The influence of financial incentives and other
socio-economic factors on electric vehicle adoption

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Abstract

Electric vehicles represent an innovation with the potential to lower greenhouse gas emissions and help mitigate the causes of climate change. However, externalities including the appropriability of knowledge and pollution abatement result in societal/economic benefits that are not incorporated in electric vehicle prices. In order to address resulting market failures, governments have employed a number of policies. We seek to determine the relationship of one such policy instrument (consumer financial incentives) to electric vehicle adoption. Based on existing literature, we identified several additional socio-economic factors that are expected to be influential in determining electric vehicle adoption rates including: charging infrastructure, environmentalism, financial incentives, fuel price, urban density, education level, per capita vehicles, number of models available for purchase, local presence of electric vehicle production facilities, introduction date, vehicle price, and electricity price. Using multiple linear regression analysis, we examined the relationship between those variables and 30 national electric vehicle market shares for the year 2012. The model found financial incentives, charging infrastructure, and local presence of production facilities to be significant and positively correlated to a country's electric vehicle market share. Results suggest that of those factors, charging infrastructure was most strongly related to electric vehicle adoption. However, descriptive analysis suggests that neither financial incentives nor charging infrastructure ensure high electric vehicle adoption rates.

1. Introduction

The IPCC (2012) noted that climate change caused by rising levels of greenhouse gases (GHGs) poses a serious threat to the physical and economic livelihoods of individuals around the globe and could negatively affect ecosystems by putting 20-30% of plant and animal species at an increasingly high risk of extinction.[1] GHGs such as CO_2 and N_2O primarily come from the burning of fossil fuels during activities including electricity production and operating internal combustion engines. In 2010, the transport sector accounted for 6.7 Gigatons of emitted CO_2 or 22% of the world's total (IEA, 2012a). Furthermore, global fuel demand for transportation is projected to grow approximately 40% by 2035 (IEA, 2012b). The IPCC noted the need to reduce GHG emissions (particularly in the energy and transport sectors) in order to avoid a 2.4 – 6.4 degree centigrade increase in 2090 temperatures relative to those from 1990 (IPCC, 2007).

Electric vehicles (EVs) are one possible innovation to help address the environmental concerns identified above. However, EV adoption is seen as being very limited without stimulation from external factors such as stringent emissions regulations, rising fuel prices, or financial incentives (Eppstein et al., 2011; Shafei et al., 2012; IEA, 2013). Of those factors, consumer subsidies are specifically identified as being necessary for EVs to reach a mass market (Hidrue et al., 2011; Eppstein et al., 2011). Part of the reason that diffusion is expected to be so slow is that pollution abatement and knowledge appropriability[2] externalities reduce EV development and consumer adoption, leading to an inefficient allocation of goods and services known as a market failure (Rennings, 2000; Jaffe et al., 2005; Struben and Sterman, 2008). In the case of EVs, market failures distort their prices relative to ICEVs, which results in fewer electric automobiles being built by firms or bought by consumers. Consequently, the potential to address climate change through EV development and use is limited by externalities; neo-classical economics indicates that government policy should be employed to help correct for such situations (Rennings, 2000). Of these policy measures, demand side instruments such as consumer subsidies are viewed as being particularly important during the early commercialization period (IEA, 2013). However, based on previous studies, there are reasons to question how effective such financial incentives would be in encouraging EV adoption.

Firstly, the literature has presented conflicting results regarding the effect of consumer subsidies on hybrid-electric vehicle (HEV) adoption. While some studies have shown financial incentives to be positively correlated to HEV sales (Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011), Diamond (2009) found that higher fuel prices, not consumer subsidies, were related to increased adoption. In addition, Zhang et al. (2013) identified only a very weak relationship between purchase subsidies and consumer willingness to buy EVs. Thus, factors other than financial incentives could be the primary drivers of EV adoption.

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[1] This is posed by the IPCC with 'medium confidence' under a situation where global temperatures are 2-3°C above pre-industrial levels.
[2] Knowledge appropriability or "knowledge spillover" relates to the ability of a firm to benefit from technologies or expertise that it develops as opposed to other companies gaining from those advances without investing in the necessary R&D e.g., reverse engineering a developed product. Knowledge spillover results in lower rates of innovation.

Secondly, due to the nature of radical innovation development (Tushman and Anderson, 1986), there may be reasons to suspect that consumers may not behave in the same fashion toward HEVs as they do toward EVs. Innovations that are further away technologically from the dominant design are associated with greater levels of uncertainty (Anderson and Tushman, 1990). Consequently, since EVs represent a more radical technological departure from ICEVs than do HEVs (Sierzchula et al., 2012), they result in increased levels of uncertainty, specifically among consumers (Sovacool and Hirsh, 2009). This uncertainty affects a broad array of industrial dynamics including future profitability of a technology, government involvement, and willingness to pay (Arrow, 1966; Nelson and Winter, 1977; Jaffe et al., 2005); the more an innovation differs from the conventional technology, the less consumers are willing to pay for it. Thus, higher consumer uncertainty regarding EVs decreases the amount that individuals are willing to pay relative to HEVs, in effect reducing the utility of financial incentives relative to EV adoption. This makes it difficult to estimate the impacts of financial incentives on the adoption of a radical innovation with significantly different performance characteristics relative to the conventional technology, as is the case with EVs. Therefore, earlier studies analyzing HEV adoption may under-represent the impact that financial incentives have on EV purchases.

