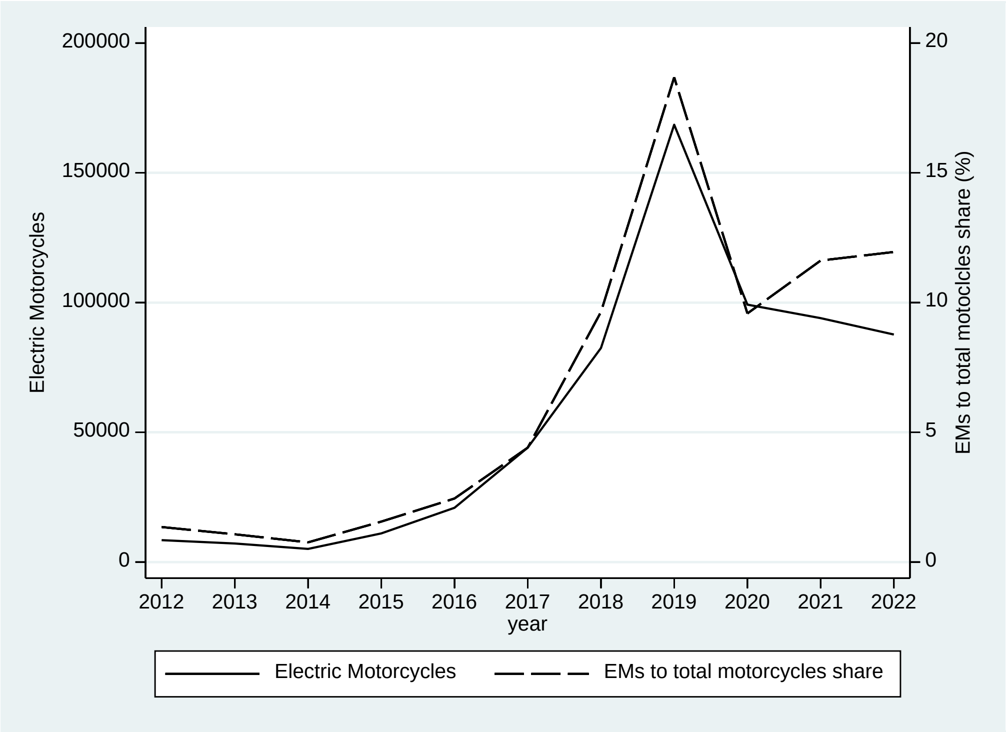

Figure 2 Annual Electric Motorcycles (EMs) and Its Share to Total Motorcycles

Source: Ministry of Transportation and Communications, Taiwan.

B. Literature Review

The growing prevalence of EMs has attracted an emerging literature to analyze the determinants of purchase intention of EMs in the past decade. As previous literature on EVs purchased focuses on the roles of government subsidy and charging infrastructure based on theoretical arguments (e.g., Chakraborty et al., 2021; Chen et al., 2018), extant studies also examined these key factors. They mainly use survey of potential consumers and focus on Asia countries, which account for 80% of the global EMs sales (Eccarius and Lu, 2020).

Jones et al. (2013) is one of first studies analyzing the effects of economic incentives and technological improvements in the adoption of EMs in Vietnam. Using a preference survey of consumers, results indicate that technological advance in battery efficiency and sales taxes have significant effects on adoption. Su et al. (2023) and Truong (2023) also examined purchasing intention of potential EMs consumers. They found that attitude factors are necessary conditions; technological factors also positively influence purchase intention, such as recharge duration and driving range. Crucially, Truong (2023) argued that potential EM users prefer subsidies for operating costs, including electricity purchase price and road-use tax.

In view of the growing EM market in Indonesian, several studies examined consumers' willingness to adopt electric motorcycles by focusing EM, battery, and respondent characteristics (Guerra, 2019; Murtiningrum et al., 2022; Yuniaristanto et al., 2022). Although EM characteristics matter to purchase intention, battery charging system and technology are more relevant to EM diffusion because consumers are deeply concerned about the charge time (Guerra, 2019); Consumers' perception of EM and environmental benefits are also relevant to purchase intention (Murtiningrum et al., 2022; Yuniaristanto et al., 2022).

