The limited influence of financial incentives on the adoption of electric vehicles

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Abstract

Researchers have long discussed the effectiveness of financial incentives in encouraging the adoption of low-emission vehicles. Government policies providing consumers financial incentives can be divided into technology specific and technology neutral categories. Previous studies have shown financial incentives to be positively related to the adoption of low-emissions automobiles such as hybrid-electric vehicles and electric vehicles. We used a comparative case study to analyze the relationship of consumer financial incentives and electric vehicle market shares of 20 countries from 2010 to 2012. Our analysis showed that technology neutral policies can and are being used to drive environmental adoption between mass market technologies of hybrid-electric vehicles and internal combustion engine vehicles as well as encourage electric vehicle adoption. However, financial incentive levels were not able to indicate levels of electric vehicle adoption. Additionally, we performed an in-depth analysis of four countries looking at the influence of other factors on electric vehicle adoption. Mature consumer organizations and existing charging infrastructure where shown to be present in countries that had high levels of electric vehicle adoption.

Keywords

Financial incentives, Technology Specific Policy, Technology Neutral Policy, Radical Eco-innovation, Electric Vehicles

1 Introduction

Climate change is a global issue with unknown and possibly catastrophic consequences. The transportation sector is a big producer of the greenhouse gasses that influence climate change. Because of this, governments have used several different policy approaches to reduce the environmental impact of the transport sector including supply-side policies e.g., stringent vehicle emissions regulation and demand-side policies e.g., financial incentives to consumers of low-emissions automobiles. Those policies encourage the development and adoption of eco-innovations, which provide lower environmental impacts compared to the dominant design (Rennings, 2000). Electric vehicles (EVs) represent one such eco-innovation that has a great deal of potential to reduce vehicle emissions in the transportation sector. However, high vehicle costs have been identified as a big obstacle to wide-spread EV adoption (IEA, 2011; Lieven et al., 2011; Hidrue et al., 2012). In order to help overcome that barrier, governments have implemented different types of financial incentive policies.

Earlier research looking at the impact of financial incentives on low emissions vehicles has largely focused on technology specific policies relative to Hybrid-Electric Vehicle (HEV) adoption. As identified in Brownstone et al. (2000) and Axsen et al. (2009), there is a tremendous amount of uncertainty involved in attempting to forecast consumer adoption of a new technology. This is born out through the conflicting results and conclusions of agent-based models looking at the relationships between financial incentives and HEV/EV adoption. Eppstein et al., (2011) and Kloess and Müller (2011) doubt the ability of financial incentives to encourage long-term adoption of fuel-efficient vehicles. However Sullivan et al. (2009) and Shafiei et al. (2012) showed that financial incentives are likely necessary to realize a higher market share of EVs.

Analyses of actual sales data have produced more consistent results. With the exception of Diamond (2009), empirical studies have found a positive relationship between the size of financial incentives and consumer HEV adoption (Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011; Chandra et al., 2010; de Haan et al., 2007). Diamond (2009) noted a strong relationship between gasoline prices but not financial incentives regarding EV adoption in the US. It is worth noting that other empirical analyses (Beresteanu and Li, 2011; Gallagher and Muehlegger, 2011) also found gasoline prices to play an important role in HEV adoption.

Policies such as financial incentives can be categorized as being either technology specific or technology neutral (Jaffe et al., 2005; Coninck et al., 2008). Financial incentives from technology specific policies e.g., subsidies to EV consumers, support individual innovations with the expectation that their increased adoption will help achieve environmental goals such as lower CO_2 emissions (Taylor, 2008). Financial incentives from technology neutral policies e.g., subsidies to consumers of automobiles with low CO_2 emissions, do not indicate which type of vehicle needs to be used to reach the identified goal (Sandén and Azar, 2005). Financial incentives from technology neutral policies reward the consumers of innovations that meet certain environmental performance criteria, regardless of the technology being used by those innovations.

Our research stems from a lack of empirical research in two areas. The first involves the relationship of technology specific and technology neutral policies to the adoption of a radical innovation. The second involves the effectiveness of financial incentives in encouraging the adoption of electric vehicles. We used a comparative case study approach to answer the following research questions (1) *what have been the roles of technology neutral and technology specific policies in encouraging the adoption of electric vehicles?* (2) *To what extent are financial incentives related to the adoption of electric vehicles?* In answering those research questions, our analysis will compare empirical data from multiple case studies to existing theory in order to derive hypotheses relative to the use of technology specific or technology neutral policies to foster technical change. This approach to building instead of testing theory is common practice in management science and organizational theory (Eisenhardt, 1989; Cavaye, 1996). It is specifically appropriate in research situations where there are a small number of cases and other methods of theory testing e.g., statistical analysis, are not possible.

2 Technology specific vs. technology neutral policies

Previous research has looked at the influence of technology specific policies on the adoption of eco-innovations such as photovoltaic cells (Vasseur and Kemp, 2011; Andersson and Jacobsson, 2000; Kemp et al., 1998), wind energy (Campoccia et al., 2009), and hybrid electric vehicles (Diamond, 2009; Gallagher and Muehlegger, 2011). Those researchers suggested that technology-specific policies are important to support the introduction of radical innovations.[1] During the introductory phase, consumer demand is an important factor in driving the development and adoption of radical innovations through economies of scale and learning-by-doing (Nemet and Baker, 2009).

