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Electric vehicles uptake and its determinants: implication on developing countries

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Abstract:

This paper examines trends and patterns of EV uptake worldwide with a view to inform responses by developing countries to the ongoing technological changes. The proxy of policies to promote EV uptake across 65 countries is constructed and used in the inter-country panel data econometric analysis between 2015 and 2021 to gain better understanding the relative importance of government incentives. The key finding suggests that EV uptakes are highly concentrated within a handful countries dominated by China and high-income countries where critical infrastructure like charging stations is well developed. The effect of government incentives and direct subsidy in particular are conditioned by presence of the infrastructure. Ramping up infrastructure capability takes time and so does the EV uses in developing countries. Optimizing instead of maximizing EV uses in the short run seems to decent policy responses to the technological changes for developing countries.

Key words: Electric vehicles, Disruptive Technology, Developing countries' responses,

JEL Classification: L62, F23, and O31

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1. Issues

Currently, the automotive industry is facing a major technological challenge by technological advance in manufacturing electric vehicles (EVs). Despite being invented back in the 19th century, EVs have become a close substitute of internal combustion engine vehicles (ICEVs) since 2006 when Tesla Motor (referred in short Tesla) introduced an EV (i.e. Tesla Roadster) that could go more than 200 miles on a single charge (Reuter, 2023). Demand for higher standards of environmental protection that began in the late 1990s continues thereby calling for more environmental friendly vehicles. Since then, price of EVs has gone down and reached the affordable price for ordinary people. In the past few years, sale volumes of EVs grew exponentially and accounted for 14 per cent of all types of vehicle sales.

Even though there are several alternatives of environmental friendly vehicles such as fuel-cell vehicles, plug-in hybrid vehicles as well as some concerns about the net environmental effect of EVs, EVs often gain policy attention. In the environmental studies literature, the technological advance in manufacturing EVs in the past two decades make them the so called *systemic sustainable product innovation*, that triggers other stakeholders at a broader societal level, such as consumer behavior or regulation (Bohnsack et al. 2020: 729). In addition, the EVs technological evolvement is often regarded as leapfrogging opportunities for many countries especially developing countries (Brezis & Krugman, 1997; Brezis et al., 1993). Appropriate policy actions could allow them to technologically catch up with, or leap over the developed countries which play a leading role in technological development. The emergence of Chinese manufactures in EV industries (both vehicles and batteries) and the government role through industrial policy are often viewed as the role model to harness these opportunities (e.g., Altenburg et al. 2022; IEA, 2019).

As a result, there are a growing number of governments worldwide introducing a wide range of policy measures promoting the use of EVs. The active role would not only avoid any disruptive effects from technological changes but also serve as the new growth engine for the industry. This seems to be in line with the revival of industrial policy sentiment across both developed and developing countries (Economist 2023).

While the range policy measures are rather wide, rom passive measures like tax exemptions, road privileges, and to a direct subsidy to EV users, there are an increasing number of countries offering direct subsidy to consumers' EV purchases in the past five years. It is done with the hope to accelerate EV uptake and then could induce other potential benefits from the early EV uptakes. While such measures were introduced in high-income countries driven by their environmental concerns, many developing countries follow suit. It seems to be risky business for developing countries where environmental concerns have yet been the social norm and fiscal resources are rather limited.

Interestingly, the effectiveness of subsidy remains debatable. According to the law of demand, the subsidy lowers prices of EVs consumers paid, thereby boosting their demand. It could also serve as the tip of the iceberg, complementing other favorable factors, including the awareness of environmental concerns and other incentives such as road privileges.

Nonetheless, as EVs are rather new to mainstream consumers as the alternative road transportation, there are uncertainties of owing EVs in various aspects such as cost, driving range, charging infrastructure, maintenance, and overall convenience. Consumers are likely to be in wait-and-see mode until adequate information revealed and uncertainty in these aspects resolved.

This is especially true as a vehicle is regarded as durable goods in economics where their services are delivered more than one period and their purchases are infrequent. There are other non-price factors significantly influencing decision to purchase EVs, including the availability of complementary products especially charging station, second-handed prices, reliability, maintain costs, all of which are related to costs consumers pay to use it over the product life cycle (Padula, 2000). In this circumstance, the effect of direct subsidy will be limited and fail to trigger the substantial adoption of EVs. Its effect could be found only when the above favorable factors are well in place.

This seems to be immense policy relevant for developing countries where fiscal space is relatively small as opposed to their developed counterparts. While the increasing importance of EVs is regarded as not only means to lower carbon emission but also technology leapfrogging opportunities, the role of non-price factors discussed above might constrain their policy effort.

Against this backdrop, this paper aims to trend and patterns of EV uptake across countries as well as the effect of promoting policies with a view to inform the debate of responses to the emerge of EVs. Inter-country panel data of EV uptakes are composed between 2015 and 2021, covering 65 countries around the world. The EV uptake records are further employed in the panel data econometric analysis to gain better understanding of its determinants. In this paper, policies in promoting EVs in these countries were reviewed to construct binary dummy variables, reflecting the extent to which countries pursue policies in promoting EV uptake over time in three aspects, i.e. tax exemption, road privileges, and direct subsidy.

To the best of our knowledge so far, this is the first systematic econometric analysis examining determinants of EV uptake across countries. There are studies investigating the impact of government subsidy on EV uptake. There are various studies, e.g. Clinton and Steinberg (2019) for US, and Azarafshar and Vermeulen (2020) for Canada, and Li et al (2023) for China, examining the impact of policy measures. Nonetheless, their analyses are country-specific. While country-specific evidence can provide policy insights and takes country-specific characteristics into consideration, their finding might not be applicable elsewhere. Their finding might be largely influenced by country-specific features. Our inter-country analysis could be well complement with these country specific studies thereby generalizing the finding.

The paper is organized as follows; it starts with the paper's analytical framework in the following section (Section 2). Section 3 presents the overview of EV uptakes. In this section, policy to promote EV uptakes as well as trends and patterns of EV uptakes are discussed. Section 4 presents the empirical model whereas the estimation results are in Section 5. Section 6 discussed the summary and the implication for developing countries.

2. Analytical Framework

EV uptake in a given country is the interplay between demand and supply factors in EV industry. For the past decade, the latter has been favorable largely due to technology advance in EV industries. The real turning point for EVs to be a close substitute to ICEVs was 2006 when Tesla's roadster in 2006, a EV going more than 200 miles on a single charge, was launched. The growing concern of environmental impacts of vehicles and their carbon emission has forced carmakers to find alternative powertrains so that the lifting environmental protection standards can be obtained.