India, the world's most populated country, has a huge domestic market for EMs. Ray and Sahney (2022) indicated that cultural factors (e.g., collectivism, long-term orientation, and masculinity) influence consumers' green purchase intention. Consistent with findings in other Asian countries, price, tax, infrastructures, and refueling (charging) time are significant determinants of the choice between EMs and traditional motorcycles (Chakraborty and Chakravarty, 2023). Characteristics of EMs are also perceived as influential attributes of consumers' choice decisions (Patil et al., 2021), such as top speed, acceleration, and charging duration.

Evidence from a consumer survey, Zhou et al. (2016) found that 65% of respondents have intention to purchase EMs in Macau, a small region suitable for EM use. The factors positively associated with the purchase intention include cognitive level, environmental consciousness and policy, charge time and cost, and driving performance (Liu and Lai, 2020; Zhou et al., 2016). The cognitive level for products and environmental concerns are also crucial factors that affect the purchase intention of potential users in Taiwan (Chen et al., 2021; Wu et al., 2015).[11]

Reviewing the literature, aforementioned studies analyzed antecedents of purchase intention through preference surveys of consumers. Although they have highlighted the vital role of subsidy and charging infrastructure on purchase *intention*, but not for actual amount of EM (or BEMs) sales. Also, they do not quantify the effects of subsidy and charging infrastructure on facilitating EMs diffusion. Our study aims to fill this research gap.

III. Empirical Specification and Data

To quantify the influences of government subsidy and charging infrastructure on BEMs sales, we specify the baseline model as follows:

$$\begin{aligned} \ln BMotor_{it} &= \alpha_1 \ln Subsidy_{it} + \alpha_2 \ln BStation_{it} + \alpha_3 \ln Network_{it} \\ &\quad + \beta_1 \ln SIZE_{it} + \beta_2 \ln INCOME_{it} + u_i + v_t + \varepsilon_{it} \end{aligned} \tag{1}$$

The outcome variable *BMotor* is the number of sold BEMs in region *i* and period *t*. Regarding incentive and technology variables, *Subsidy* is government subsidy. Previous discussions have mentioned two kinds of subsidies: new purchases and old-to-new subsidies, which are accompanied by corresponding co-subsidies provided by the local government. Thus, either new purchase or old-to-new subsidy varies across regions. However, detailed information regarding the shares of new purchases and old-to-new sales in total sales is

[11] Scorrano and Danielis (2021) also examined factors differentiating adoption of electric and petrol scooters in an advanced country, Italy. Their focused factors include the scooter's technical characteristics, financial attributes, and the respondents' socio-demographic variables. Please see Eccarius and Lu (2020) for a review of earlier studies regarding the adoption of EMs.

unavailable. Because each green purchase can apply either new purchase or old-to-new subsidies, implying that the amount of subsidy ranges between these two subsidies. Thus, we adopt several measures of government subsidy variables through various weighting schemes. The first two are a region's new purchase subsidy (New_Subsidy) and old-to-new subsidy (O_N_Subsidy). The third one is a weighting average of new purchases and old-to-new subsidies with a weight of 0.25 (0.5) and 0.75 (0.5), respectively (W1_Subsidy and W2_Subsidy). This weighting strategy is because the old-to-new subsidy is much larger than the new purchase subsidy, and it has witnessed a fast BEMs diffusion since 2015 (Figure 2) when the old-to-new policy measure was promulgated.[12] *BStation* is the number of new BSS built in a region in a period, denoting the charging infrastructure. An alternative measure, the number of newly installed batteries (*Battery*), is also adopted. It is because the equipped number of batteries varies across BSSs, depending on the location of a BSS. BEMs companies allocate more batteries to BSSs located in densely populated areas, whereas BSSs located in rural areas put fewer batteries.

As charging stations have a network externality for electric vehicles (Springel, 2021), another examined key issue is: whether the widespread BSSs in other regions generate a network effect stimulating BEMs sales. Here, we use the number of adjoining regions' BSSs to measure this potential positive externality (*Network*). The adjoining region is defined as counties that share county border with one county.

Regarding other regional characteristics that affect the demand for EM, we include mainly market size (*Size*) and income (*Income*) which are measured by the population and per capita yearly disposable income in a region. Other factors, such as the prices of gasoline and gasoline motorcycles, may be relevant to the decision of adopting EMs, while they are the same across regions and cannot be estimated; moreover, the preference of EM may vary across regions. Thus, we include a series of region dummies (u) to capture regional fixed effect. Finally, v and

[12] We have also tried various weighting combinations by assigning a larger weight to the old-to-new subsidy. Estimates on the subsidy variable are associated with the same sign and statistical significance.