In addition, consumer subsidies may have little effect on EV sales uptake if buyers are uncomfortable with the technology (Egbue and Long, 2012), or do not see enough EVs in the fleet around them (a threshold effect) (Eppstein et al., 2011). Our paper aims to contribute to the literature by examining if and to what extent financial incentives and other socio-economic factors explain EV adoption.

2. Barriers limiting innovation

The literature has identified several obstacles which limit the diffusion of new technologies such as EVs. For example, knowledge spillover applies broadly to all innovations while pollution abatement and bounded rationality[3] are typically associated with limiting the development and adoption of environmental technologies (eco-innovations) (Jaffe et al., 2005; Rennings, 2000). These barriers, which limit EV diffusion by influencing both the manufacturers that produce the automobiles and the consumers that buy them, are described more comprehensively below.

2.1. General barriers

In studying the development of innovations, Arrow (1962) determined that in a capitalist system, firms will underinvest in research and development of new technologies. This is primarily due to uncertainty, but also because an innovation's *public* benefit (for which businesses receive little financial compensation) often outweighs its *private* value to the company. The externality, of 'positive knowledge spillover,' occurs when innovations provide valuable information to non-consumers (Horbach, 2008).

For example, firms are not always able to prevent competitors from gaining from their R&D efforts. The degree to which a firm is able to defend the profits of an innovation from competitor imitation is referred to as its appropriability (Teece, 1986). Because it is not possible for a firm to keep every element of a new technology secret, other companies can gain by learning from and in some cases

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[3] The notion that an individual's decision making is influenced by the information that he/she has.

stealing the work of the original innovating entity. Thus, due to knowledge spillovers, businesses are less likely to invest in the development of innovations that are easily copied (having low levels of appropriability) because they will not be able to reap all of the rewards from a successful new technology (Teece, 1986). Positive knowledge spillover influences the industrial landscape such that although firms do invest in the research and development of new technologies, they do so at a lower level than would be expected based on the financial benefits that innovations provide.

In addition, emerging technologies face further barriers because they often compare poorly to existing dominant designs in important criteria such as price and performance (Adner, 2002). For that reason, the first individuals to adopt an emerging radical innovation are often willing to pay a premium or cope with sub-par performance in order to have the latest technology (Rogers, 1995). The larger proportion of the population known as early/late majority adopters are much more risk adverse, and are not willing to purchase an innovation so different from the dominant design (Rogers, 1995). It is vital for radical technologies to attract a significant enough number of early adopters to develop a viable market niche (Geels, 2002). Thereafter, industrial forces such as learning by doing and scale economies can rapidly lower costs and improve performance (Foster, 1986; Christensen, 1997). In order for an innovation such as electric vehicles to have a significant environmental impact, it needs to be widely adopted (and have dramatically lower emissions levels compared to ICEVs). For that to happen, there must first be enough demand within the EV niche market that manufacturers continue to develop and sell the automobiles. Consequently, governments have employed financial incentives to help attract early EV adopters.

2.2. Barriers that reduce eco-innovation

Eco-innovations differ from other new products and services in that they provide a lower environmental impact than the conventional technology (Rennings, 2000). Examples range from incremental improvements to existing designs such as turbocharging in automobile engines to more radical technologies, like solar cells and wind turbines. The distinct nature of eco-innovations improves general social utility through lower pollution abatement levels. However, this externality also creates market failure, and ultimately limits their development and adoption (Jaffe et al., 2005).

Investments in eco-innovation are specifically disincentivized because benefits from lower pollution levels are not included in a product's price. The externality pollution functions such that that even though many societal members profit from eco-innovations through improved health (however marginally), firms are not able to charge those individuals for their gains. As a result, eco-innovations have lower adoption levels than if societal benefits from decreased pollution were included in product costs (Brown, 2001).

An additional barrier that has contributed to lower eco-innovation diffusion is bounded rationality, which can influence consumer valuation of a product's purchase price, operating expenses, and lifetime cost. Instead of using rational choices to maximize an individual's utility, individuals are aware of only a portion of the available options and thus act on imperfect information (Nelson and Winter, 1982). Thus, in place of calculating out the total cost of ownership of a product, consumers often rely on heuristics or rules of thumb to guide their purchasing behavior (Jaffe and Stavins, 1994; Schleich, 2009). This can lead an individual to place too much emphasis on the purchase price and not accurately value operating

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expenses (Levine et al., 1995). Because many eco-innovations have high purchase prices and low operating expenses, they have often experienced slow diffusion rates (Brown, 2001). Specifically regarding EVs, consumers looking to purchase alternative fuel vehicles do not accurately incorporate fuel economy in their vehicle purchase decisions, leading to irrational behavior (Turrentine and Kurani, 2007).