Another push is the emergence of China. As the latecomers on ICEVs production, Chinese firms, strongly supported by the government, have made substantial investments in EVs technologies. As early as 2001, EV technology was introduced as a priority science research project in China's Five Year Plan, the country's highest-level economic blueprint. The policy momentum has been driven by other factors including the severe air pollution in China, the heavy reliance on imported oil, the need stimulus to cushion adverse effect of Great Recession 2008. In addition, in 2007, the newly appointed Minister of Science and Technology, Mr. Wan Gang who had worked for Audi in Germany for a decade, and been a big fan of EVs, made the national decision to go all-in on EVs. Since then, EV development has been consistently prioritized in China' s national economic planning (Yang 2023). As a result, many carmakers have started paying attention to EVs and offered a wide range of EVs to the market.

While supply factors have been favorable to EV uptakes, it is demand factors that are rather complicated and play a pivotal role in determining EV uptake that varies across countries. To a large extent, a vehicle regardless its power training is durable goods which deliver services for more than one period (Padula, 2000). Hence, the decision to purchase needs to be casted in a framework where decisions are made over time. In this regard, price relevant to consumers is user costs instead of that of product itself although the latter is one important component. User cost arises from the dynamics of the purchase and resale price of durable goods which generate capital gains or losses for the consumer. Hence, consumer preferences, constraints and uncertainties on the product matter in influencing decision to purchase.

Consumers' environmental concern seems to play an important role in determining consumer preferences over types of vehicles. Generally, the more the concern, the more the likely they will purchase EVs. Despite heterogenous across individual the environmental concern is positively related to the level of income per capita as pointed in a number of environmental studies (e.g. Gillison, 2007; Lo, 2016; Brieger, 2018)). This suggests that demand for EVs as opposed to other vehicles is expected to be high in developed countries as opposed to developing ones, all other things being constant.

Financial constraints are another factor affecting purchasing decision. Like other durable goods, prices of vehicles are relatively high. Access to financial credit greatly attributes to demand for vehicles (Reed, 2023; Cheng et al., 2022; Attanasi et al. 2008). In addition, they can be used as collateral. Hence, the probability of being liquidity constrained thus could influence decision to purchase a vehicle. In addition, re-selling EVs in a second-hand market remains challenges. Arguably, EV battery is the largest costly component in EVs, accounting for nearly 50 per cent of its value. Hence, the battery is approaching its end of product life so does the price of EVs. Hence, their value in the second-hand market is falling faster than as opposed to ICEVs. Nonetheless, there are counterarguments about presence of the second-hand market for EVs (e.g. Ilfran, 2023; Paris, 2024). At best, how second-hand market of EVs remains uncertain and will be resolved when more and more EVs are traded in the second-hand market.

A wide range of uncertainties loom over the decision to swift to EVs, from technologies related to EVs and their parts, availability of charging stations, and driving ranges. Like other durable goods, in this circumstance, adjustment cost when consumers made mistakes seem to be high. In presence of such uncertainties, consumers might deter their purchase until these uncertainties are resolved.

3. EV uptakes

3.1 Policy in promoting EV uptakes

Generally, developed countries express more enthusiastic to EVs than their developing counterparts. Canada and some Scandinavian countries were the pioneer in offering incentives to promote the EV adoption. For example, the provincial government in Ontario, Canada offered fee exemption on congested roads to EVs (Green plate) (Goddard, 2011) whereas that in Quebec offered tax refunds with 5,600 USD from 2012 USD (Loveday, 2011) Scandinavian countries were another pioneers in launching the promotion policy measures but the incentives varied vastly. Norway was the first country offering the direct subsidy to consumers in buying EVs in addition to other promotion measures including tax exemption, and road privileges. By contrast, Estonia's incentive schemes have been on and off fashion.

To indicate the extent to which a country offers incentive to promote the EV adoption, this study develops bi-nary dummy variables. To construct them, policy measures introduced by more than 60 countries are reviewed. Documents from international organizations such as European Automobile Manufacturers' Association

(ACEA), International Energy Agency (IEA), European Alternative Fuels Observatory (EAFO), Country-specific automotive associations, and peer-reviewed journals are prioritized. Other supplement documents such as blog, newspapers, automotive websites are used to cross-check for accuracy purpose (All documents used are reported in Appendix 1)

All measures are reviewed and grouped into three categories. They are (1) direct subsidy and tax deduction. ($Subsidy_{j,t}$), (2) tax incentives ($Tax_{j,t}$) (e.g. road tax exemption, registration fee exemption) and (3) privileges in road uses (e.g. free parking fees, special lanes, parking spot privileges). These three types of measures seem to have different effects on decision to purchase EVs. $Subsidy_{j,t}$ seems to be the most powerful incentive to entice consumers to use EVs as it lowers the EV users' cost directly and instantaneously. This seems to be different tax incentives whose effect is relatively small and takes time. For example, the EV buyers would benefit from the registration fee once it is renewed (e.g. a year or six months) and the benefit is often smaller as opposed to the subsidy. It is more difficult to compare the effect of $Road_{j,t}$ as a similar privileges could have different effects across countries. For example, special lanes privileges matters only when the traffic is often jammed.

The binary dummy variable is used to capture presence of these measures, i.e. the variable equals to one when the policy is in place and zero otherwise. The shortcoming of using the binary dummy variable is the magnitude of incentives provided may vary from country to country. This is especially true for subsidy whose sizes matter. Nonetheless, it is very difficulty to develop a consistent measure across countries due to the fact that their true magnitude is conditioned on various country-specific factors. For example, Spanish government introduced 4,000-5,000 and 1,900-2,600 EURO for BEVs and PHEVs respectively. The actual subsidy depends on whether a buyer turns in the old vehicle for EVs and the age of turn-in vehicle ACEA (2020). This is different from

France where the subsidy varies across carbon dioxide emission. In Greece, the subsidy is in a wide range from zero to 5000 EURO. To create a quantitative measure, many arbitrary assumptions are needed to be imposed.1 This could do more harm than good. Hence, the binary dummy variable is chosen. Its shortcoming will be taken into consideration when interpreting the results.

Another policy area numerous governments have paid attention is to install EV charging points. Some countries have taken the lead in investing them whereas the others have granted investment incentives for private firms to do. As charging infrastructure is seen as a key prerequisite for EV adoption, it deserves special attention over and above the three policy groups discussed above.

As revealed in Table 1, there are 22 out of 65 countries introducing at least one of the three policy categories in 2015. Particularly, there were 22 countries offering tax incentives whereas only 10 and 9 countries offering $Subsidy_{j,t}$ and $Road_{j,t}$, respectively. The number rose to 35 in 2021.