ε are a series of dummies and the white-noise error term.

Unlike previous analyses obtained through preference surveys of consumers, this study adopts actual information of BEMs sale, subsidy amount, and BSS (battery) number. A county-level panel data in 2018-2022 is adopted and the dataset is drawn from various sources. The main source is the databank of the "Network of Electric Motorcycle Industry,"[13] which is maintained by the Industrial Technology Research Institute. This databank contains information on the number of subsidized BEMs in each county/city. The number of subsidized BEMs is slightly smaller than that of licensed BEMs, while it is an adequate measure of BEMs diffusion because the public procurement of BEMs is not included in the statistics of subsidized BEMs.[14] This databank also collects information on subsidies provided by the government (Ministry of Economic Affairs and Ministry of Environment) and the local government (county/city) across years. As the list of local government subsidies is incomplete, we refer to the websites of individual local governments to restore missing information.

Regarding this technological infrastructure, we construct this variable using the number of GoStations because the PBGN-powered BEMs account for more than 90% of the market. However, collecting the number of GoStations in each region across years is a big challenge. The detailed location information of individual BSS is available from the Gogoro website because providing a BSS map for riders is necessary, while the operation date information of each BSS is unavailable. Fortunately, one website designed by an engineer provides the date of operation for individual GoStation, which began to operate in 2018.[15] Using the Python

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[13] https://www.lev.org.tw/.

[14] Separating subsidized BEMs into new purchase subsidy and old-to-new subsidy enables us to evaluate the effectiveness of two subsidy measures precisely. However, this information is unavailable after requesting from each local government. This is the main data limitation of this study.

[15] https://mowd.tw/gostation/map/. The information about the establishment date of GoStations which began to operate earlier than 2018 is unavailable.

programming to record the establishment data of each BSS and then linking to Gogoro website to check the correctness, we obtain the number of GoStations (BSSs) and their battery numbers of individual region each year in the period between 2018 and 2022. The information of two regional variables, population and per capita yearly disposable income, is drawn from the National Statistics of Taiwan.[16]

To evaluate the network effect, we use 19 counties located in the main island of Taiwan which have adjoining regions, implying that the three island counties (Penghu, Kinmen, and Lienchiang) are excluded. Furthermore, considering the charging station information, we use the sale of BEMs in a half-year as an observation and obtain ten-period, regional-level panel data in 2018-2022, yielding a total of 190 observations. Table 1 summarizes variable definitions and their descriptive statistics.[17]

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[16] https://www.stat.gov.tw/.

[17] The correlation coefficient matrix of independent variables is summarized in the Appendix Table.

Table 1 Variables Definitions and Basic Statistics

Variable	Definition	Mean (S.D.)
BMotor	The number of sold battery electric motorcycles	2,686 (3,632)
New_Subsidy	New purchase subsidy: subsidizing people for purchasing a new electric motorcycle (NT dollar)	13,381 (5,341)
O_N_Subsidy	Old-to-new subsidy: subsidizing a gasoline-fueled motorcycle owner for purchasing an electric motorcycle by abandoning the old one (NT dollar)	19,319 (6,075)
W1_Subsidy	Weighted subsidy: weights for new subsidy and old-to-new subsidy are 0.25 and 0.75, respectively.	17,834 (5,652)
W2_Subsidy	Weighted subsidy: The weights for new subsidy and old-to-new subsidy are 0.5 and 0.5, respectively.	16,350 (5,375)
BStation	The number of new battery-swapping station	17.00 (25.01)
BStation_stock	The accumulated number of battery-swapping station in a region	113.38 (133.96)
Battery	The number of new installed batteries	522.72 (816.84)
Network_S	Network of BSS: the number of battery-swapping stations in neighboring regions	453.01 (325.35)
Network_B	Network of battery: the number of installed batteries in neighboring regions.	13,693 (10,287)
SIZE	the population in a region (thousand)	1,219.25 (1,107.35)
INCOME	per capita yearly disposable income in a region (NT$ thousand)	345.90 (53.08)