3. Factors influencing EV adoption

Because EVs were introduced to the broader consumer market only recently in 2010 (not including their temporary commercialization in the 1990s), there is little research that uses empirical data to analyze factors which affect adoption rates. Thus, much of our knowledge about such contributing elements comes from stated preference studies. However, because of a phenomenon known as the 'attitude-action gap', there is the concern that information from consumer surveys may have little relation to the purchase of low-emission vehicles (Lane and Potter, 2007). This raises the value of research that analyzes actual consumer actions (revealed preferences), such as that performed in our paper.

HEVs provide a good comparison basis for EVs (even though they are less of a radical innovation) because they have several of the same key elements including a battery and electric motor based powertrain and lower environmental impacts. As HEVs have been commercially available since the late 1990s, there are several studies that used revealed preference data to investigate factors that influenced consumer uptake for those automobiles. In the absence of similar research for EVs, we have incorporated in our model variables that were found to be significant drivers of HEV adoption in those articles e.g., education level, fuel price, and environmentalism (Lane and Potter, 2007; Diamond, 2009; Gallagher and Muehlegger, 2011). Based on the findings in HEV revealed preference research, EV survey studies, and theoretical articles, we have collected and categorized the factors that are assumed to determine the decision of whether or not to purchase an electric vehicle as belonging to the technology itself, the consumer, or the context.

The technology category comprises aspects of electric vehicles including battery costs and performance characteristics (driving range and charging time). EV purchase prices, which are heavily dependent on battery costs, have been identified as being the most significant obstacle to widespread EV diffusion (Brownstone et al., 2000). The IEA (2011) found that the purchase price of an EV with a 30 kWh battery (approx. 85 miles[4] of driving range at 0.17 kWh/mile) would be $10,000 (all financial amounts in this article should be read as US dollars) more than a comparable ICEV. Battery costs also have an impact on the driving range of an EV. An increase in the size of an EV's battery (in kWh) raises both its driving range and purchase cost. Therefore, although consumers are sensitive to a limited driving range (Lieven et al., 2011) that aspect must be balanced with its relation to vehicle battery costs. An additional factor which influences consumer adoption is vehicle charging time (Hidrue et al., 2011; Neubauer et al., 2012). Whereas most ICEVs are able to refuel in roughly four minutes, EVs require ~30 minutes at a fast charging station and up to several (>10) hours for charging from a 110 or 220 volt outlet, dependent on battery size (Saxton, 2013). Relative to a comparable ICEV, an EV's high purchase price, limited driving range, and long charge period all have a negative impact on adoption rate.

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[4] 136 kilometers

In addition to factors relating to the EV, consumer characteristics also play a role in determining uptake. Studies have identified levels of education, income, and environmentalism to all be positively correlated to likelihood to purchase an EV (Hidrue et al., 2011) or HEV (Gallagher and Muehlegger, 2011). However, these factors, specifically environmentalism, are often less important to consumers than vehicle cost and performance attributes such as those identified in the paragraph above (Lane and Potter, 2007; Egbue and Long, 2012).

A third set of elements, which the literature has found to influence adoption rates and is external to both the vehicle and consumer, is categorized as context factors in our research. In several studies, fuel (gasoline or diesel) prices have been identified as one of the most powerful predictors of HEV adoption (Diamond, 2009; Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011), and have also been influential in agent-based models forecasting EV diffusion (Epstein et al., 2011; Shafei et al., 2012). Related to fuel prices, although less commonly incorporated in analyses, are electricity costs. Those two factors combine to determine a majority of EV operating expenses which in turn have an impact on adoption rates (Zubaryeva et al., 2012; Dijk et al., 2013). Other studies have identified availability of charging stations as an important determinant in consumer acceptance of alternative fuel vehicles e.g., EVs (Yeh, 2007; Struben and Sterman, 2008; Egbue and Long, 2012; Tran et al., 2012). A country's level of urban density could facilitate greater EV adoption as shorter average travel distances might allow for wider use of the vehicles' limited driving range (IEA, 2011). Finally, there are several factors specific to EVs that could influence adoption rates including vehicle diversity i.e. the number of models that consumers can buy (Van den Bergh et al., 2006), local involvement i.e. the presence of a local manufacturing plant (IEA, 2013), and public visibility i.e. the number of years EVs have been available for purchase (Eppstein et al., 2011).

4. Method

This section describes how EV adoption rates across a series of countries were analyzed using a set of socio-economic variables. Section 4.1 describes the data that were collected. Section 4.2 outlines a more detailed description of how financial incentives were operationalized. Section 4.3 provides the final model specification.