Due to market failures, the development and adoption of eco-innovations often requires government intervention (Rennings, 2000). The market disincentivizes the development of eco-innovations through two externalities. The first externality occurs because lower pollution is not adequately incorporated into the cost of an eco-innovation. The second externality occurs though knowledge spillover as all firms gain from the development of an eco-innovation (Jaffe et al., 2005; Horbach, 2008). Beise and Rennings (2005) see those externalities affecting eco-innovations such that they suffer from a loss of competitiveness with government policies being necessary in order for them to be competitive in the market. Governments have attempted to stimulate eco-innovation through various policy instruments such as subsidies, taxes, and environmental standards (Ashford et al., 1985; Kemp, 1997; Beise and Rennings, 2005). In this theory section we discuss the role of innovation-stimulating policies within a technology neutral or technology specific theoretical framework.

2.1 Technology specific policies

Technology specific policies support the adoption of a particular innovation and are often used in conjunction with more ambitious long-term goals (Sandén and Azar, 2005). Radical technologies may have greater potential for achieving stated objectives while at the same time they may not be competitive in the market. For that reason, some researchers see technology specific policies as being necessary to encourage the development and adoption of radical innovations (Kemp, 1997). Indeed, many

[1] We define radical innovations as requiring knowledge different from that used in the conventional technology.

important radical innovations such as semiconductors, computers, and jet engines were developed with government support from technology specific policies (Nelson, 1982). Jaffe et al. (2005) however, identifies a danger in technology specific policies in that governments are "picking winners", and the innovations being supported may not represent the best option based on price/performance characteristics. Sandén and Azar (2005) address this point by noting that technology specific policies should be used to bring radical innovations to the market while technology neutral policies should be used to encourage competition between alternatives that are commercially available. There is also a strand of literature that identifies technology specific policies as being necessary to shepherd radical innovations through the beginning phase of commercialization (Kemp, 1997; Norberg-bohm, 2000). This largely entails using supportive policies to create a protected niche until the radical innovation has developed a sustainable market. However both Jaffe et al. (2005) and Sandén and Azar (2005) caution against using technology specific policies to support the commercialization of innovations as it can lead to "lock-in" of inferior technologies.

2.2 Technology neutral policies

Technology neutral policies *do not require* a particular innovation to be used to reach a specific objective. Although the question of whether policies can actually ever be 'technology neutral' has been raised (Azar and Sanden, 2011), most researchers make the distinction between policies that are technology oriented e.g., encouraging EV adoption or goal oriented e.g., lowering CO_2 emissions (Jaffe et al., 2005; Kemp et al., 1998). For technology neutral policies supporting lower automobile CO_2 emissions, it does not matter if the vehicles use more efficient internal combustion engines or electric drivetrains as long as they have lower CO_2 emissions. Technology neutral policies are identified as helping to avoid the entrenchment of inferior innovations by allowing firms to use the most cost-effective approach to achieve the specified objective (Jaffe et al., 2005). However (Sandén and Azar, 2005) pointed out that in many cases, technology neutral policies do not encourage firms to develop radical innovations because those technologies are often not competitive in the market. Thus technology neutral policies are often seen as encouraging the attainment of environmental goals through incremental innovations to existing commercial alternatives. However, technologies can become "locked-in" through increasing returns via learning-by-doing and economies of scale (Arthur, 1994). This creates path dependency where it is difficult for new technologies to be competitive due to market barriers. Unruh (2000) identified how path dependency in fossil-fuel intensive technologies has created macro-level barriers for carbon-saving innovations.

The underlying argument from the literature is that technology neutral policies are good at driving incremental innovations. However, they rarely encourage the development of radical innovations necessary to break technological lock-in such as that seen in carbon-intensive industries (Sandén and Azar, 2005; Unruh, 2002). An important exception is that very stringent technology neutral policies can and have functioned to encourage radical innovation. For example, the 1990's Zero Emissions Vehicle mandate from California was a technology neutral policy because it was exclusively focused on emissions, but it basically only supported the development of battery electric vehicles (van den Hoed, 2007; Dijk and Yarime, 2010).

We use the technology specific/neutral policy distinction for financial incentives that are used to encourage electric vehicle adoption. As identified above, those two types of policies generally stimulate two different types of innovation. Our research shows their respective roles relative to the adoption of electric vehicles. This should help inform their use regarding the development and commercial introduction of other radical innovations.

3 Methods

In this paper, we sought to analyze the relationship between financial incentives and EV adoption. We started our analysis with an overview of national EV markets and the amount and policy type of financial incentives available in those countries. Section 3.1 of this methods section identifies how those financial incentives were calculated. We collected and analyzed data from 20 countries spanning the EV early adoption period of 2010 to 2012. Financial incentive and EV sales data came from diverse sources including the European Automobile Manufacturing Association (ACEA), Automotive Industry Data (AID), the Japanese Auto Manufacturers Association (JAMA), the China Association of Automobile Manufacturers (CAAM), and government agencies. The year 2010 was selected as the start date because it represented the first year in which significant numbers of EVs were sold. We selected countries for our analysis that had relatively high EV sales figures based on industrial research and government sources. Those countries allowed for analysis of the interplay between financial incentives and EV adoption. The following countries were used in our initial analysis of EV markets: Australia, Austria, Belgium, Canada, China, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States. In our analysis, we included both pure battery electric vehicles such as the Nissan LEAF and Mitsubishi i-MiEV as well as plug-in hybrid electric vehicles such as the Opel Ampera and Fisker Karma.