IV. Results and Discussion

Table 2 reports the empirical results by focusing on the effect of government subsidy. The estimation strategy is as follows: we first conduct estimations by using both random effect (RE) and fixed effect (FE) of panel data model in columns 1 and 2, respectively. The RE model assumes that individual effects are not correlated with covariates, whereas FE model assumes individual effects are correlated with covariates. The Hausman test can judge which one is more adequate: if the value of Hausman test is statistically significant, it suggests that the FE model is more adequate. However, the Hausman test statistics may not be calculated (appears a negative value) sometimes because the asymptotic assumptions of the Hausman may not hold; individual effects are probably correlated with few covariates only. Encountering this situation, an alternative approach is Mundlak RE estimation by adding the time averages of the time-variant explanatory variables as additional covariates. Judge the adequateness of this approach based on the Mundlak test (Mundlak, 1978). A statistically significant value of Mundlak test indicates this approach is adequate. Columns 4 – 6 present estimation results of the RE model because the Hausman test does not reject the null hypothesis.

Notably, all estimated coefficients of the subsidy variable are positive and significant in all estimations. This result suggests that government subsidy serves as an effective economic incentive to facilitate BEMs sales. Our finding echoes the importance of economic incentives on green purchases, evidenced by EVs (e.g., Breetz and Salon, 2018; Kong et al., 2020; Santos and Rembalski, 2021; Sheldon and Dua, 2020; Springel, 2021).

Estimated magnitudes of coefficients on subsidy suggest that old-to-new subsidy exhibits a larger enhancement effect on BEMs diffusion than that of new purchase subsidy. It is an encouraging result from the policy perspective because the old-to-new purchase has an incremental emission reduction effect by replacing an old gasoline-powered motorcycle.

Table 2　Government Subsidy and Sales of Battery Electric Motorcycles

	(1) RE	(2) FE	(3) RE Mundlak	(4) RE	(5) RE	(6) RE
lnNew_Subsidy	0.556***	0.493***	0.493***			
	(0.129)	(0.134)	(0.134)			
lnO_N_Subsidy				0.665***		
				(0.132)		
lnW1_Subsidy					0.966***	
					(0.152)	
lnW2_Subsidy						0.862***
						(0.145)
lnSIZE	1.153***	0.711*	0.711*	1.117***	1.111***	1.108**
	(0.079)	(0.398)	(0.398)	(0.085)	(0.081)	(0.083)
lnINCOME	0.492	−0.615	−0.615	0.352	0.505	0.431
	(0.472)	(0.950)	(0.950)	(0.493)	(0.473)	(0.483)
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	No	Yes	No	No	No	No
Means (variant variable)	No	No	Yes	No	No	No
R-square	0.895	0.672	0.899	0.891	0.900	0.896
Hausman test		4.10		3.21	1.89	2.44
Mundlak test			4.04			
Observations	190	190	190	190	190	190

Note: All estimations include a constant term. Figures in parentheses are standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A 1% increase in old-to-new (new purchase) subsidy is associated with a 0.665% (0.556%) increase in BEM sales, highlighting that the BEM diffusion effect of government subsidy is considerable in Taiwan. Another interesting finding is that this diffusion effect is larger in the weighting measure of government subsidy. Thus, the government can consider adequate subsidies for new and old-to-new purchases to enhance the diffusion of BEMs.

Regarding other factors, we find market size exhibits a larger positive association with the demand for BEMs: a 1% increase in regional population is accompanied with a more 1.1% increase in BEMs sales. This result is intuitive economically, because firms can sell more BEMs in a larger market, *ceteris paribus*. However, income is less relevant to the purchase of BMEs. Although higher disposable income enables people to be capable to purchase BEMs, high-income people may prefer purchasing cars rather than motorcycles on the one hand. On the other hand, the subsidy may neutralize the income effect of green purchase. Thus, income has no significant influence on the demand for BEMs.

Next, we examine the role of technological infrastructure, BSSs, in affecting BEM sales. Table 3 presents various estimation results. Estimates in columns 1 – 8 are obtained by using various estimation techniques referring to the statistical criterion of Hausman and Mundlak tests.

As shown in Columns 1 – 4, the ln*BStation* is associated with a significantly positive coefficient in all estimations, indicating the facilitating role of charging infrastructure on BEM demand. A 1% increase in the number of BSSs in a period is associated with a 0.077% – 0.109% increase in the sale of BEMs in a region, on average. Our results support the importance of technological infrastructure on BEM diffusion, as found in EVs (Sonar et al., 2023). More BSSs going into operation enables riders of BEMs to mitigate range anxiety, thereby increasing their intention to purchase BEMs.