4.1 Data collection

We collected and analyzed data from 30 countries for 2012. The year 2012 was selected as the study date because important information such as charging infrastructure and EV adoption rates were unavailable in earlier years. Our statistical analysis used data from the following countries: Australia, Austria, Belgium, Canada, China, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Greece, Germany, Iceland, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. We selected these countries because of the availability of data, specifically EV adoption and charging infrastructure figures. In our study, we defined electric vehicles as including both pure battery electric vehicles, e.g., Nissan LEAF, as well as plug-in hybrid electric vehicles, e.g., Chevy Volt. As this definition of EVs was based around vehicles with a plug, other HEV models such as the Toyota Prius were not included in our analysis.

Based on the factors identified in Section 3, we collected data for the following variables for each country in our study: EV market share, financial incentives, urban density, education level, an environmentalism indicator, fuel price, EV price, presence of production facilities, per capita vehicles, model availability, introduction date, charging infrastructure,[5] and electricity price. EV adoption was operationalized as national market shares of electric vehicles. Variable descriptions and their sources are provided in Table 1. Notable absences include driving range and charging time. Those variables were not added to our model because generally the same electric vehicles were available for purchase in the countries in our sample. Thus, there is no fundamental difference in the driving range of a Nissan LEAF in China or a Nissan LEAF in Germany.[6]

<<**Table 1:** Description of variables and sources>>

4.2 Financial incentives

To encourage EV adoption, countries have used financial incentives from both technology specific policies, such as subsidies to EV consumers, and technology neutral policies, such as emissions-based vehicle taxes. These were applied either at the time of a vehicle's registration or on its annual circulation fee (license fees in the US). In some cases, countries lowered automobile taxes for EVs, and in others they provided subsidies apart from normal registration and circulation fees, thus presenting a very diverse financial incentive landscape. This section of the study describes how such a heterogeneous environment for subsidies was operationalized to allow for analysis across countries.

In order to compare financial incentives that used different emissions and monetary units, policies were standardized relative to CO_2 emissions and 2012 US dollars. To convert fuel use to CO_2 emissions, we used the following formula: 1 liter/100km = 23.2 gram CO_2/km (UNEP, 2012). We converted currencies to US dollars using the averaged quarterly exchange rates from 2012. In some situations, it was necessary to use a vehicle's performance characteristics, e.g., CO_2 emissions[7] in order to calculate the financial incentives of a particular policy. An example would be an annual circulation fee in which the amount paid was dependent on a vehicle's CO_2 emissions levels. However, this does not give an indication of the savings relative to the purchase of an ICE vehicle (there is no basis for comparison). In order to calculate the value of such financial incentive policies, we used information from an ICEV and EV (a 2012 Volkswagen Golf and Nissan Leaf respectively). Table 2 provides a description of the basic characteristics of these vehicles.

<<**Table 2:** ICEV and EV used for policy valuation>>

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[5] Charging stations were identified such that there could be multiple stations at a location, and multiple charging points (plugs) per station.
[6] Differences in temperature would affect driving range. With that in mind, the same vehicle in different countries might have slightly different performance characteristics depending on weather conditions. However, the precise effects of temperature on EV driving radii are still being determined. For that reason driving range as influenced by temperature was not included in our model, but could still contribute to differences in adoption between countries such as Spain and Sweden.
[7] For the policies analyzed in our study, CO_2 emissions were calculated from a vehicle's tailpipe, based on standard driving cycles e.g., NEDC and FTP-75.

Some policies, such as registration taxes, were applied on a one-time basis. For other policies that required annual payments e.g., circulation fees, we sought to provide a more realistic notion of their monetary value. We did this by using a 3 year payback period and consumer discount rate of 30% (based on the work of Greene et al., 2005 and Yeh, 2007). For example, a one-time registration subsidy of $1,000 maintains that value, but an annual circulation subsidy of $50 provided a financial incentive of $90.81 in our analysis.

For the countries studied in our sample, financial incentives did not change considerably in 2011 and 2012. In absolute terms during those two years, Portugal saw a $5,500 decrease in financial incentives offered to EV adopters while Finland saw a $4,600 increase. Otherwise, national financial incentive levels have remained constant over that time period.

4.3 OLS regression

The variables from Table 1 were incorporated into an ordinary least squares (OLS) regression with a logit transformation of the dependent variable to normalize distributions of EV market share. This transformation is appropriate when data are skewed, or bounded such as with a proportion (Lesaffre et al., 2007). A histogram of the EV market share was skewed to the right, and the variable was a proportion. After the logit transformation, a second histogram showed EV market share to be normally distributed, validating this approach. The final model specification is given as

$$\log\_MarShr_i = \alpha + \beta_1 Incentive_i + \beta_2 UrbanDensity_i + \beta_3 Education_i + \beta_4 Env_i + \beta_5 Fuel_i \\ + \beta_6 ChgInf_i + \beta_7 Elec + \beta_8 PerCapVehicles + \beta_9 EV\_Price \\ + \beta_{10} Availability + \beta_{11} Introduction + \beta_{12} HQ + \varepsilon_i$$

where the subscript *i* denotes the country, and ε is an error term.

5. Results and discussion

This section includes a correlation matrix of variables used in the model, a descriptive analysis of EV-specific factors, and results from the statistical model identified above. Stress tests of the model were employed to determine its general robustness and the relative impact of specific variables. Finally, we discuss implications that arise from the results, which provide a notion of how different policy measures such as fuel taxes, consumer subsidies, and installing charging stations could influence EV adoption.