Following the initial analysis of 20 countries, four national case studies were selected to provide insight into the influence of several factors, including financial incentives, on EV adoption. We selected the countries to be analyzed based on their having very high or very low levels of financial incentives and EV adoption rates. This approach to analyzing cases that provide the best example of the process being investigated is supported by case study literature (Pettigrew, 1988; Eisenhardt, 1989). The individual countries analyzed in our comparative case study were Norway (high financial incentives, high EV adoption), Belgium (high financial incentives, low EV adoption), Switzerland (low financial incentives, high EV adoption), and Germany (low financial incentives, low adoption). Information relative to EV adoption in those case studies was gathered from academic articles, governmental research and expert interviews. National experts came from government agencies, non-governmental organizations, and EV manufacturers.

3.1 Financial incentive calculation

Financial incentives were categorized as coming from either technology specific or technology neutral policies depending on whether they targeted EV adoption or vehicle CO_2 emissions respectively. Technology specific adoption policies provided financial incentives for the purchase and use of EVs. Technology neutral adoption policies gave financial benefits or penalties to consumers of vehicles based on their vehicle's CO_2 emissions.

In order to compare financial incentives that used different emissions and monetary units, policies were converted relative to CO_2 emissions and US dollars. Converting fuel use to CO_2 emissions used the following formula: 1 liter/100km = 23.2 gram CO_2/km (UNEP, 2012). Currencies were converted to US dollars using the annual exchange rates from 2010, 2011, or 2012. In some situations, it was necessary to use a vehicle's performance characteristics in order to calculate the financial incentives of a policy. An example would be an annual usage or circulation tax in which the fee varied depending on a vehicle's CO_2 emissions. Such a tax would likely charge an EV consumer very little. However that does not give an indication of the savings relative to if the EV consumer had bought an ICE vehicle. We used a fictional ICE and electric vehicle to calculate the value of such financial incentive policies. Table 1 provides a description of the basic characteristics of those fictional ICE and electric vehicles.

Table 1: Fictional ICE vehicle and electric vehicle used for policy evaluation

	Fictional ICE vehicle	*Fictional electric vehicle*
Cost	$25,000	$40,000
Tailpipe emissions	140 CO2 g/km	0 g/km
Fuel efficiency	19 km/l	45 km/l
Weight	1550 kg	1950 kg
Engine/battery pack	2.0 l 77 kW	20 kWh Li-ion

The monetary value of financial incentive policies were calculated for an eight year period, which mirrors the warranty period of the Nissan LEAF and Chevy Volt. Some policies such as registration taxes were applied on a one-time basis. However, for other policies that were levied on an annual basis such as circulation taxes, we wanted to provide a more realistic notion of the monetary value of taxes and they way they could influence consumer choice. We used an annual discount rate of 4% to calculate the net present value of future financial incentives. We selected a discount rate of 4% because that is the average rate of return for government bonds over the past 200 years (Newell and Pizer, 2004). For example, a one-time registration tax of $1,000 would maintain that value, but an annual circulation tax of $50 would provide a financial incentive of $343.80 in our analysis.

4 Results and discussion

The results chapter is split into four subsections. Section 4.1 describes how financial incentives from technology specific and technology neutral policies were used relative to EV adoption. Section 4.2 details the relationship between financial incentives and EV consumer adoption for the 20 countries in our analysis. Section 4.3 includes case studies of Norway, Belgium, Germany and Switzerland. Section 4.4 compares and discusses those four different cases.

4.1 Technology specific and technology neutral financial policies

Appendix A shows financial incentives from technology specific and technology neutral policies during the 2010 to 2012 timeframe for all of the countries in our study. Financial incentives from technology neutral policies were placed under the heading CO_2 policies. Financial incentives from technology specific policies were placed under the heading EV policies. A fictional EV and ICE vehicle were used in some instances to calculate the corresponding financial incentives for some policies. The characteristics of those fictional vehicles were provided in Table 1 of the methods section.

Technology specific policies generally came in the form of subsidies relative to one-time vehicle registration taxes and tended to be for higher monetary values than those found with technology neutral policies. Technology neutral policies, on the other hand, were largely found in relation to annual circulation taxes. For example, in Ireland electric vehicles were exempt from the registration tax and fell under the lowest band for the annual circulation tax. Financial incentives for an EV consumer were worth $7,112 from registration taxes and $841 from circulation taxes.[2] That example gives an indication of the difference in monetary value between financial incentives from technology neutral and technology specific policies.