However, when the technological infrastructure is measured by the number of newly installed batteries (columns 5 – 8), we overall find an insignificant coefficient associated with ln*Battery*, except for the estimate in column 6 which is significant at the 10% statistical level. This inconsistent result arises from the fact that riders of BEMs care more about the number and location of BSSs rather than the number of batteries. As illustrated in Figure 1, a BSS generally contains many batteries. One BEM uses only one or two batteries, so it is easy for a rider to find one/two full-charging batteries (or with a certain percentage of power) to replace the empty batteries.

Table 3 Battery Swapping Stations and Sales of Battery Electric Motorcycles

	(1) Mundlak RE	(2) RE	(3) FE	(4) RE	(5) Mundlak RE	(6) RE	(7) FE	(8) RE
lnNew_Subsidy	0.458***				0.474***			
	(0.134)				(0.135)			
lnO_N_Subsidy		0.660***				0.657***		
		(0.130)				(0.131)		
lnW1_Subsidy			0.907***				0.921***	
			(0.163)				(0.164)	
lnW2_Subsidy				0.841***				0.847***
				(0.143)				(0.145)
lnBStation	0.082*	0.109***	0.077*	0.101**				
	(0.044)	(0.041)	(0.041)	(0.040)				
lnBattery					0.031	0.038*	0.027	0.035
					(0.023)	(0.022)	(0.022)	(0.022)
lnSIZE	0.743*	1.033***	0.815**	1.032**	0.714*	1.079***	0.787**	1.074**
	(0.395)	(0.082)	(0.375)	(0.079)	(0.397)	(0.085)	(0.376)	(0.081)
lnINCOME	−0.901	0.290	−0.469	0.380	−0.774	0.303	−0.344	0.394
	(0.955)	(0.452)	(0.909)	(0.435)	(0.956)	(0.478)	(0.911)	(0.459)
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	No	No	Yes	No	No	No	Yes	No
Means (variant variables)	Yes	No	No	No	Yes	No	No	No
R-square	0.920	0.898	0.921	0.903	0.917	0.947	0.705	0.909
Hausman test	−10.61	18.33	393.65***	26.58	−1.11	8.02	52.46***	9.74
Mundlak test	14.29***				12.35**			
Observations	190	190	190	190	190	190	190	190

Note: All estimations include a constant term. Figures in parentheses are standard errors. A negative value of the Hausman test denotes model fitted on these data fails to meet the asymptotic assumptions of the Hausman test. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Literature of EM purchase intention (section 2.2) argued that government subsidy and charging infrastructure affect the purchase propensity of potential BEM users, while it did not evaluate the economic magnitude of their effect. Our above analysis echoes the argument in literature and, more importantly, provides quantitative evidence on their influences on sales of BEMs. The finding of varying effects of new purchase subsidy and old-to-new subsidy on the demand of BEM also provides indirect evidence to support the theoretical argument in Chen et al. (2018) that various subsidy policies may influence and segment the vehicle market.

As discussed above, one disadvantage of BEMs is the short cruising endurability compared with their gasoline counterparts. A BSSs in neighboring regions could generate a positive network effect that extends BEMs' drive range, enabling BEMs to be capable of long-distance journeys like cars, thereby lowering the range anxiety. To examine whether this network effect further stimulates the sales of BEMs, we add the network variable to implement estimation and report results in Table 4.

Columns 1–4 show that ln*Network_S* is associated with an insignificant coefficient. Similarly, using batteries (ln*Network_B*) as the measure of network effect, its estimated coefficient is overall insignificant, except for the estimate in column 7 which is significantly positive at the 10% statistical level. Across various specifications, our analyses find a limited network effect on the demand market of BEMs. This first evidence on the network effect – green purchase nexus in BEMs contradicts with the argument that charging stations are characterized by a network effect for EVs (Greaker, 2021; Qian et al., 2024; Springel, 2021) and it is probably attributed to the difference in usage patterns between BEMs and E-cars.