5.1 Correlation analysis of model variables

Looking at relationships between individual variables can help to highlight dynamics that are not evident in linear regression models. Appendix 1 provides a Pearson's correlation coefficient and statistical significance between the variables used in the base model specification. One of the patterns that appears when analyzing this matrix is that many of the EV-specific variables are strongly correlated (price, year of introduction, availability, market share, financial incentives, and charging infrastructure), indicating that industrial dynamics can become interwoven during the early commercialization of a radical innovation. Another observation is that the EV price variable has a negative correlation to a country's market share. Mitsubishi MiEVs were most expensive in countries where adoption rates were

low e.g., Turkey, China, and New Zealand, and they were cheaper in the US, Norway, and Japan, countries with relatively high EV market shares. Sometimes this difference was dramatic as with Australia ($53,126) and Switzerland ($26,925). And while it is difficult to draw any conclusive results from such correlations, they do provide a good basis for further analysis.

An additional correlation that was not included in Appendix 1 was between charging infrastructure and the type of EV (plug-in hybrid or purely battery electric). Potentially, a country with a higher proportion of plug-in hybrid-electric vehicles (PHEVs) would have less dependence on charging stations, which could weaken the relationship between a country's EV adoption and its charging infrastructure. However, preliminary model estimations identify that percent of PHEVs did not have a statistically significant relationship to either charging infrastructure or EV market share. This suggests that the proportion of a country's EVs with an internal combustion engine does not significantly relate to its charging infrastructure or adoption rate.

5.2 Descriptive analysis of EV-specific variables

In addition to socio-demographic factors such as income and education level, our model also incorporated several EV-specific variables including financial incentives, charging infrastructure, model availability, and presence of a local manufacturing facility. The descriptive analysis of these variables provided below identifies how significant correlations found in Appendix 1 can actually involve a great deal of heterogeneity and diversity, indicating the existence of other influential factors.

5.2.1   Financial incentives

Financial incentives and EV adoption in Figure 1 display a positive and significant relationship (P-value of .01). Even so, there is substantial variation among the data points. In addition, there appears to be two groups of countries. The first is constituted by approximately the bottom half of our study sample (14 countries) as represented by nations with financial incentives less than $2,000. They exhibited lower EV market shares with the exceptions of Sweden (.30%) and Switzerland (.23%), and to a lesser extent Germany (.12%), and Canada (.13%). Consequently, 10 countries showed little EV activity as measured by either financial incentives or EV adoption.

<<**Figure 1**: Financial incentives by country and corresponding EV market share for 2012>>

The other group in Figure 1 is distinguished by the countries with higher levels of financial incentives and greater variation in their EV market shares. Some countries such as Norway and Estonia matched high financial incentives with increased EV adoption. However, this relationship was not uniform as other countries, including Denmark and Belgium, offered high financial incentives but had relatively low levels of adoption. Figure 1 suggests that there are factors other than financial incentives that drive EV adoption.

In addition to variables captured by the model, there are likely to be country-specific factors that influenced national EV market shares. For instance, consumers in Estonia adopted 55 EVs in 2011 (mnt.ee, 2013), but the federal government decided to purchase approximately 500 MiEVs in 2012 (Estonia, 2011). That single act largely explains why it had such a high market share in 2012. Conversely,

Norway installed extensive charging infrastructure in 2009, and has experienced a more gradual increase in EV adoption rates since 2010, predominantly through household consumers (SAGPA, 2012). An additional factor which is not captured by the financial incentive variable is the subsidy's recipient. Through their purchase of a majority of EVs through 2012, fleet managers were identified as being very important early adopters (IEA, 2013). However Belgium's financial incentives were directed specifically toward households, so they may have largely missed engaging the fleet market, hurting the country's adoption figures. These country specific factors provide insight into factors not included in the model that had the potential to greatly influence national EV adoption levels.

As identified in the methods section, countries employed several different types of financial incentives based on the vehicle's tonnage, company car status, emissions, and powertrain, which can be broadly categorized as either registration or circulation subsidies. Figure 2 below identifies how countries approached financial incentives according those policy categories.

<<**Figure 2**: Breakdown of financial subsidies types offered by countries>>

Figure 2 notes that most available EV financial incentives (78%) came in the form of registration as opposed to circulation subsidies. The difference between the two is that registration funds were offered the year that the EV was purchased while those based on a vehicle's annual circulation provided benefits over a multiple year time span. Perhaps one reason why registration subsidies were the dominant form of financial incentives is due to consumer high discount rates for circulation subsidies, effectively lowering their perceived value. A correlation test between EV market share and registration/circulation subsidies did not return a significant value suggesting that it was the total financial incentive value and not the specific policy type that was relevant for adoption rates.