Many countries began with $Tax_{j,t}$which is rather passive. While $Tax_{j,t}$ was still the popular policy measure, there were more countries offering $Subsidy_{j,t}$ over and above $Tax_{j,t}$ to enhance EV uptake. There were 30 countries offering $Subsidy_{j,t}$ in 2021.

Noticeably, some developing countries started offering $Subsidy_{j,t}$ to lift EV uptakes. In 2021, 5 developing countries offered $Subsidy_{j,t}$, including China, Korea, Malta, Hungary, and Slovak Republic. Other countries latter launched it (e.g. Thailand in 2022 onward) or is considering to follow suit (e.g. Malaysia, Indonesia and Vietnam).

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[1] For example, Tietge et al (2016) did construct the quantitative measure of fiscal incentives across European countries. Making the advantage of common market nature of Europe, certain vehicle models are selected as the benchmark in their quantitative calculation. For example Mitsubishi Outlander 2.0 and Mitsubishi Outlander PHEV2.0 are used as the benchmark for large gasoline and plug-in hybrid powertrain. Imposing such a benchmark could turn to be restrictive when the country coverage is more than a continent. In addition, by 2020 onward, there have been more EV choices available. This makes the consistent quantitative measure rather risky business.

By contrast, $Road_{j,t}$ was not very popular policy category offered to increase EV uptakes. It increased from 9 in 2015 to 12 by 2021. It is partly due to challenges in implementing them effectively.

Another remark is that it is more likely that a country offers more than one policy measure concurrently. In 2021, the most popular combination is $Subsidy_{j,t}$ and $Tax_{j,t}$ offered by 24 countries offering. The least popular one is $Subsidy_{j,t}$ and $Road_{j,t}$ offered by 7 countries in the same year. Such policy preference could reflect the presumption about EV uptakes that are largely constrained by their price that is generally higher than its ICEVs for a comparable capacity. At best such a presumption remains testable hypothesis.

--- Insert Table 1 around here ---

3.2 Trends and Patterns of EV uptake

Generally, EVs are composed of two subcategories, one is battery and plug-in hybrid electric vehicles (BEVs, and PHEVs). The former is vehicles that run solely on electric power, supplied by a large battery pack, whereas the latter is vehicles that combine a traditional internal combustion engine with an electric motor and a battery pack. While BEVs are more environmentally friendly than PHEVs in terms of carbon emission, decision to buy the former as opposed to the latter heavily hinges on the availability of supplement infrastructures especially charging points and is largely influenced by ongoing uncertainties about using BEVs. Hence, it is worth to separate them in the discussion in this subsection.

As illustrated in Figure 1, a number of BEVs experienced steady growth sold from 2009 to 2015 and then grew rapidly especially from 2020 onward. BEVs' sales volume reached 7.7 million units by 2022. Their share to total EVs (BEVs+PHEVs) averaged out at 70 per cent from 2017 to 2022.

--- Insert Figure 1 around here ---

Interestingly, BEVs have been sold in a handful of countries, the patterns of cumulative shares of BEV uptakes from 2017 to 2022 (Figure 2). Despite slightly more diversified, the sum of top-5 shares of EVs adoption were all greater than 80 per cent over the considering periods. It was 88.6 per cent in 2017 to 83.4 per cent in 2022. China was the largest EV uptake over the considering period, accounting for more than half of global EV uptakes. The four runners-up in each year from 2017 to 2022 varied within a small group of high-income countries including US, Germany, United Kingdom, Norway, Netherlands and France. The high concentration nature was also found in PHEV uptake but relatively less than that of BEVs (Figure 3).

--- Insert Figures 2 &3 around here ---

Figure 4 reveals the upward trends of charging station points (the sum of fast and normal charging points). They grew nearly 7 times, from 0.4 million units by 2017 to 2.7 million units by 2022. Interestingly, the recent installed stations were fast charging inspite of the fact that installing fast charging points is much more expensive than that of normal ones. Particularly, the share of fast charging points increased from 24.9 per cent to 36.1 per cent from 2017 to 2022.

--- Insert Figure 4 around here ---

Noticeably, the rapid growth of charging points has been uneven, as revealed in Figure 5 the cumulative share of charging points. For example, China was the top in terms of the charging points. The share to world charging points increased from 50.5 per cent in 2017 to 66.7 per cent in 2022. The sum of top-5 countries of the charging points rose from 77.4 per cent to 80 per cent over the same period. The concentration was even higher when solely focusing on the fast charging points (Figure 6). These top-5 countries in terms of charging points were largely those in terms of EV uptakes. This points to the role of charging points to the EV uptake.

--- Insert Figures 5 & 6 around here ---

Table 2 illustrates the ratio between EV sales/charging points available between 2017 and 2022 of the 2022 top-10 EV uptake countries. As the availability of charging points is crucial for the EV uptake, the larger the decline in the ratio, the higher the potential of EVs to grow. Clearly, China was the only one experiencing the ratio decline. Chinese's ratio drop from 3.3 EVs/points in 2017 to 2.6 EVs/points in 2022. The opposite pattern was found for the other top-10 countries. While the optimal ratio of charging point to EV remains largely unknown, the observed pattern raises worrisome for the growth of EV uptake to a certain extent.

4. The Model

4.1 Model specification

As discussed in Section 2, EV uptake is the interplay between demand- and supply factors. While supply-side factors make EVs more feasible, the demand side ones play the pivotal role in determining EV uptake. EV uptake of Country i at time t ($Q_{i,t}$) is a function of a series of factors affecting demand for EVs in Equation 1;

$$Q_{i,t} = \gamma_0 + \alpha_2 Y_{i,t} + \alpha_3 Infra_{i,t} + \alpha_4 Policy_{i,t} \quad (1)$$

$Q_{i,t}$ is measured by two alternatives, a number of EVs sold (PHEVs + BEVs) ($Q\_A_{i,t}$) and only BEVs ($Q\_BEV_{i,t}$) sold in Country *i* at time *t*. As argued above, they could behave differently to explanatory variables. Arguably, $Q_{i,t}$ could be influenced by the market size, all other things being equal. To incorporate the market size effect, population size ($Pop_{i,t}$) is introduced as the controlling variable.

The first explanatory variable is income per capita ($Y_{i,t}$). The higher the income the greater the demand, all other things being equal. In addition, income per capita also reflects the awareness of people toward environment concerns. Hence, the corresponding coefficient is expected to be positive. Income per capita is measured by (Real) GDP per capita.

