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Impacts of Policy on Electric Vehicle Diffusion

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Abstract

Selection and design of appropriate government policies to support electric vehicle (EV) adoption can be aided by modelling the future impact of policy instruments relative to a given baseline estimate. This paper highlights the innovative application of a diffusion model to analyse complex impacts of EV policy instruments on future incremental EV uptake. Several versions of four key policy instruments are tested in the model: linking electric vehicle sales to Renewable Electricity Purchases (RE-EV), financial subsidies, smart charging incentives and a common cost metric to educate consumers about the lifetime costs of EVs. Market share between battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), hybrid electric vehicles (HEVs) and internal combustion engine vehicles (ICEVs) were forecasted out to the year 2034 across all 1.5 million households in the state of Victoria, Australia. The RE-EV scenario had the strongest performance in terms of economic and societal indicators. Non-subsidy policy instruments can also support uptake of EVs, especially in the case of encouraging BEV adoption. We found feebate scenarios were more effective policies than rebates. Rebate and feebate scenarios applied within the 2014-2019 timeframe compared better than those with longer timeframes. Our analyses showed how combined policy scenarios not only further improved EV uptake but also allowed government to fund rebates through feebate income.

Key words: Electric vehicles, market, policy, diffusion, modelling

1. Introduction

The age of electric vehicles (EVs) has begun. The world's largest car companies including Toyota, GM, Ford and Nissan have all begun mass production and new entrants such as Tesla are quickly gaining in popularity with sales expectations exceed 55,000 vehicles this year (Debord, 2015). Several credible sources forecast that, over the next 30 years, plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), or collectively "EVs", will be the dominant cars sold in the Australian market (AECOM, 2011; Graham, Reedman, & Poldy, 2008). This trend has the potential to bring substantial benefits in terms of air and greenhouse emissions, the economy and potentially the electricity system. Country to country variation and the rate of diffusion will be strongly correlated to policies at various levels of government. In this regard, Australia has the opportunity to lead the EV charge through the development and implementation of good policies.

Our paper addresses major knowledge gaps, namely: the potential impact that specific government policy instruments will have on EV uptake and diffusion. For this modelling research, we use Victoria, Australia as a case study to model four different policy instruments, including EV-Renewable Energy Coupling, Financial Subsidies and Fees, Smart Charging Incentives and creation of a Common Cost Metric. Specifically, we model policies that are implemented over a twenty-year time frame, from 2014 to 2034. The objective of this analysis is to compare and contrast the relative impacts of each policy type in terms of additional vehicle years, societal benefit cost ratio, and gross cost effectiveness to provide indicative guidance on the relative performance of varying policy types, when implemented individually and simultaneously.

This work builds on previous research undertaken as part of the Electric Driveway Project, a three year collaborative study in Victoria investigating the potential for integration of EVs into the transport sector and household power systems (Paevere et al 2012) in Australia. This research also builds on previous investigations of EV technologies, barriers and policies, and diffusion modelling (Usher, Horgan, Dunstan, & Paevere, 2011; Usher et al., 2011; Usher et al., 2012; Paevere et al., 2012).

2. Literature Review

2.1 Evaluating the real-world impact of policies on EV uptake

There are several precedents for quantifying the impact of policy initiatives on EV adoption internationally. While examining government policy and the development of EV's in Japan, Åhman (2006) found that through legislation and standards implemented by the government, niche markets and R&D initiatives were established for generating newer targeted technology advances. Furthermore, he concluded that flexibility, adaptability and cooperation are imperative to the outcome and success of the policies (Åhman, 2006). Many countries have used tax incentives to increase consumer adoption of EV's. Through extensive research, it has been found that tax rebates used in Canadian provinces have had a significant impact on increasing hybrid vehicle sales (Gallagher and Muehlegger, 2011). Furthermore, if these policies and technical initiatives are delivered at the right time they can have a strong influence on EV market penetration (Nemry and Brons, 2010).

2.2 Modelling EV uptake and the impact of policies

As international electric vehicle adoption increases, several studies have forecasted the diffusion of this technology over the medium and long terms in Australia (Graham et al. 2008; AECOM, 2011; Higgins et al. 2012).

Graham et al. (2008) used an Energy Sector Model to forecast a 33 percent share of road vehicle fleet for PHEVs and BEVs by 2050. HEVs are projected to account for another 50 percent of the fleet, leaving internal combustion vehicles occupying only one sixth of vehicles (Graham et al, 2008).