5.2.2   Charging infrastructure

Figure 3 exhibits a positive and significant relationship (P-value of .000) between charging stations (adjusted for population) and EV adoption rates. Despite an overall positive correlation, there were examples of wide discrepancies in the data as evidenced by Estonia and Israel. Both countries had similar proportions of charging stations, but Estonia had an EV adoption level 11 times higher than that of Israel. There also appears to be seven countries with very low levels of both charging stations and EV adoption.

 <<**Figure 3**: National charging infrastructure by country and corresponding EV market share for 2012>>

Not as much information is available about national charging infrastructure as financial incentives, perhaps because in many countries they are largely installed by local municipalities (Bakker and Trip, 2013). Among the countries in our sample, there have been several different approaches to building charging infrastructure from federal mandate (Estonia) to auto manufacturer led (Japan) to local government initiative (Belgium) to public-private partnerships (Norway) (Estonia, 2013; SAGPA, 2012; ASBE, 2013; Nobil, 2012). This variety in approach to charging infrastructure development likely relates to other factors that influence EV adoption e.g., local involvement.

Analyzing Figures 1 and 3, five (out of the 30) countries showed very little activity during the introductory phase of EVs, as measured by financial incentives, adoption, or charging infrastructure installation. Thus, countries in our study could be divided into two groups with divergent attitudes toward EV adoption as reflected by government policy and consumer purchase behavior. One set of countries seemed to be actively engaged in the EV introductory market while the other appeared to show very little interest. However, the discrepancy between the two groups will likely have little effect on the overall success or failure of EVs as the countries invested in their adoption represent a substantial majority of global GDP based on national purchasing power parity (World Bank, 2013c).

5.2.3   Number of models available and local EV production

As identified in the correlation matrix, many of the EV-specific variables displayed strong correlations. In order to better understand how these factors interact, Figure 4 looks at three such variables: the number of models available for purchase, whether a country produced EVs locally (bolded columns), and adoption rates.

Figure 4: Number of EV models available for purchase, production facilities, and national market shares

In total, 45 different types of EVs were purchased in 2012 although a small number of models such as the Nissan Leaf, Chevy Volt/Opel Ampera, and Toyota Plug-in Prius accounted for the lion's share (62%) of those sales. The Mitsubishi MiEV was the most widely available, being adopted in 26 of the countries in our sample. There was a positive correlation between a country's EV adoption rate and the number of models that were available for purchase. In many instances, manufacturers sold a limited number of several different EV models in their native country e.g., Ford in the US and Mercedes in Germany. In those instances, manufacturers were likely experimenting with a limited production of specific EV models before expanding their sales efforts.

Countries where native manufacturers heavily invested in EVs e.g., Japan, France, and the US, had some of the highest EV market shares. Other countries with EV production facilities but low adoption rates including Germany and Italy did not have EVs made by native manufacturers broadly available. This suggests a strong relationship between consumer adoption of EVs and their being manufactured by native firms. Several of the larger countries were much more prone to adopt native models, specifically China and Japan where only EVs from native manufacturers were purchased. Of those two countries, China stands out because very few EVs made by Chinese auto makers were sold outside the country. Many manufacturers e.g., Ford, Audi and Mia Electric, were nation-specific with sales only or primarily occurring in the country where their production facilities were located. The relationship between the variables in Figure 4 suggests a complex relationship between consumers, manufacturers, and national attitude regarding EVs.

5.3 OLS model results and implications

Table 3 shows regression results from the 30 countries in our study for 2012. We regressed the log of EV market share on financial incentives, urban density, education level, an environmentalism indicator, fuel price, EV price, the presence of production facilities, per capita vehicles, model availability, introduction

date, charging infrastructure, and electricity price. We used graphical and numerical analyses to ensure that the data met expectations of linearity, normality, and homoskedasticity. We used ANOVA tests and histograms to test for linearity, Shapiro-Wilk tests for normality, and visual analysis of scatter plots for heteroskedasticity.

<<**Table 3**: Regression results for 2012 electric vehicle adoption>>

The model's adjusted R^2 was 0.628 which means that almost 2/3 of the variation in national EV market shares was explained by the tested variables. The coefficients for financial incentives and charging infrastructure were positive and statistically significant with P-values of 0.039 and 0.004 respectively. Of those two variables, charging infrastructure had higher Beta values (both standardized and unstandardized), indicating that it was stronger at estimating adoption levels. Thus, adding a charging station (per 100,000 residents) had a greater impact on predicting EV market share than did increasing financial incentives by $1,000. The presence of a local EV manufacturing facility was also a significant variable, although to a lesser extent with a P-value of 0.079.

From the information in Table 3, it is possible to extrapolate the relationship of both financial incentives and charging infrastructure to EV market share. Holding all other factors constant, each $1,000 increase in financial incentives would cause a country's EV market share to increase by .06 percent. For example, a country with an EV market share of .22 percent that increased its financial incentives to consumers by $2,000 would see its adoption rate go up to .34 percent (.22% + .06% + .06%). For charging infrastructure, holding all other factors constant, each additional station per 100,000 residents that a country added would increase its EV market share by .12 percent. This suggests that each charging station (per 100,000 residents) could have twice the impact on a country's EV market share than $1,000 in consumer financial incentives, albeit with different bearings on a nation's budget.