The second variable is presence of EV charging points available ($Infra_{i,t}$). As mentioned above, availability of chargers would influence consumers' decision to buy EVs. This is especially true of BEVs. The more the chargers, the greater the use of EVs, ceteris paribus. The positive sign is expected. In our analysis, two alternative measures of charging stations are employed, one is total (fast + normal) ($AInfra_{i,t}$) charging points and the other is only fast charging ones ($FInfra_{i,t}$). As mentioned above, the recent government effort in building up charging facilities is in favor of the fast-charging ones, installing them are much more costly as opposed to normal ones. Hence, it is worth to examine whether fast-charging points have larger impact on consumers' EV uptake and justify fiscal resources spent on the charging infrastructure.

The third variable is related to policy measures introduced by a given country ($Policy_{i,t}$). Three policy aspects are examined in this paper. They are direct subsidies ($Subsidy_{i,t}$), tax incentives ($Tax_{i,t}$), and other benefits, such as road privilege ($Road_{i,t}$). Each aspect is measured by the 0-1 binary dummy. While it would be much superior to quantify the magnitude of the subsidy instead of relying on the binary dummy, making them more compatible across countries tends to do more harm than good. This is due to the fact that the subsidy schemes introduced have been very complex and conditioned by several country-specific factors. All of them make it very difficult to undertake a consistent quantitative measure across countries. In fact, an indepth case study is needed for each country to provide the meaningful measure. This is applicable to tax incentives as well. Therefore, the simple bi-nary dummy variables are employed to examine its impact.

Arguably, these policy measures would be in effect when other fundamentals are well in place. In this regard, the effect of these policy measures could be conditioned by the availability of key infrastructure like charging points availability. To address it, these policy dummy variables are interacted with the charging points.

In addition, six dummy variables (D_i) for each year (2016-2021) are introduced into the model, with the year 2015 serving as the baseline. The coefficients on these dummies are expected to be positive and increase every year. The positive and increasing coefficients would reflect the more favorable supply-side factors. They also indicate growing demand over years as uncertainties have been faded out.

4.2 Variables Measurement and Econometric Procedures

EV uptake in this paper is measured by a number of EVs sold in a given countries. There are two main data sources. The first source is from International Energy Agency (IEA) where there are 32 countries. The second source is from European Alternative Fuels Observatory (EAFO) where there are another 16 European countries. For other countries, it is assumed zero EV uptake.[2] In line with the general practice in the gravity equation

[2] Note that in reality, they could also be due to the data collection constraints by IEA, EAFO as well as origin countries.

analysis, the motivation to include zero EV uptake is simply because the observed zero EV uptake could be derived from economic fundamentals. Excluding them from the analysis would result estimation biases. To identify them, the lists of countries whose vehicle sale records are reported by International Organization of Motor Vehicle Manufacturers (OICA) are matched with 48 countries with non-zero EV uptakes. All in all, there are 65 countries in our analysis whereas 48 countries reported non-zero EV uptake records. Lists of countries are in Table 3.

--- Insert Table 3 around here ---

Data for GDP per capita and population size are from the World Development Indicator online database. The number of public charging points stations are from the International Energy Agency (IEA) and European Alternative Fuels Observatory (EAFO). Three policy variables are based on discussion in Section 3.1. Descriptive statistics for the variables used in the model are shown in Table 4.

--- Insert Table 4 around here ---

In line with the standard practice in bilateral trade analysis where a number of dependent variables have zero value, the Poisson Fixed Effect Model (PPML) is employed. In PPML, the dependent variable has a Poisson distribution and that its conditional mean value is an exponential function with explanatory variables. To alleviate the endogeneity problem, one-year lagged explanatory variables are used. All in all, the empirical equation is expressed in Equation 2.

$$\begin{aligned} Q_{i,t} &= \gamma_0 + \alpha_2 Y_{i,t-1} + \alpha_3 Infra_{i,t-1} + \alpha_4 Subsidy_{i,t} + \alpha_5 Tax_{i,t} + \alpha_6 Road_{i,t} \\ &\quad + \alpha_7 Pop_{i,t-1} + \alpha_8 Infra_{i,t-1} * Subsidy_{i,t} + \sum_{t=2016}^{2020} \beta_i D_t + \delta_i + \varepsilon_{i,t} \end{aligned} \qquad (2)$$

where

$Q_{i,t}$ = EV uptake by Country i at time t alternatively measured by

(1) $Q\_A_{i,t}$, total EVs sold (PHEVs+BEVs)

(2) $Q\_BEV_{i,t}$), only BEVs

Explanatory variables

$Y_{i,t-1}$ (+) = (real) income per capita of Country i at time *t-1* (in natural log)

$Infra_{i,t-1}$ (+) = EV charging points available in Country i at time *t-1* measured by two alternatives;

(1) $AInfra_{i,t}$ = all types of charging points (fast +normal charging)

(2) $FInfra_{i,t}$ = only fast charging points

$Subsidy_{i,t}$ (?) = binary dummy proxied presence of subsidy scheme in Country i at time *t-1* (1 = presence and 0 otherwise)

$Tax_{i,t}$ (?) = binary dummy proxied presence of tax exemption scheme in Country i at time *t-1* (1 = presence and 0 otherwise)

$Road_{i,t}$ (?) = binary dummy proxied presence of road privileges scheme in Country i at time *t-1* (1 = presence and 0 otherwise)

$Pop_{i,t-1}$ (+) = population of Country i at time *t-1* (in natural log)

D_t = Year t dummy variable (1 = in Year t and 0 otherwise)

δ_i = Country i 's fixed effect

$\varepsilon_{i,t}$ = e

6. Results

The results are reported in Tables 5 and 6. In Table 5, $Q\_A_{i,t}$, is used as the dependent variable. Columns 1-4 in Table 5 are based on $AInfra_{i,t}$, whereas those in Columns 5-6 are based on $FInfra_{i,t}$. The difference between the results in Columns 1 and 2 of Table 5 is that there is not $Infra_{i,t-1} * Subsidy_{i,t}$ in the latter. Results of other explanatory variables not sensitive to whether $Infra_{i,t-1} * Subsidy_{i,t}$ is included or not. Their log pseudo-likelihood values are in favor of Column 1 where $Infra_{i,t-1} * Subsidy_{i,t}$ is included. Results presented in Columns 3 and 4 of Table 5 are similar to Columns 1 and 2 but with year-dummies.

--- Insert Table 5 around here ---

The charging points attribute to EV uptake. The coefficient corresponding to $AInfra_{i,t}$ turns out to be positive and statistically significant at one per cent. The more the charging points, the higher the EV uptake. In policy circle, the relationship between EV uptake and charging points is often explained in the chicken-and-egg metaphor but our results seem to be in favor that charging points positively affect EV uptake. This is in line with the finding by Li et al. (2017).