BEMs are not the popular two-wheel vehicles for long-distance journeys compared to gasoline motorcycles, particularly heavy ones. Instead, the daily commute and a short-distance means of transportation are the main purpose of using BEMs in townships and cities in Taiwan. Drivers of BEMs are normally not familiar with road and traffic conditions and the deployment of BSSs in other regions. Indeed, more geographically widespread

Table 4 Network of Battery Swapping Stations and Sales of Battery Electric Motorcycles

	(1) RE	(2) Mundlak RE	(3) Mundlak RE	(4) Mundlak RE	(5) RE	(6) RE	(7) Mundlak RE	(8) Mundlak RE
lnNew_Subsidy	0.517***				0.509***			
	(0.129)				(0.130)			
lnO_N_Subsidy		0.603***				0.634***		
		(0.139)				(0.132)		
lnW1_Subsidy			0.862***				0.879***	
			(0.165)				(0.163)	
lnW2_Subsidy				0.781***				0.794***
				(0.156)				(0.154)
lnBStation	0.101**	0.096**	0.077*	0.087**	0.101*	0.111**	0.075*	0.086**
	(0.043)	(0.042)	(0.041)	(0.041)	(0.043)	(0.041)	(0.041)	(0.041)
lnNetwork_S	−0.115	0.653	0.584	0.585				
	(0.170)	(0.421)	(0.411)	(0.415)				
lnNetwork_B					−0.107	−0.082	0.658*	0.611
					(0.084)	(0.076)	(0.396)	(0.400)
lnSIZE	1.097***	0.655*	0.714*	0.697*	1.097***	1.050***	0.655*	0.648*
	(0.093)	(0.388)	(0.380)	(0.382)	(0.072)	(0.083)	(0.385)	(0.388)
lnINCOME	0.276	−0.934	−0.485	−0.669	0.278	0.140	−0.397	−0.593
	(0.418)	(0.918)	(0.906)	(0.907)	(0.417)	(0.471)	(0.905)	(0.907)
Period FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Means (variant variable)	No	Yes	Yes	Yes	No	No	Yes	Yes
R-square	0.906	0.915	0.923	0.920	0.906	0.902	0.924	0.920
Hausman test	0.25	−0.07	−10.94	−11.99	1.74	0.03	−2.17	−3.77
Mundlak test		10.22*	10.59*	9.85*			11.40**	10.23*
Observations	190	190	190	190	190	190	190	190

Note: All estimations include a constant term. Figures in parentheses are standard errors. A negative value of the Hausman test denotes model fitted on these data fails to meet the asymptotic assumptions of the Hausman test. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

technological infrastructure in neighboring regions, in terms of stations or batteries, can largely alleviate the range anxiety in riding a BEM for traveling to other regions. Meanwhile, the comprehensive information regarding locations for BSSs provided by BEM manufacturers has helped BEM drivers to find battery stations in other regions easily. In combination with the rarely use of BEMs for long-distance journeys in Taiwan, this indirect network effect on fostering BEM sales is limited.

V. Robustness Checks

The analysis above finds significant influences of government subsidy, BSSs, and the network effect of BSSs on the demand for BEMs are pronounced. The subsidy policy is an exogeneous that is determined by the government. However, the establishments of BSSs might be BEM manufacturers' strategy by considering sales of BEMs simultaneously. Prior studies on EVs (e.g., Mortimer et al., 2022) also demonstrated that growth in EVs per year leads to more charging parks in urban agglomeration areas. As there is an interdependence between EV adoption and charging station investment (Li et al., 2017),

Thus, one may be concerned about the possibility that more BEMs lead firms to construct more BSSs, implying a simultaneity problem. This "chicken-and-egg" link could be minor in the BEMs market. As mentioned by the manager of a BEM company, the supply of BSSs already exceeds market demand. Notwithstanding, constructing sufficient technological infrastructure in advance enables potential customers to feel relieved about purchasing and using BEMs. Specifically, there are barriers to the construction of a BSS that require support from the government, such as land acquirement, specialized electric application, coordination with nearby stores, and others. There exists a certain time lag if the establishment of BSSs is brought by the increased sales.

To alleviate the concern of the endogeneity problem, we implement a panel causality test developed by Dumitrescu and Hurlin (2012) and report testing results in Table 5. The results show that at one-period lag length, tests statistics are associated with a *p*-value larger than 10%, indicating that the null hypothesis cannot be rejected. In other words, there is no causality from BEM sales to the number of newly established BSSs.