Out of the 20 countries in our study, 11 had circulation taxes. The amounts that vehicles needed to pay were tied to specific CO_2 emissions bands levels. The lowest emission band levels generally ranged between 100 g/km and 130 g/km. That means that from those technology neutral policies, an electric vehicle with 0 (tailpipe) emissions would pay the same circulation taxes as an ICE vehicle with CO_2 emissions of 99 g/km. Although this approach does not favor any particular technology, it does not take into account vehicles with emissions levels below 100 g/km. Table 2 identifies the emissions levels of several EVs, PHEVs, HEVs and ICE vehicles from 2012.

Table 2: Fictional ICE vehicle and electric vehicle used for policy evaluation

Vehicle	*Type*	*CO_2 Emissions (tailpipe)*
Toyota Yaris	HEV	79 g/km
Toyota Prius	HEV	89 g/km
Smart ForTwo (gasoline)	ICE	99 g/km
Kia Rio (gasoline)	ICE	114 g/km
Chevy Volt	PHEV	27 g/km
Toyota Prius Plug-in	PHEV	49 g/km
Nissan LEAF	EV	0 g/km
Mitsubishi i-MiEV	EV	0 g/km

Table 2 shows that EVs/PHEVs had distinctly lower tailpipe emissions levels than did HEVs/ICE vehicles.[3] Analyzing the national emissions bands along with Table 2, it becomes apparent that while circulation taxes did provide financial incentives for vehicles with lower emissions levels, they did not give additional enticement for consumers to purchase EVs or PHEVs over the HEVs and ICE vehicles with low emissions levels such as the Toyota Yaris and Kia Rio. In that sense, technology neutral policies in the form of circulation taxes did little to encourage EV adoption. Instead, they functioned to drive down emissions levels between HEVs and ICE

[2] Ireland had an additional EV subsidy, which explains the higher total in Appendix A.
[3] Total emissions for vehicles that use electricity from the grid are higher than the values displayed in Table 2. This values depend on the source of the electricity i.e., nuclear, coal, wind, natural gas. However, the emissions values in Table 2 are used in determining the amount that vehicles should pay for related taxes.

vehicles. It is possible to use technology neutral policies to drive EV adoption, but it requires much lower CO_2 emissions bands.

4.1.1 The Dutch and French model

As a rule, financial incentives regarding a vehicle's registration were almost always technology specific. The Netherlands and France served as an exception to that rule and provided subsidies based on a vehicle's CO_2 emissions, making those financial incentives technology neutral. The highest level of financial incentives in the Netherlands was reserved for buyers of vehicles with CO_2 emissions below 51 g/km; in France, this was below 60 g/km. Tables 3and 4 provides a breakdown of the French and Dutch 2012 policies according to emissions levels and financial incentives.

Table 3: 2012 financial incentives for France

	France			
CO_2 (g/km)	< 60	61-90	91-110	111-150
Financial incentives	€ 5,000	€ 800	€ 400	€ 0

Table 4: 2012 financial incentives for the Netherlands

	The Netherlands[4]			
CO_2 (g/km)	<51	52-96	97-116	>116
Financial incentives	€ 6,250	€ 2,750	€ 1,250	€ 0

Comparing Tables 2-4, presents a different models for encouraging environmental innovation among automobiles. Both France and the Netherlands used emissions bands which gradually became more stringent while at the same time giving out successively higher levels of financial incentives. This approach encourages lower emissions among HEVs and ICE vehicles at the ~100 g/km range while still providing high financial incentives for EV adoption at the < 60 g/km range. Additionally, the emissions and financial incentive levels can be modified depending on the automobile technology and budgetary constraints. In fact, the France policy uses a complementary malus element which taxes consumers of vehicles with high emissions levels. A nimble and flexible vehicle emissions policy has the potential to be budget neutral while still encouraging environmental improvement in automobiles.

4.2 Adoption of electric vehicles

Appendix B provides both the absolute number of EV sales and the percent of market share in the 20 studied countries from 2010, 2011, and through June of 2012. Due to data availability, EV sales statistics were not collected for Canada, China, and Finland in 2010.

The average EV market share for the countries in our study increased by more than a factor of eight from .035% in 2010 to .29% in 2012. In 2010, only Norway had an EV market share above .1%. In 2012, 12 of the 20 countries had an EV market share above .1%. Norway had the highest EV market share in each year peaking at 2.59% of

[4] The financial incentives for the Netherlands were calculated using characteristics from the fictional ICE and electric vehicle in Table 1.

all automobile sales in January through June of 2012. Other countries with relatively high proportions of EV sales included Denmark, France, Japan, the Netherlands, Switzerland, and the US. However, Norway was the only country that had an EV market share over 1% for any given year.

Figure 1 includes the total amount of financial incentives along with the percent of market share captured by EVs for the different countries in 2011. The monetary values of financial incentives coming from technology neutral (CO_2 emissions) and technology specific (EV) policies are identified.