The coefficient corresponding to $Pop_{i,t-1}$ turns out be positive and stastistically signficant. The larger the market size, the higher the EV uptake, all other things being equal. Interestingly, the statistical significance vanishes when year-dummies are introduced (Columns 3 and 4). Given the fact that EVs are durable goods, their demand is likely to grow gradually over time as uncertainties faded out instead of simply the population growth.

When the effect of policy measures is concerned, the effectiveness of $Subsidy_{i,t}$ is not always found but conditioned by presence of EV charging points. In particular, the coefficient corresponding to $Subsidy_{i,t}$ is negative but that to $Infra_{i,t-1} * Subsidy_{i,t}$ is positive. Both are statistically significant. They suggest that the effectiveness of $Subsidy_{i,t}$ will be observed only when a country reaches certain threholds. For the other policy variables, only road privileges were found to have a significant and positive effect on EV uptakes. While the tax incentives are statistically significant, they bear a negative sign. The found negative effect perhaps reflects the weak policy signal in promoting the EV uptake.

Clearly, the statistical significance of $Y_{i,t-1}$ confirms the relative important role of income on EV demands. It can reflect people's awareness of environmental issues. Countries with higher average incomes are more likely to care about environmental issues than countries with lower incomes. This finding is in line with that in previous studies (e.g. Gillison, 2007; Lo, 2016; Brieger, 2018).

When $AInfra_{i,t}$ (both fast and normal charging points) is replaced by $FInfra_{i,t}$ (fast charging points only), the coefficient associated with the charging variable turns to be statistically insignificant (Columns 5 and 6 in Table 5). Its statistical significance is found only when the charging variable intereacting with $Subsidy_{i,t}$. Our result suggests that types of charging points installed do not matter. In fact, both types of charging points have their own advantage and disadvantage. It would be sensible for the government to optimize instead of maximizing fast charging points to promote EV uptake.

Estimation in Table 6 is to illustrate the sensitivity of results to types of EVs. Columns 1 and 2 are based on $AInfra_{i,t}$ whereas the others are on $FInfra_{i,t}$. Estimation result in Columns 1 and 3 in Table 6 is identical to that in Columns 3 and 5 in Table 5. Overall, the results are not sensitive to whether all EVs or BEVs only are used. That is, EVs remain new to mainstream consumers regardless whether they are PHEVs or BEVs. Income and infrastructure, such as charging points, are likely to play a pivotal role in purchasing them. Policy measures can play a role only when critical infrastructure like charging points is well installed.

--- Insert Table 6 around here ---

7. Conclusion and Policy Inferences

This paper examines trends and patterns of EV uptake worldwide with a view to inform responses by developing countries to the ongoing technological changes. The proxy of policies to promote EV uptake across 65 countries is constructed and used in the inter-country panel data econometric analysis between 2015 and 2021 to gain better understanding the relative importance of government incentives. The policies are grouped into three categories; (1) direct subsidies; (2) tax exemption; and (3) privileges to use road. They are introduced over and above the demand-side factors including income and charging station.

The key finding suggests substantial EV uptakes remain highly concentrated within a small group of high-income countries where critical infrastructure like charging stations is well developed. Our econometric analysis suggests that despite recently popular, the direct subsidy is effective only when charging points have been adequately installed. While privileges to use road is another policy measure that could promote EV uptake, they are not popular due to their implementing challenge.

Three policy inferences can be drawn from this study. Firstly, our results raise the cautious in using direct subsidy as a quick win measure and promoting EV uptake. Its effectiveness is conditioned by the availability and adequacy of charging points. Consumers' awareness toward environment protection also matters.

Secondly, ramping up infrastructure capability like charging points as well as raising consumers' awareness take time. So does the EV uses in developing countries. To lower carbon emission from vehicles, policy focus should be on the net carbon emission from vehicles regardless types of powertrains. Optimizing instead of maximizing EV uptake in the short run seems to decent policy responses to the technological changes for developing countries.

Finally, our results reveal that all types of charging points matter. While fast charging points matter only when EVs are used for long-distance travel (e.g. across provinces), installing them is costly. The normal charging points are well suited for resident areas and the likes. Strategic plan for installing EV charging points is needed to avoid overinvestment in fast charging points.

Table 1
A number of countries offering the three policy incentive categories from 2015 to 2021

	2015	2016	2017	2018	2019	2020	2021
# of countries offered							
$Subsidy_{j,t}$	10	11	14	17	18	23	30
$tax_{j,t}$	22	25	31	31	30	32	35
$Road_{j,t}$	9	10	10	11	11	12	12
# of developed countries offered							
$Subsidy_{j,t}$	9	10	11	14	15	20	25
$tax_{j,t}$	19	21	23	23	22	23	25
$Road_{j,t}$	7	8	8	8	8	9	9
# of countries offered more than one measures simultaneously							
$Subsidy_{j,t}\&tax_{j,t}$	9	10	13	15	15	20	24
$Subsidy_{j,t}\&Road_{j,t}$	3	4	5	5	5	8	7
$Road_{j,t}\&tax_{j,t}$	9	10	10	10	10	11	11
$Subsidy_{j,t}\&tax_{j,t}\&Road_{j,t}$	3	4	5	5	5	8	7

Source: Constructed by the authors

Table 2
The ratio of EV sales to charging points available from 2017 to 2022
of the top-10 EV uptakes (Units/charging point)

	2017	2020	2022
China	3.26	1.29	2.63
USA	2.30	2.32	6.25
Germany	2.73	4.63	6.36
United Kingdom	1.01	4.11	5.69
France	1.48	3.48	2.72
Norway	3.66	4.62	6.54
Korea	1.05	1.00	0.78
Sweden	1.10	2.70	5.76
Canada	1.48	2.91	4.45
Japan	0.63	0.55	3.03
Netherlands	0.29	1.15	0.63

Sources: the authors' compliation from IEA database

Table 3
List of countries covered in this study and related sources

45 countries with data on EVs registrations.			20 other countries	
IEA		EAFO		
Australia	Mexico	Austria	Kuwait	Vietnam
Belgium	Netherlands	Malta	Ecuador	Egypt
Brazil	New Zealand	Ireland	Kazakhstan	Philippines
Canada	Norway	Bulgaria	Ukraine	Israel
Chile	Poland	Croatia	Peru	Argentina
China	Portugal	Cyprus	Morocco	Malaysia
Denmark	South Africa	Estonia	Uzbekistan	Saudi Arabia
Finland	Spain	Greece	United Arab Emirates	Turkey
French	Swedish	Hungary	Colombia	Indonesia
Germany	Switzerland	Latvia	Pakistan	Russia
Greece	United Kingdom	Lithuania		
Iceland	United States	Romania		
India	South Korea	Slovakia		
Italy	Thailand	Slovenia		
Japan		Czech Republic		
		Luxembourg		