However, as a note of caution, while our model did identify that financial incentives and charging infrastructure were positively correlated to national EV adoption levels, there is no guarantee that these relationships hold for all countries, as evidenced in Figures 1 and 3. For example, in Figure 1 Belgium and Denmark had very high financial incentives, but relatively low rates of adoption. Conversely, Switzerland and Sweden exhibited the opposite dynamic with low consumer subsidies but high EV uptake levels. Figure 3 displayed the same sort of mixed relationship between charging infrastructure and EV market share. Thus, financial incentives and charging infrastructure should be seen as being likely but not certain to predict a country's EV adoption rate.

The empirical results provide a useful comparison with stated preference surveys. While charging infrastructure and financial incentives were (as expected) significant in predicting EV adoption, this was not the case with broader socio-demographic variables e.g., income, education, environmentalism, and urban density that the literature had anticipated to be influential (Lane and Potter, 2007; Gallagher and Muehlegger, 2011; Egbue and Long, 2012). In addition, despite its strong and positive correlation to HEV adoption in earlier studies (Diamond, 2009; Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011), fuel price was not significant in predicting a country's EV market share. However, there are fundamental differences in those papers and our study that could help explain these conflicting results. Firstly, the

HEV studies examined a single nation over several years whereas our study looked at several countries for a single year. Secondly, fuel prices in those earlier studies exhibited much greater variation than was found in our data. Conversely, it could be that differences such as the complexity of total ownership cost calculation and the role of charging infrastructure result in fuel prices not having the same impact on EV purchases that they do with HEVs. More research is necessary to identify the relationship between fuel price and EV adoption, specifically studies that span multiple years and look at a single country.

5.3.1 Sensitivity tests

In addition to econometric results found in Table 3, we also performed several estimations to test the sensitivity of different variables (specifically financial incentives and charging infrastructure) and the base model's overall robustness. These are described below in Tables 4 and 5 and are referred to as Models 1-5 respectively. The individual variable(s) explored through sensitivity analysis is identified below the Model's number e.g., charging infrastructure in Model 1.

<<**Table 4**: Model sensitivity analyses 1 and 2>>

In Model 1, normalizing charging infrastructure for urban density did not drastically affect results with the variables financial incentives, production facilities, and charging infrastructure remaining significant while the adjusted R^2 (0.613) was also similar to that of the base estimation. As such, the base model remains robust to this sensitivity test. Model 2 explored the sensitivity of EV adoption to financial incentives with different discount rates and payback periods. While the US Energy Information National Energy Modeling System uses a 3 year payback period and discount rate of 30%, other studies have found that consumers, specifically businesses and government agencies, may more accurately calculate the total lifetime costs of an innovation (Nesbitt and Sperling, 1998; Menanteau and Lefebvre, 2000). As such, we ran a sensitivity test for a lower discount rate (1.25%) and longer payback period (8 years, which is the warranty period for a Nissan Leaf or Chevy Volt). This approach resulted in $25,000 more in available financial incentives from $180,000 in the base model. This sensitivity test did not substantially change the significant variables (financial incentives, charging infrastructure, and EV manufacturer location) or the models adjusted R^2, (0.628) suggesting that differences in discount value and payback period have a relatively weak influence on national EV adoption rates, although that could be due to the small number of multi-year consumer subsidies i.e. those that address circulation taxes.

<<**Table 5**: Model sensitivity analyses 3 – 5>>Sensitivity analyses 3 – 5 show how the model's explanatory power changed with the removal of financial incentives and charging infrastructure variables. Removing the financial incentives variable in Model 3 resulted in the adjusted R^2 decreasing from 0.623 in the base analysis to 0.533. Taking out charging infrastructure in Model 4 caused a more drastic reduction in adjusted R^2 to 0.391. Removal of both factors in Model 5 caused the model to lose most of its explanatory power; it had no significant variables and an adjusted R^2 of 0.238. From these sensitivity tests this it is possible to conclude that in our model, charging infrastructure was considerably stronger than financial incentives in explaining EV adoption rates.

There were several limitations in our models which had the potential to produce misleading results. During the introduction of new technologies, there are often discrepancies in supply among locales.

Differences in EV availability by locality may have contributed to variation in national adoption numbers. In addition, our study analyzed financial incentives from national governments. There are undoubtedly monetary benefits, such as free parking or toll exemptions provided by regions and cities that were not included in this study and were likely to have been influential. The small number of observations per year is also cause for caution when interpreting the results. Furthermore, by only studying one year, the data does not allow for analysis of the relationship between important variables e.g., financial incentives and charging infrastructure.