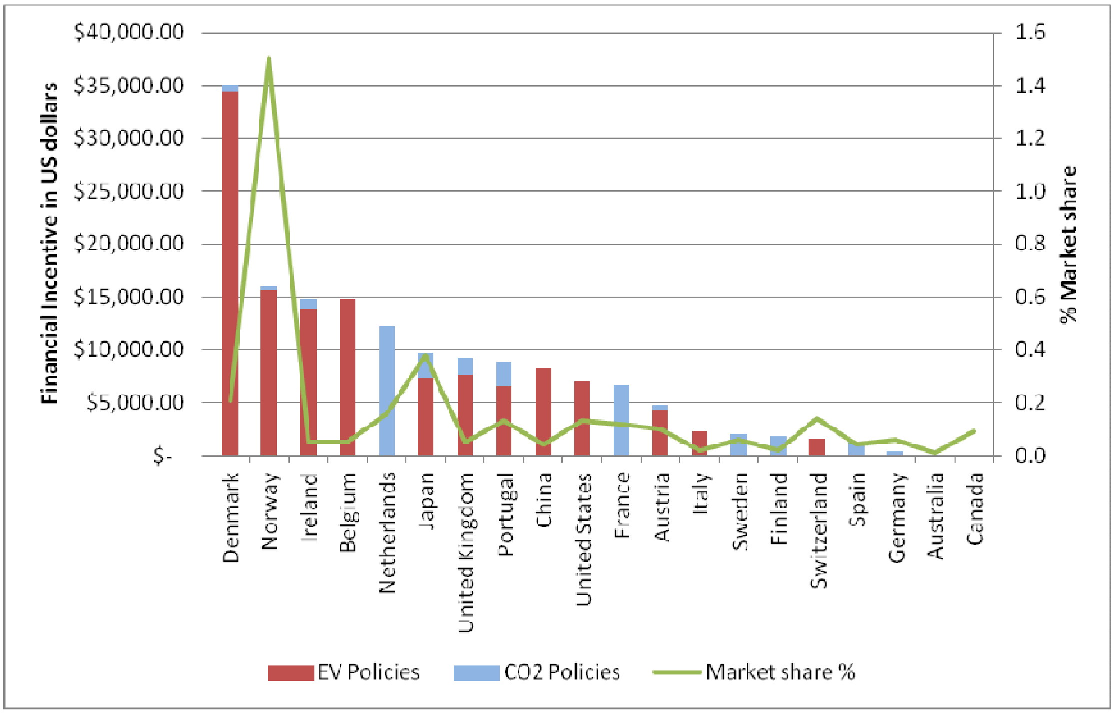

Figure 1: Policy incentives by country and corresponding 2011 EV market share

The correlations between financial incentives and EV adoption rates for 2010, 2011, and 2012 were .370, .309, and .334 respectively. These results indicate a lack of correlation between those two variables. There were a few countries where high levels of technology specific policy incentives and EV adoption rates coincided e.g., Norway, Denmark, and Japan. However, high levels of financial incentives did not necessarily equate to high EV market shares as evidenced by China, Belgium, and the UK. With the exception of Switzerland, countries with very low financial incentives had very low EV market shares. Based on Figure 1, it appears that financial incentives were not sufficient to stimulate EV adoption. This contrasts with earlier research that only looks at vehicle cost as a barrier to EV adoption (Sullivan et al., 2009; Mabit and Fosgerau, 2011). Our research indicates that there are factors other than vehicle cost that have played an important role in EV adoption.

4.3 Country descriptions

Due to space limitations, we were not able to include a case study of all of the countries in Figure 1. Instead, we analyzed four countries that had different levels of EV adoption and financial incentives. This included looking at the influence of additional elements such as infrastructure, support organizations, native manufacturers, and consumer preferences on EV adoption rates. Earlier research identified those factors as being important for successful introduction of electric vehicles (Dijk et al., 2012; Magnusson and Berggren, 2011; Hidrue et al., 2011).

4.3.1 Norway

Norway has the highest proportion of EV adoption among any country in the world. It has used high financial incentives to reduce the difference in purchase costs between an EV and comparable ICE vehicle. In 2010, EVs accounted for .28% of automobile sales in Norway. This proportion has increased over the years to 1.5% in 2011 and 5% in September 2012 (Gronnbil, 2012). In total, there were 8,615 EVs in Norway as of September 2012 (OFV, 2012). The combination of several factors has made Norway the greatest national success in EV adoption. Those include:

- A longer continuous history of EV production and adoption
- Mature associations that have lobbied for the interests of EV consumers
- Installation of sufficient charging infrastructure to
- Minimal price difference between an EV and an ICE vehicle
- Policy stability and certainty
    - The current EV financial incentives will be in place until 2018
- A sufficient supply of EVs in dealerships across the country

In the late 1990s and early 2000s, the Norwegian government implemented EV financial incentives such as no import duties and no registration fees (Nordic Energy Research, 2012). Those technology specific policies along with available models from Kewett and Think led to a small but functioning market comprised mainly of enthusiasts that charged their EVs at home. Early owners created associations that lobbied for their interests and provided information conduits to the government and manufacturers. The Think City and Kewett Buddy were small vehicles, and only appealed to a small portion of the market. This resulted in supply shortage for EVs in Norway. Once the Mitsubishi i-MiEV and Nissan LEAF became available in 2011, that latent demand resulted in strong EV sales beyond the enthusiastic early adopters (Nordic Energy Research, 2012). In June 2012, automobiles from Mitsubishi, Nissan, and PSA accounted for 48% of the Norwegian EV market share (Gronnbil, 2012).