Source: Authors

Table 4
Descriptive statistics for variables use in the model

Variables	no. of sample	Mean (SD)	Min	Max
$\ln Q\_A_{i,t}$	448	4.86 (6.73)	-4.61	17.10
$\ln Q\_BEV_{i,t}$	448	4.50 (6.48)	-4.61	16.89
$AInfra_{i,t-1}$	448	2.87 (5.89)	-4.61	14.70
$FInfra_{i,t-1}$	448	1.20 (5.18)	-4.61	13.74
$Pop_{i,t-1}$	448	16.84 (1.73)	12.70	21.07
$Y_{i,t-1}$	448	9.71 (1.05)	7.19	11.60
$Subsidy_{i,t}$	448	0.27 (0.45)	0	1
$Tax_{i,t}$	448	0.46 (0.50)	0	1
$Road_{i,t}$	448	0.17 (0.37)	0	1

Source: Authors' calculation

Table 5
The estimation results of Poisson Fixed Effect Model

Variables	(1)	(2)	(3)	(4)	(5)	(6)
$AInfra_{i,t-1}$	0.78***	0.72***	0.12**	0.08*		
	(0.13)	(0.11)	(0.05)	(0.05)		
$Pop_{i,t-1}$	13.08**	17.20***	-1.32	1.73	0.11	1.99
	(6.60)	(6.67)	(8.64)	(9.94)	(8.87)	(9.92)
$Y_{i,t-1}$	3.29**	4.49***	4.91***	5.48***	5.63***	5.78***
	(1.36)	(1.49)	(1.01)	(1.44)	(1.08)	(1.46)
$Subsidy_{i,t}$	-1.71**	0.52***	-1.87***	0.074	-1.13***	0.00
	(0.85)	(0.20)	(0.54)	(0.15)	(0.34)	(0.13)
$AInfra_{i,t-1} * Subsidy_{i,t}$	0.18**		0.16***			
	(0.07)		(0.05)			
$Road_{i,t}$	1.20**	1.04**	0.74**	0.57**	0.66**	0.47**
	(0.53)	(0.46)	(0.34)	(0.25)	(0.32)	(0.22)
$Tax_{i,t}$	-1.32***	-1.27***	-0.62**	-0.53*	-0.39	-0.38
	(0.40)	(0.39)	(0.32)	(0.28)	(0.27)	(0.23)
D_{2016}			0.23*	0.22*	0.32**	0.33**
			(0.12)	(0.12)	(0.14)	(0.14)
D_{2017}			0.37	0.45*	0.54**	0.64***
			(0.24)	(0.25)	(0.25)	(0.24)
D_{2018}			0.59*	0.67*	0.77**	0.87**
			(0.34)	(0.36)	(0.36)	(0.36)
D_{2019}			0.64	0.71	0.82*	0.93**
			(0.44)	(0.47)	(0.45)	(0.47)
D_{2020}			1.33***	1.46***	1.57***	1.73***
			(0.50)	(0.56)	(0.50)	(0.52)
D_{2021}			1.87***	1.92***	2.18***	2.25***
			(0.50)	(0.60)	(0.51)	(0.56)
$FInfra_{i,t-1}$					-0.01	-0.02
					(0.02)	(0.02)
$FInfra_{i,t-1} * Subsidy_{i,t}$					0.10***	
					(0.04)	
Observations	296	296	296	296	308	308
Number of country code	44	44	44	44	44	44
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: Numbers in parentheses are robust standard errors; *** p<0.01, ** p<0.05, * p<0.1;
Source: Authors' calculation

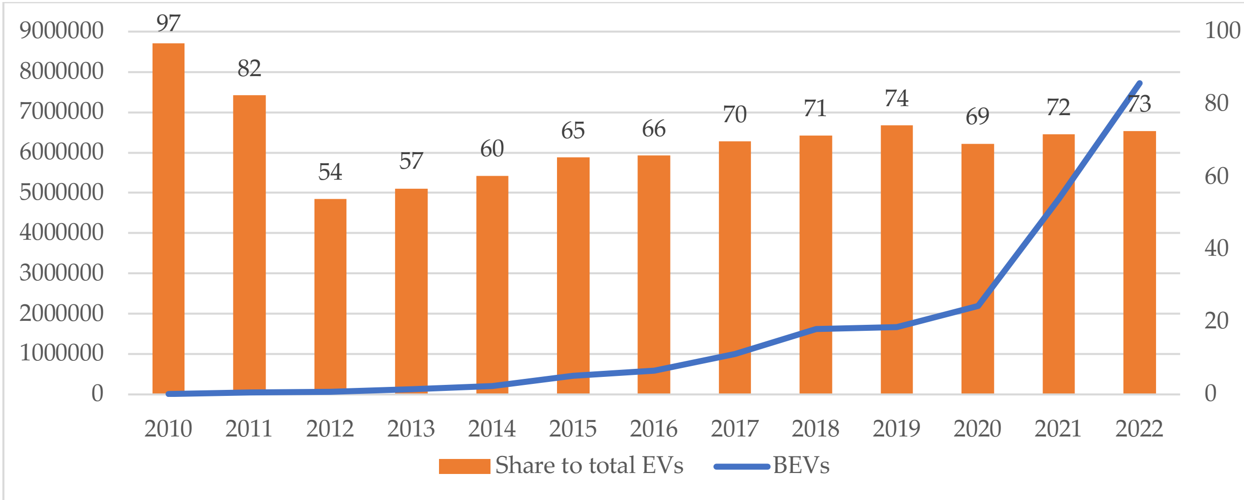
Table 6
The estimation results of Poisson Fixed Effect Model