6. Conclusions

The purpose of this research was to explore the relationship between financial incentives and other socio-economic factors to electric vehicle adoption across several countries. We found that financial incentives, the number of charging stations (corrected for population), and the presence of a local EV manufacturing facility were positive and significant in predicting EV adoption rates for the countries in our study. Of those variables, charging infrastructure was the best predictor of a country's EV market share. However, descriptive analyses indicated how country-specific factors such as government procurement plans or the target recipient of subsidies could dramatically affect a nation's adoption rate. On the whole this analysis provides tentative endorsement of financial incentives and charging infrastructure as a way to encourage EV adoption.

A second conclusion is that EV-specific factors were discovered to be significant while broader socio-demographic variables such as income, education level, and environmentalism were not good predictors of adoption levels. This could be because national EV markets were so small relative to overall automobile sales. Thus, while many EV consumers may have high levels of education and be passionate about the environment, within the perspective of a country such individuals still represent a tiny portion of the overall population. Therefore, socio-demographic variables may not provide a good indicator of adoption levels when comparing countries. If EVs emerge from a niche market, then socio-demographic data might be more accurately used to predict adoption levels at the national scale. Until then, EV-specific factors such as amount of charging infrastructure, level of consumer financial incentives, and number of locations that sell the automobiles are likely to be more correct for estimating a country's market share.

6.1 Policy implications

Based on our results, a sensible policy approach for addressing EV market failures arising from pollution abatement and knowledge spillover would be for governments to provide consumer subsidies and/or increase their number of charging stations. Due to the importance of consumer adoption during the commercial introduction of a radical innovation (Nemet and Baker, 2009), such supportive measures could make a wide difference in the level of EV diffusion in the coming decades. As the charging station variable was the strongest predictor of EV adoption based on Beta values stress tests, their installation may be more effective than financial incentives. However, since these two factors are likely to be complimentary, supporting both measures could be expected to lead to higher market shares than focusing on either financial incentives or charging infrastructure alone.

However, this study also provides three notes of caution to countries that expect that they can achieve high EV adoption rates by increasing their levels of financial incentives or charging infrastructure. Firstly, the descriptive analysis identified several countries that displayed a relatively weak relationship between the two factors and EV market share. Secondly, it is possible that financial incentives or charging infrastructure mask other dynamics which are significant in driving EV adoption. Consequently, building policy only around those two factors may not support important underlying elements. Thirdly, due to the constantly evolving environment during the emergence of a radical innovation, industrial dynamics may change from year to year. Therefore, while this study does show that financial incentives and charging infrastructure are positively correlated to national EV market shares, it is definitely not evidence of a causal relationship and should be treated with prudence.

While national governments have been primarily responsible for consumer financial incentives, installing charging points has largely been left to local public bodies such as cities (IEA, 2013). However, the IEA (2013) found that "infrastructure spending has been relatively sparse" (pg. 16), which suggests that local and national levels of government should strengthen coordination in order to better encourage EV adoption, supporting earlier research by Bakker and Trip (2013).

Now that we have identified policies that could be effective in encouraging EV adoption, a next question is whether they are actually efficient in a societal and economical sense. To answer this question, an elaborate ex-ante Cost Effectiveness Analysis (CEA) or Cost Benefit Analysis (CBA) would be needed. However, given the dynamic nature of radical innovations, one should be careful when applying these methods to the EV case. That is to say, EVs may not significantly reduce GHG emissions in the short term, but they have the potential to cause dramatic decarbonization post 2020 (2012c), assuming a dramatic increase of the share of renewables in the electricity mix. In that respect, financial incentives today may be important for stimulating broader EV adoption in the future, and consequently may provide benefits outside those typically included in a status quo based CBA. Such additional benefits may be reason to implement these policies even if the results from a traditional CBA were not very favorable.

Furthermore, it is difficult to compare the costs of financial incentives for EVs with at least some competing policy options to reduce CO_2 emissions. Financial incentives to increase the sales of EVs on a temporary basis may be needed in the early stages of EVs because they cannot compete yet with internal combustion engine vehicles. If, in a few decades, EVs would become a success, financial incentive policies could prove to have contributed to this success. In other words, there may be a snowball effect of current financial incentives which are fundamentally difficult to grasp in a conventional CEA or CBA. We therefore suggest that these analyses can be used to support decision making, but that their outcomes should be treated with caution and that decision makers should always take a long term perspective when interpreting these.

6.2 Suggestions for future research

This study looked at a country's total charging infrastructure, not taking into account how a heterogeneous distribution of charging stations (many in one city, few elsewhere) might influence EV adoption. Specifically because of the important role played by local municipalities in installing charging

infrastructure, their allocation could have an important affect on a country's EV adoption rate (Bakker and Trip, 2013). Therefore, we suggest that future research focus on the relationship between the distribution of charging infrastructure within a country and its EV adoption rate.

In addition, our model found charging infrastructure and financial incentives to be powerful predictors of EV adoption rates for the countries in our sample. However, it is possible that the variables concealed other important factors. Therefore, further analysis is necessary to unpack the importance of charging infrastructure and financial incentives to determine whether they are on their own good predictors of EV adoption, or if there are other elements that also need to be present but were not included in our model. For instance, fuel price volatility may provide insight into EV adoption that is not captured through absolute fuel prices.

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