We also adopt two strategies to mitigate this simultaneity problem, in order to obtain robust estimates on the role BSSs on facilitating BEMs diffusion. First, we replace the flow measure of battery stations (*BStation*) by a stock measure one (*BStation_stock*) because the stock measure is the accumulated number of BSSs which cannot be simultaneously determined by considering the current sales of BEMs. Second, this study adopts the system generalized method of moment (system-GMM) developed by Arellano and Bover (1995) and Blundell and Bond (1998) to implement estimation. This technique can not only examine the potential persistence in sales of BEMs, but also deal with the endogeneity problem. Table 6 shows estimation results.

As illustrated in columns 1 – 4, the stock of BSSs has a significantly positive influence on sales of BEMs. When the number of BSSs increase 1% in a region, it is accompanied with a 0.249% – 0.290% increase in sales of BEMs. These robustness checks above confirm the finding that BSSs are a critical factor of facilitating sales of BEMs in Taiwan. However, lnNetwork_S is again associated with an insignificant coefficient, indicating that there is no network effects on stimulating BEMs sales brought by BSSs in neighboring regions.

Table 5 Panel Causality Test

Lag order: 1	
W-bar =	0.553
Z-bar =	−1.378 (0.488)
Z-bar tilde =	−1.231 (0.276)
H0: BEM sale does not Granger-cause new BSS	
H1: BEM sale does Granger-cause new BSS for at least one panel (region)	

Note: Figures in parentheses are *p*-values computed using 500 bootstrap replications.

Table 6　Robustness Checks

	(1) RE	(2) RE	(3) RE	(4) RE	(5) System-GMM
lnBMotor(-1)					−0.668
					(0.452)
lnN_Subsidy	0.532***	0.501***			0.362***
	(0.127)	(0.128)			(0.128)
lnW1_Subsidy			0.908***	0.890***	
			(0.150)	(0.153)	
lnBStation_stock	0.290***	0.282***	0.254***	0.249***	1.052*
	(0.095)	(0.095)	(0.093)	(0.094)	(0.568)
lnNetwork_S		−0.099		−0.054	
		(0.070)	(0.408)	(0.077)	
lnSIZE	0.845***	0.875***	0.847***	0.865***	0.542
	(0.118)	(0.120)	(0.119)	(0.121)	(0.549)
lnINCOME	0.543	0.328	0.502	0.389	3.845**
	(0.383)	(0.416)	(0.410)	(0.444)	(1.516)
Period FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
R-square	0.909	0.913	0.914	0.915	
Hausman test	12.47	14.92	4.51	6.12	
AR(1) (p-value)					0.607
AR(2) (p-value)					0.225
Sargan test					3.390
Observations	190	190	190	190	171

Note: All estimations include a constant term. Figures in parentheses are standard errors.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The system-GMM estimation in column 5 reconfirms the role of BSSs in sales of BEMs. Notably, the estimated coefficient of one-year lagged dependent variable (sales of BEMs) is insignificant, in combination with the AR(1) test displayed on the bottom of Table 6, the sales of BEMs in a region do not appear a persistent feature.

VI. Concluding

Two-wheel motorcycle is the most popular vehicle in most developing and less developed countries, while gasoline-powered motorcycles contribute to a substantial emission of air pollutants. The diffusion of BEMs is a feasible strategy to reduce CO2 emissions and sustain the environment. Although an emerging line of studies have indicated the important roles of government subsidy and charging infrastructure on consumers' intention of adopting EVs, the determinants of actual BEM sales remains unexplored.

This study provides one of the first evidence of the influences of government subsidy and battery-swapping stations on the demand of BEMs. Notably, the issue of whether BSSs in neighboring regions generate a network effect to facilitate more demand of BEMs is also examined in this study. Based on half-year BEM sales and BSS deployment in each county/city in Taiwan from 2018 to 2022, our empirical estimations find that government subsidy and have an enhancing effect on BEM sales. Compared with new purchase subsidy, the stimulation effect enhancement effect on BEM sales induced by old-to-new subsidy is larger, highlighting the varying effects of different subsidy policies. Constructing new BSSs and installing more batteries also lead to more sales of BEMs in a region. Benefited from the feature of panel data, the panel causality test confirms that there is no causal relation from BSSs to BEM sales, and *vice versa*. However, the deployment of BSSs across regions does not generate a network effect to promoting BEM adoption indirectly because the short-range battery electric motors are mainly used for means of transportation rather than across-region cruise.