In addition to a strong history of EV use, charging infrastructure has also played a key role in Norway's high adoption figures. In 2009 and 2010, private companies and the Norwegian government built approximately 2,000 charging stations as a response to the financial crisis. This approach created a strong foundation for EV adoption when the Mitsubishi i-MiEV and Nissan LEAF were introduced in 2011. This method differed from what has occurred in Japan where Nissan has been the primary driver of charging infrastructure installation. As of July 2012, Norway had 3,239 public EV charging stations with a majority located in the region around the capital Oslo (Gronnbil, 2012).

4.3.2 Belgium

Belgium provides an example of a country with relatively high financial subsidies but low EV adoption. From January of 2010 to July of 2012, there were 702 electric vehicles sold in Belgium; accounting for a market share of .01% in 2010, .05% in 2011, and .14% in 2012. During this time, Belgium was providing approximately $16,000 in financial incentives to EV adopters, one of the larger amounts among the countries in our study. Based off government reports and expert interviews, possible limiting factors for this low level of EV adoption have been identified as a mismatch of financial incentives to consumer demand, a late start to developing consumer associations, and little charging infrastructure.

Financial incentives for EVs purchased by businesses were less generous than those bought by households. This situation could have led to low EV adoption if company cars represented the more promising market in Belgium. In other European countries such as the Netherlands, France, and Germany, the vast majority (~ 90%) of EV adoption has come in the form of company cars (Agentschap, 2012; AID, 2012; Center for Automotive Research, 2011). The lack of household demand could help explain Belgium's low EV adoption rate.

In Belgium, financial incentives appeared later (2010) than they did in other countries, which likely hindered the initial development of EV support organizations (ACEA, 2010). The lack of a Belgian EV market has meant that consumer associations have had to develop from the ground up in the late 2000s and early 2010s. This has resulted in relatively immature organizations that are still identifying the best ways gathering information and conveying it to consumers, government agencies, and manufacturers. Belgium is attempting to analyze the interaction of dynamics that are important to EV adoption through experiments and field trials. However, these efforts have taken place later in Belgium than in other countries. The delay in identifying important factors of EV adoption has likely led to a situation where Belgium is a couple years behind other countries in several important areas such as effective communication techniques, charging station placement, and charging station operability.

In September 2012, there were approximately 200 charging stations in Belgium (ASBE, 2012). This number is significantly lower in absolute and per capita terms when compared with many other countries such as France, the Netherlands, Norway, and Germany. The Belgian government has been largely uninvolved with developing charging stations. Instead, they have used a bottom-up market-driven approach to developing infrastructure that has led to few publically available charging stations.

4.3.3 Germany

Germany is an example of a country that has low levels of both EV financial incentives and adoption. Even though EVs have represented a small proportion of all automobile sales in Germany since 2010 (.06%), Germany has still been the second largest EV market in Europe behind France with 3,648 EVs sold from 2010 through June of 2012. The country has the goal of 100,000 EVs on the road by the end of 2014 and 1 million EVs by the end of 2020 (NPE, 2010). Germany has taken a market-driven approach to EV adoption involving minimum government regulation. It includes the following three phases: pre-commercial preparation till 2015, ramp-up through 2017, and introduction to the mass market thereafter (NPE, 2012). This approach has consisted of field trials in eight model regions starting in 2009 which shifted to four larger showcase regions in 2012. Through the market preparation phase through June 2012, there has been very limited EV adoption. According to expert interviews and the German government analysis of electromobility (NPE, 2012), possible factors include

- Low financial incentives
- A lack of EV charging infrastructure
- Limited EV availability from German manufacturers

- Price inelasticity of German consumers at low price ranges
- Immature EV consumer associations

Germany has implemented a technology neutral annual circulation tax based on engine size and CO_2 emissions, charging \$2.50 per 100 cc (gasoline) and \$2.50 per g/km over 120 (ACEA, 2012). Electric vehicles and other automobiles with CO_2 emissions below 120 g/km were exempt from the circulation tax. As noted earlier, this kind of technology neutral financial policy largely functions to drive down emissions between ICE vehicles and HEVs. Additionally those types of financial incentives were of low monetary value and did not do much to address the big difference in cost between an EV and a comparable ICE vehicle. Instead of giving financial incentives to consumers, Germany has selected to provide \$1.4 billion in R&D funding to EV manufacturers in 2012 and 2013 (Insideline, 2011). This approach fits with the pre-market phase which focuses on identifying consumer preferences and establishing the well-functioning dynamics between government, academia, and manufacturers (NPE, 2012).

As of May 2012, Germany had approximately 2,200 publically available EV charging stations largely concentrated in big cities such as Stuttgart and Hamburg (NPE, 2012). Compared to other countries such as Norway and the Netherlands, Germany has far fewer EV charging stations per capita. These charging stations were largely built in connection with model and showcase regions from the late 2000s and early 2010s.

Limited participation of German native auto manufacturers also has likely played a factor in the country’s EV adoption. During our research timeframe, many large German manufacturers such as Volkswagen, BMW, and Daimler-Mercedes had not made EVs available on a broad scale. The companies had been involved in the model and showcase regions, but their involvement in stimulating EV adoption was minor when compared to their role in the national economy. This situation contrasts with Japan where the manufacturers Nissan and Mitsubishi have been heavily involved in promoting electric mobility and installing charging stations.