Variables	(1)	(2)	(3)	(4)
	All EVs	BEVs	All EVs	BEVs
$AInfra_{i,t-1}$	0.17**	0.10**		
	(0.05)	(0.04)		
$Pop_{i,t-1}$	-1.32	4.83	0.11	5.32
	(8.64)	(8.90)	(8.87)	(9.00)
$Y_{i,t-1}$	4.91***	5.18***	5.63***	5.77***
	(1.01)	(0.98)	(1.08)	(1.11)
$Subsidy_{i,t}$	-1.87***	-1.43***	-1.13***	-0.64
	(0.54)	(0.50)	(0.34)	(0.41)
$AInfra_{i,t-1} * Subsidy_{i,t}$	0.16***	0.12***		
	(0.05)	(0.04)		
$Tax_{i,t}$	-0.62**	-0.56	-0.39	-0.35
	(0.32)	(0.34)	(0.27)	(0.29)
$Road_{i,t}$	0.74**	0.72*	0.66**	0.60*
	(0.34)	(0.37)	(0.32)	(0.34)
D_{2016}	0.23*	0.20*	0.32**	0.27**
	(0.12)	(0.11)	(0.14)	(0.13)
D_{2017}	0.37	0.37*	0.54**	0.54**
	(0.24)	(0.21)	(0.25)	(0.22)
D_{2018}	0.586*	0.554*	0.770**	0.743**
	(0.34)	(0.31)	(0.36)	(0.33)
D_{2019}	0.64	0.59	0.82*	0.78*
	(0.44)	(0.40)	(0.45)	(0.42)
D_{2020}	1.33***	1.32***	1.57***	1.57***
	(0.50)	(0.47)	(0.50)	(0.49)
D_{2021}	1.87***	1.82***	2.18***	2.12***
	(0.50)	(0.47)	(0.51)	(0.49)
$FInfra_{i,t-1}$			-0.00	-0.00
			(0.02)	(0.02)
$FInfra_{i,t-1} * Subsidy_{i,t}$			0.10***	0.06
			(0.04)	(0.04)
Observations	296	296	296	296
Number of country code	44	44	44	44
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes

Note: Numbers in parentheses are robust standard errors; *** p<0.01, ** p<0.05, * p<0.1;
Source: Authors' calculation

Figure 1

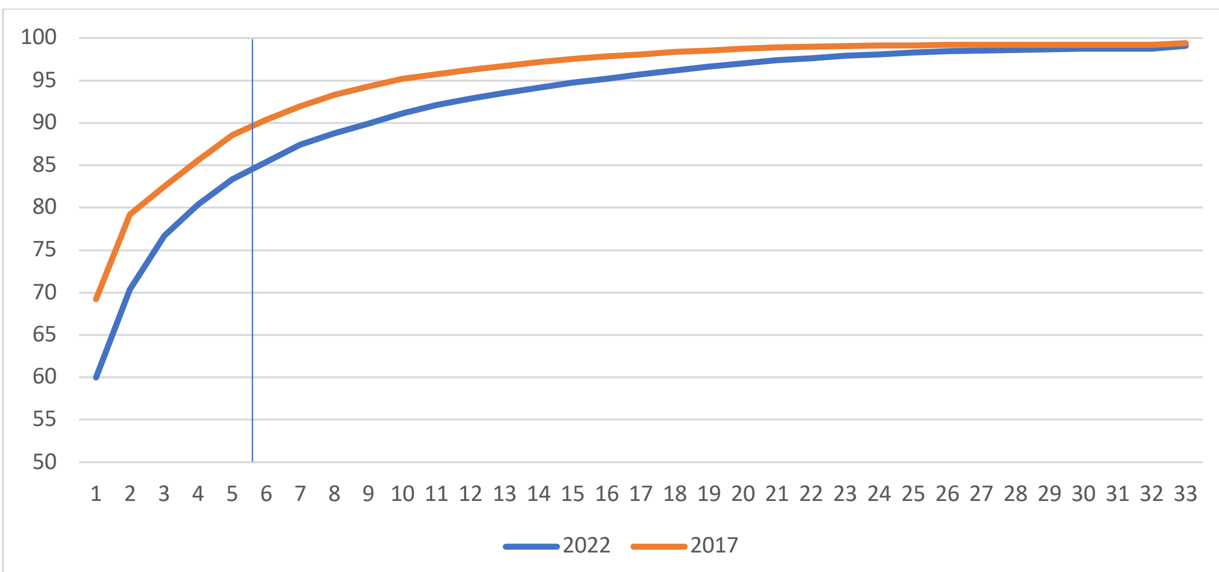
A number of BEVs and their share to total EVs (BEVs+PHEVs)



Sources: the authors' compliation from IEA database

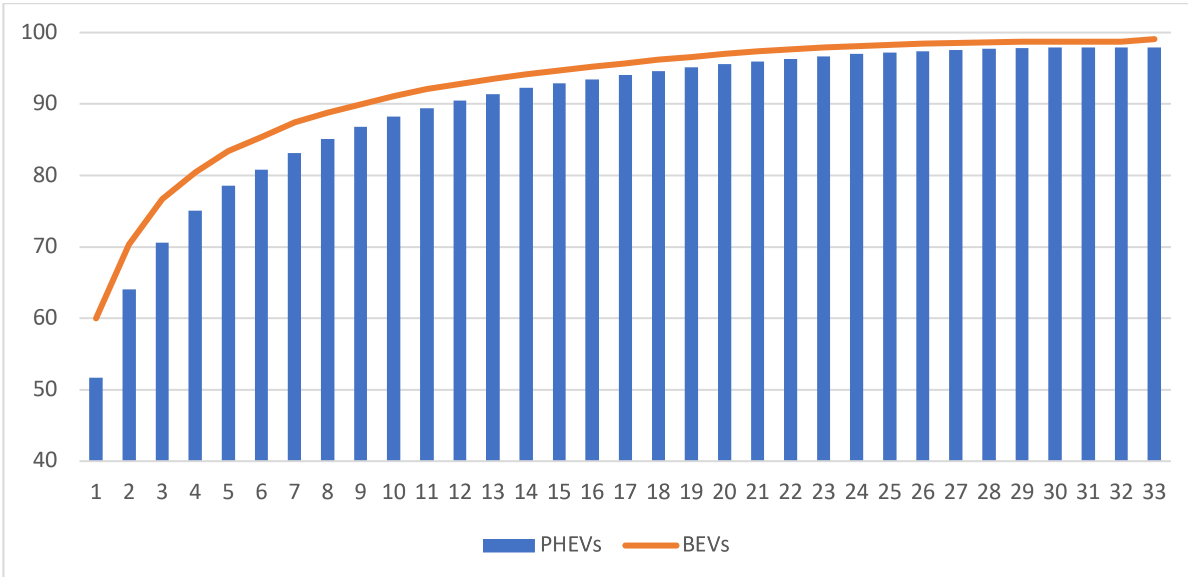
Figure 2

Cumulative share of BEVs in 2017 and 2022.