AECOM (2011) considered a 30-year time frame for vehicle uptake in Metropolitan Victoria. Their study differentiates between vehicle sizes, distance travelled, and vehicle type and three scenarios are compared against a base case. The three scenarios have varying amounts of charging facilities and service stations available. The characteristics of the base case and Scenario 3, along with the resulting annual market sales, are presented in Table 1:

Table 1: Predicted EV vehicle sales per year ('000) in 2034 in Metropolitan Victoria (adapted and estimated from AECOM, 2011), which includes small, medium, large passenger vehicles as well as light commercial vehicles and taxis

Scenario	Assumptions	Results	Vehicle sales per year ('000) in 2034 (% of annual market sales)		
			HEV	PHEV	BEV
Base Case	Only ICEs and HEVs available (no PHEVs or BEVs)	The sale of HEVs grows gradually to 2014 then increases rapidly following the removal of the supply constraint in 2015 and the convergence of HEV purchase prices to that of an ICE vehicle in 2020.	255 (71%)	0	0
Scenario 3	Level 1 and Level 2 household charging, Level 2 public charging in the Victorian Metropolitan Region and EV service stations that offer quick charge or battery replacement.	PHEVs and BEVs gradually become the dominant engine configuration in the mid-2020s as prices converge with ICE vehicles. The share of HEVs declines dramatically as PHEVs grow to hold the largest share of sales by the mid-2020s. PHEVs remain the largest proportion of sales in 2040 however BEVs 20% by 2040.	75 (21%)	195 (55%)	55 (15%)

In sum, the AECOM vehicle choice model predicts a transition to HEVs in the near term (5-10 years), especially for the small passenger vehicle category; PHEVs over the medium to long term (10-20 years) and BEVs over the long term (15 years plus) (2011). AECOM also concludes that the take-up of PHEVs and BEVs is sensitive to the year in which parity with internal combustion engine vehicles (ICEVs) is achieved. They also found the provision of charging infrastructure (both public and commercial) is expected to have a significant impact on the sales of BEVs.

At the state scale, CSIRO modeled and published findings for Victoria, Australia, based on an earlier version of the model also used for this research (Higgins et al., 2012). The model was tested to forecast market share of EVs through to 2030, using vehicle stock across all 1.5 million households in Victoria, Australia. Assuming the stock of HEVs was 3% in 2011 (consistent with AECOM, 2011) and calibrating the model to Graham, et al (2008), Higgins et al. found that in a base case, the share of BEVs increases significantly from 2020 (versus PHEV) due to projected performance improvements and falling prices.

2.3 Innovations of this research

This research builds on previous work (Higgins, et al., 2012) by using the model to extensively evaluate four types of government policies in Victoria, across a range of policy scenarios and implementation time frames. Additionally, key model improvements have been made, as described in the method section below.

3. Diffusion Model

The diffusion model combines features of choice modelling, multi-criteria analysis and dynamic systems. The primary goal of a diffusion model is to forecast the stock of each vehicle option at incremental time intervals (e.g. 3-monthly) through to a target date. The multi-criteria analysis features accommodate the different variables that influence when a consumer will replace their existing vehicle and what vehicle option will replace it. The model provides a capability to analyse adoption patterns of the competing vehicle options under a range of features that a buyer would consider for a purchase. A full mathematical description is contained in Higgins et al (2012).

The model is dynamic in that it updates the eligible purchasers and choice amongst possible options at each time interval. The number of households eligible to purchase a vehicle in a given time period, is a statistical function of lifespan of the vehicle that they already have and other variables that may determine whether the consumer will replace the vehicle sooner. For example, a high-income household may replace their vehicle sooner than a lower income household.

Once the number of households eligible to purchase in a given time period is determined, the next "closely linked" decision is what choice to make amongst the competing vehicle options. This is where the choice modelling component comes in. The probability of choosing a BEV vs PHEV vs HEV vs ICE is a weighted logistic function of the range of variables that a consumer would consider when making a choice. Once the probability of choosing each option is calculated, the model updates the stock of each option in the current time interval and then proceeds to the next.

In constructing a suitable diffusion/choice model, the original model developed for forecasting uptake of electric vehicle options (Higgins et al 2012) was extended to include several novel features. In Higgins et al (2012) the time between replacement of a vehicle was fixed. In this paper, the probability of vehicle replacement is a function of failure time (or average length of time between replacement), as well as a utility sub-function of other drivers of replacement. When implemented, it accommodates the socio- demographic differences of consumers who are early versus late replacers of the technology, as well as the effects of incentives to reduce the time to replacement.

When considering a long forecasting horizon, there is the need to incorporate differences in familiarity (or perceived risk) between consumers replacing their EV with another EV versus first time purchasers. The feature can also accommodate differences in upfront costs. For example a consumer purchasing an EV for the first time may purchase charging infrastructure or Vehicle-to-Grid connectivity, which would not be required again when purchasing a replacement EV.

To set up the diffusion model, a suitable typology was produced to represent all possible combinations of location, building type, demographics and number of vehicles. The resulting typology has about 142,000 categories for Victoria.

The variables used in the model are contained in Table 2. These represent key features of EVs that consumers would consider when purchasing the vehicle. The weights in Table 2 were calibrated into the model using two methods. Firstly, a large-scale survey of 2,500 individuals was undertaken across Victoria and the results are contained in Gardner et al (2011). The survey was informed by a previous focus group study and literature review of consumer behaviour for low emission technologies. This research highlighted the relative importance of different demographic and psychographic criteria, as well as perceptions of technology specific factors, such as upfront costs, range, and potential to reduce emissions.