Price inelasticity among German consumers in smaller vehicle segments may have affected adoption of EVs such as the Mitsubishi i-MiEV, Peugeot iON, and Nissan LEAF which cost significantly more than comparable ICE vehicles. It is possible what German consumers in the luxury segment will have higher price elasticity and be willing to pay more when EVs such as the Tesla Model S and BMW i3 become available.

The almost non-existent EV market in Germany until 2011 has led to very slow development of related consumer associations and other support organizations. The lack of such organizations has meant that they needed to be created and fine-tuned, which has been a priority during the current pre-commercial phase.

4.3.4 Switzerland

Switzerland represents one of the most fascinating cases of EV adoption among the countries that we studied. It had very low financial incentives, and yet relatively high levels of EV adoption. Similar to Germany, Switzerland used a market-driven approach involving little government regulation or financial incentives. Swiss financial incentives include an exemption for EVs from the national automobile tax of 4% of the vehicle’s sale price. This is a technology specific policy, however compared to other countries such as Norway or Belgium it offers significantly lower financial incentives for EV buyers as shown in Figure 1. There are several factors that have likely contributed to Switzerland's high adoption level. They include a continued history of EV use and adoption, a strong foundation of charging infrastructure in the larger Swiss cities, and a consumer willingness to pay a premium for EVs over comparable ICE vehicles.

The Swiss Federal Office of Energy (SFOE) has been funding EV demonstration projects since the early 1990s. One large project involved market trials from 1995 to 2000 in cities around Switzerland. The initial interest in EVs quickly evaporated once the high government financial incentives of approximately 50% of the vehicle's price were removed (Hoogma et al., 2002). However, those trials led to the early development of 600 charging stations as well as the founding of several companies, such as Protoscar, Brusa and Mes-dea, which continue to operate in the EV industry. Although there are no large auto manufacturers in Switzerland, a couple companies have emerged such as Kamoo and SwissCleanDrive that convert existing ICE vehicles to EVs. Those companies in addition to sales of the Think City led to a small market of EV consumers in Switzerland throughout the 2000s. Additionally, the Swiss association e'mobile was established in 1998, and has served to distribute information regarding electric vehicles (IEA, 2012). It also functions as a way for EV consumers to communicate with one another and the government.

Since the large market trial effort in the late 1990s, SFOE has continued to sponsor EV pilot projects. Those projects, along with the existing user base, charging stations, and support organizations created an environment that was ready to engage in greater levels of adoption once large manufacturers e.g., Nissan and Mitsubishi introduced their EVs to the Swiss market.

There are some characteristics of Swiss consumers which have also been contributing factors to the high rate of adoption. They have displayed a certain tendency toward environmental innovations such as HEVs (SFOE, 2012). Switzerland was the third highest adopter of HEV's in Europe behind the Netherlands and Norway. Additionally, Swiss consumers have a high level of purchasing power parity, which helps to explain why the expensive Tesla Roadster has one of the highest rates of sale in Switzerland. That combined with dense urban environments has created a situation where EVs have been well received by the Swiss population.

4.4 Discussion of cases

The sorts of socio-technical transitions involved in switching from ICE vehicles to EVs are known to be a long, slow process (Geels, 2002; Dijk et al., 2012). Based on the information gathered from academic articles, government reports, and expert interviews, it is apparent that each country's situation is unique and will necessitate individual paths to high EV adoption rates. However, there are some similarities between the countries that have succeeded in stimulating EV adoption and those that have not. Broad and early availability of EV charging infrastructure and a lengthy functioning EV market were characteristics of Norway and Switzerland which both had high adoption levels. Belgium and Germany started developing those foundational elements at a much later date, which likely played a role in their low EV adoption levels.

While extensive EV infrastructure has been found in most countries with high adoption rates, countries have pursued different approaches to building those charging stations. Norway and Switzerland elected to use government-led programs while in

Japan it has largely been a market-based approach. In addition to their charging infrastructure, both Norway and Switzerland established a strong foundation throughout the 1990s and 2000s consisting of EV users and consumer support organizations. The combination of those factors set the scene for strong EV adoption when the LEAF and i-MiEV appeared in 2011.

In contrast, both Belgium and Germany attempted to set up foundational elements for their EV market in the late 2000s and early 2010s. These efforts did not allow important elements such as consumer organizations enough time to mature and properly function to support EV consumers. Additionally, communication between important players such as consumers, manufacturers, and government agencies are still being sorted out. The case studies above indicate that it takes a combination of several factors and a slow build-up phase for EVs to be successful. With those elements in place, both Belgium and Germany could make better use of available financial incentives.

5 Conclusions

In the introduction section, we posed research questions regarding (1) the role of technology neutral and technology specific policies in encouraging the adoption of electric vehicles and (2) the relationship between financial incentives and electric vehicle adoption.