Some insightful policy and management implications obtained from our analyses for Taiwan can be helpful for developing countries that intend to promote the adoption of BEMs. First, government subsidy is an effective economic incentive and particularly, the old-to-new subsidy has a larger stimulation effect than new purchase subsidy. The "out with the old and in with the new," strategy can contribute to environmental sustainability effectively in the short-run because it encourages the old gasoline-powered motorcycles which generate more exhaust gas emissions. Thus, designing a more efficient one is a feasible strategy. However, both subsidy schemes are composed of government and local government subsidies, as well as depend on fiscal conditions to provide various amounts of subsidies across years. Sufficient fiscal resources to afford the subsidy expenditure is one thing; the argument vis-a-vis unfair subsidy by non-subsidized gasoline motorcycle firms is another. Therefore, the implementation of economic incentives can consider the composition between subsidy and tax credit as claimed in the theoretical work of Chakraborty et al. (2021).

Second, we confirm the vital role of technological infrastructure within regions in facilitating demand for BEMs. Notably, no causal relation exists from demand to BSS in the BEMs market, contrasting to the finding in the market for EV (Li et al., 2017). Establishing battery swapping stations is a prerequisite infrastructure for promoting BEM adoption, while there are barriers that need to be overcome by firms. Government support can play a critical role in the construction of technological infrastructure. In addition to widely adopted policies, such as subsidies and tax credits, several measures implemented by Taiwan's government might be effective and worth taking as a reference. Land acquisition is the largest obstacle to constructing a swapping station. The government requires gasoline stations to accept the establishment of BSSs (an example is shown in Figure 1) and assists firms in establishing BSSs in public areas. Moreover, the widespread conventional stores also assist firms in establishing swapping stations, helping the diffusion of technological infrastructure.

Two management implications inspired by this analysis. First, though government subsidy facilitates the demand for BEMs, this subsidy cannot last a long time. BEM manufacturing firms should consider the issue of how to reduce the production cost, enabling potential users to purchase this green product with a lower price. Then, the goal of replacing gasoline motorcycles by BEMs can be achieved gradually.[18] Secondly, the insignificant network effect

[18] Although our study did not examine the influence of battery subscription package on purchase decision, Hsu et al. (2021) indicated that the monthly battery payment is more

of BSSs in neighboring regions is probably attributed to the range limitation of battery that becomes a disincentive to long journey for riders. Thus, developing long-range batteries for BEMs, as the continuous technological progress in EVs' battery, remains a key technology issue in promoting electric vehicles.

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Appendix. Supplementary material

Supplementary data to this article can be requested from the authors.

expensive than the fuel motors. Thus, BEMs companies can consider the pricing strategies of battery subscription packages for high- and low-mileages users.

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Appendix Table Correlation Coefficient Matrix

	lnNew_Subsidy	lnO_N_Subsidy	lnW1_Subsidy	lnW2_Subsidy	lnBStation	lnBattery	lnNetwork_S	lnNetwork_S	lnSIZE	lnINCOME
lnNew_Subsidy	1									
lnO_N_Subsidy	0.692	1								
lnW1_Subsidy	0.907	0.927	1							
lnW2_Subsidy	0.808	0.983	0.980	1						
lnBStation	0.188	0.374	0.305	0.347	1					
lnBattery	0.155	0.363	0.281	0.329	0.949	1				
lnNetwork_S	–0.460	–0.511	–0.526	–0.526	–0.132	–0.145	1			
lnNetwork_B	–0.456	–0.512	–0.524	–0.526	–0.129	–0.141	0.998	1		
lnSIZE	0.100	0.265	0.192	0.232	0.581	0.442	0.085	0.083	1	
lnINCOME	–0.252	–0.141	–0.206	–0.174	0.078	0.025	–0.070	–0.068	0.309	1

政府補助、換電站與綠色採購：臺灣電動機車需求的實證研究

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摘　要

本文旨在探討政府補助與換電站佈建對臺灣電動機車需求的影響，並探討臨近縣市的換電站設立是否存在網路效果，促進電動機車的需求。利用臺灣本島 19 個縣市 2018 年到 2022 年的半年期資料爲研究樣本，實證結果發現：政府補助對電動機車的銷售量具正向顯著的影響，特別是汰舊換新補助。其次，換電站的技術基礎建設佈建亦促進電動機車的採用。然而，鄰近縣市換電站的網路效果相當有限，隱含電動機車的使用爲縣市內的短途旅程爲主。不同的頑強性檢定支持上述的實證結果。

關鍵詞：電動機車、補助、換電站、網路效果

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