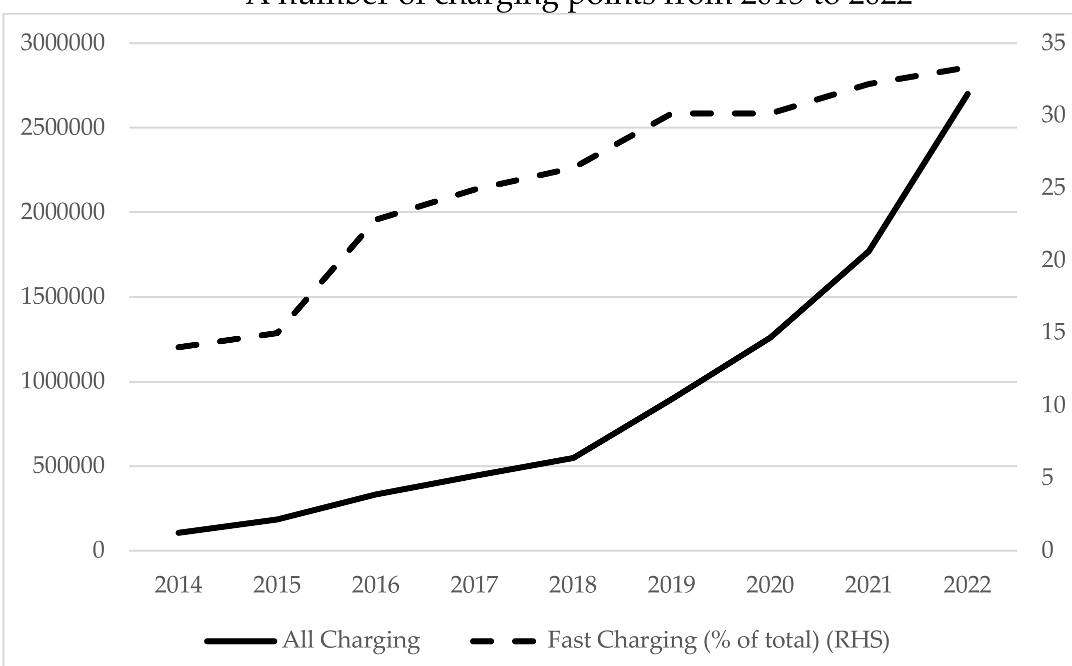
Sources: the authors' compliation from IEA database

Figure 3
The cumulative share of BEVs and PHEVs in 2022.



Sources: the authors' compliation from IEA database

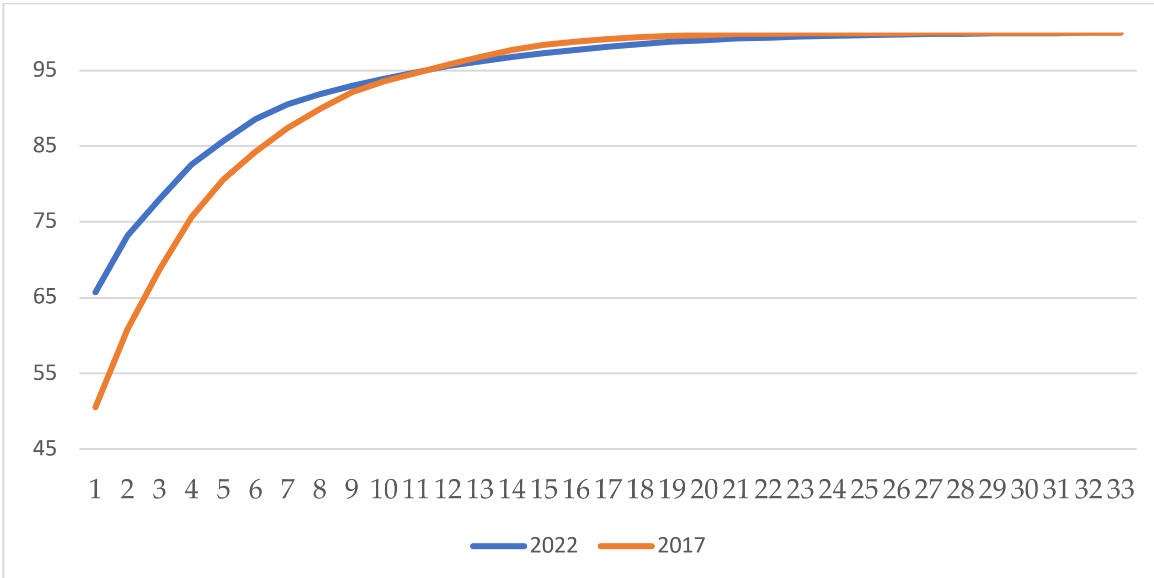
Figure 4
A number of charging points from 2015 to 2022



Sources: the authors' compliation from IEA database

Figure 5

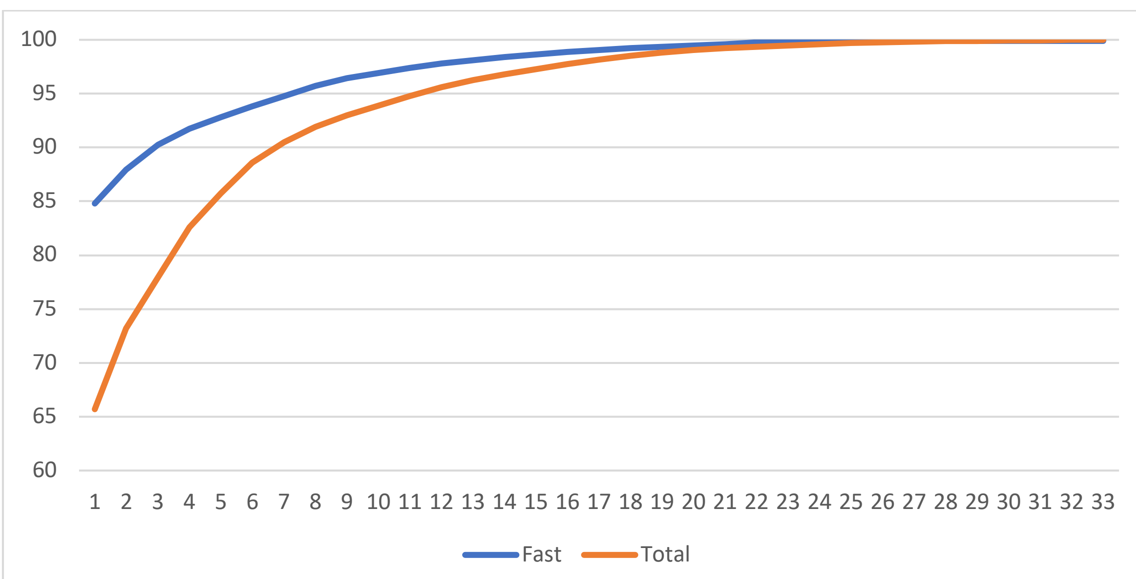
Cumulative share of total charging station points 2017 and 2022



Sources: the authors' compliation from IEA database

Figure 6

Cumulative share of fast and total charging points in 2022



Sources: the authors' compliation from IEA database

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