Regarding the first question, the financial incentives in our study closely followed the setup that was identified in Sanden and Azar (2005) where technology neutral policies drive environmental improvements among mass market technologies and technology specific policies support innovations with greater potential for lessening environmental impacts. In our study, technology neutral policies used CO_2 emissions levels to encourage environmental improvements among HEVs and ICE vehicles while technology specific policies stimulated EV adoption. In that way governments have used technology specific policies to help shepherd electric vehicles, a radical innovation, through the early adoption phase (Kemp, 1997; Norberg-bohm 2000). However, with France and the Netherlands as an example, it is possible to use technology neutral policies to drive both incremental and radical innovation among automobiles. By having progressive levels of CO_2 emissions bands with increasing financial incentives, the Dutch and French policies encourages lower environmental impacts among HEVs and ICE vehicles while still stimulating EV adoption.

Regarding the second question, financial incentives were seen as being sufficient to indicate a country's level of EV adoption. A broader analysis of potential contributing factors showed that ample infrastructure and a continuous history of EV use were both common elements in countries with high levels of EV adoption e.g., Norway and Switzerland. In those cases, infrastructure appeared before broader uptake of EVs, giving one answer to the "chicken or egg" question of whether charging stations or electric vehicles should come first. This leads credence to the notion that a technological transition is a process that requires the interaction of complex socio-technical factors. Such interactions take time to develop, which indicates that adoption of electric vehicles will be a lengthy affair if it is to succeed at all.

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Appendices

Appendix A: CO_2 and EV specific policies from 2010-2012 (ACEA, 2010a; ACEA, 2010b; ACEA, 2011a; ACEA, 2011b; ACEA, 2012a; ACEA, 2012b; ICCT, 2011)

	2010		*2011*		*2012*	
	CO_2 Policies	EV Policies	CO_2 Policies	EV Policies	CO_2 Policies	EV Policies
Australia	$ -	$ -	$ -	$ -	$ -	$ -
Austria	$ 383	$ 4,158	$ 402	$ 4,364	$ 390	$ 4,235
Belgium	$ -	$ 11,516	$ -	$ 14,718	$ -	$ 14,692
Canada	$ -	$ -	$ -	$ -	$ -	$ -
China	$ -	$ -	$ -	$ 8,225	$ -	$ 8,762
Denmark	$ 580	$ 32,787	$ 609	$ 34,412	$ 592	$ 33,454
Finland	$ 1,803	$ -	$ 1,893	$ -	$ 6,446	$ -
France	$ 6,369	$ -	$ 6,684	$ -	$ 6,486	$ -
Germany	$ 346	$ -	$ 363	$ -	$ 353	$ -
Ireland	$ 801	$ 10,119	$ 841	$ 13,898	$ 816	$ 13,488
Italy	$ -	$ 2,159	$ -	$ 2,266	$ -	$ 2,199
Japan	$ 4,458	$ 6,556	$ 2,503	$ 7,220	$ 3,883	$ 7,516
Netherlands	$ 11,683	$ -	$ 12,261	$ -	$ 11,900	$ -
Norway	$ 377	$ 14,495	$ 406	$ 15,628	$ 406	$ 15,616
Portugal	$ 2,118	$ -	$ 2,223	$ 6,608	$ 2,157	$ -
Spain	$ 1,196	$ -	$ 1,255	$ -	$ 1,218	$ -
Sweden	$ 1,883	$ -	$ 2,090	$ -	$ 764	$ -
Switzerland	$ -	$ 1,401	$ -	$ 1,647	$ -	$ 1,637
United Kingdom	$ 1,479	$ -	$ 1,534	$ 7,703	$ 1,759	$ 7,884
United States	$ -	$ 7,000	$ -	$ 7,000	$ -	$ 7,000

Appendix B: EV statistics in selected national markets 2010-2012 (JATO, 2011; AID, 2012; CAAM, 2012, goodcarbadcar, 2012; JAMA, 2012;Caradvice, 2012)

	2010		*2011*		*2012 (through June)* [5]	
	EV sales	% Market	EV sales	% Market	EV sales	% Market
Australia	112	0.05	27	0.01	11	0.01
Austria	96	0.03	631	0.10	204	0.11
Belgium	34	0.01	263	0.05	405	0.14
Canada	-	-	468	0.09	886	0.10
China	-	-	5655	0.04	3,021	0.04
Denmark	15	0.01	362	0.21	290	0.34
Finland	-	-	29	0.02	23	0.04
France	133	0.01	2,630	0.12	2,271	0.22
Germany	185	0.01	2,154	0.06	2,004	0.12
Ireland	17	0.02	46	0.05	62	0.09
Italy	40	0.002	302	0.02	293	0.04
Japan	2,359	0.05	13,449	0.38	17,793	0.60
Netherlands	87	0.02	862	0.16	1,878	0.57
Norway	353	0.28	2,038	1.50	1,795	2.59
Portugal	18	0.01	203	0.13	33	0.06
Spain	76	0.01	319	0.04	209	0.05
Sweden	5	0.01	178	0.06	183	0.13
Switzerland	167	0.06	433	0.14	418	0.24
United Kingdom	90	0.001	1,082	0.05	809	0.08
United States	345	0.03	17,731	0.13	19,537	0.27

[5] Due to data availability, the 2012 EV market share for Australia only goes through May.