The surveys show that households with incomes greater than AU$75,000/year would pay a higher upfront price for a vehicle compared to the lower-income categories. Secondly, model parameters in Table 2 were scaled so that the “state wide” market share for the ICEV and

HEV vehicle types, aggregated across Victoria, matched that of Graham et al (2008) for their scenario "Energy Information Administration – emissions target 60% below 2000 by 2050 for high oil price for ICE". The national level projections of Graham et al (2008) were chosen as the base case benchmark for the diffusion modelling in this report, as they were developed by a group of leading community, industry and government experts. The scaling of the weights accommodated the differences in assumptions made in the Graham et al (2008) report.

Weights in Table 2 are not always proportional to the priority of the criteria, as they also depend on the variability and distribution of the scores. For example, driving distances will form a negative exponential distribution across households due to the much higher proportion of households being located in cities. A transformation function was applied to the scores of the 'Driving Distance' criteria (Higgins et al, 2012) to reduce the effect of very long distances (e.g. rural areas) and increase the differentiation of inner versus outer Melbourne suburbs.

Table 2. Description of variables used in the diffusion model

Criteria	Initial settings (all financial figures in AUD)	Annual change with time	Weight
Familiarity	Starting at 0 as there are presently less than 100 EVs in Victoria	Familiarity score is proportional to their market share in that locality.	1.1
Performance Scale of 0 (worst) – 10 (best)	BEV: 4 PHEV: 8 HEV: 8 ICEV: 9	BEV: 3% PHEV: 0.5% HEV: 0.25% ICEV: 0%	2
Upfront cost (small/large vehicle)	BEV: $43/$80K, PHEV: $39/$70K, HEV: $35/$63K, ICEV: $18/$45K		2.5
Annual cost (small/large vehicle)	BEV: $2.3/$2.8K,PHEV: $2.4/ $3K HEV: $2.7/$3.3K, ICEV: $3.5/$4.5K	BEV: 2.5%, PHEV: 2.5%, HEV: 2.5%, ICEV: 3%	2
Household income Divided into brackets	<$30K $30-75K and >$75K	3%	2
Demographic suitability	Different for each household group	0	4
Driving distance	Twice distance from nearest major CCD	0	1.5

4. Policy Instruments

A brief description of the policies, their associated model inputs and how these inputs impact the various parameters in the model is presented below. See Usher et al. (2012) for further explanation of the methodology used to develop the model inputs. All scenarios are compared against **Scenario 100** which is the case of no policy interventions.

4.1 RE-EV Coupling

The RE-EV policy refers to the connection of renewable energy use/purchases to the number of EVs sold or EV vehicle kilometres travelled (VKT). Connecting renewable energy targets or purchase to EV growth will ensure a transition to zero-emission motoring. This policy is also expected to encourage adoption of EVs by attracting individuals who are concerned about the environment (Gardner et al., 2011). In the model, the RE-EV policy is expected to increase the 'Demographic Suitability' weighting, by 20% for only those consumers whose demographics are more suited to BEVs. For PHEV-suited demographics, we increase the Demographic Suitability proportional to the percent of driving that is electric. This change in weighting has the effect of increasing the non-financial attractiveness of EVs in locations that are already more likely to purchase EVs due to transport mode and household demographics. The following policy was modelled for RE-EV:

Scenario 101 (RE-EV): Government increases the renewable energy target based on the sales of EV (with no additional cost to consumers), implemented from 2014 – 2034.

4.2 Smart-charging (ToU)

In this paper, smart-charging policy refers to Time of Use (ToU) tariffs. In the model, the smart charging policies impact the 'Annual Cost' parameter. ToU tariffs are designed to incentivise drivers to charge their EVs during off-peak periods. The benefit accrued to EV owners for ToU charging was estimated as the avoided cost of charging off-peak versus on-peak (an annual savings of AU$150 was used in the model). Whilst this is a small financial incentive compared to upfront rebates, it is paid every year during the life of the EV ownership. It will have a greater effect on the probability of purchasing an EV as the price reduction in EVs slows towards 2034. The following ToU policy was modelled:

Scenario 104 (ToU): ToU annual incentive of AU$150 per year, 2014 - 2034

4.3 Common Cost Metric

Consumers interested in buying EVs may be aware of the lower fuel prices (electricity compared to petrol) but few have a clear awareness of the comparative running costs (Gardner et al., 2011). As part of consumer education, government could implement a common cost metric to summarise the total life cycle costs of EVs and ICEVs. Research has shown that providing meaningful numbers to consumers on delayed costs and benefits will change consumer behaviour (GHK Consulting, 2010). The model aims to capture this effect by advancing the level of familiarity forward by 2 years. The greater the market share of a vehicle, the greater the familiarity relative to the other vehicle types. Moving the familiarity forward by 2 years is achieved by calculating the familiarity as a function of the market share of the EV two years out in the base case. For example, under the CCM scenario, the familiarity in 2014 is calculated as a function of the Base Case market share in 2016. The following scenario of this policy was modelled:

Scenario 108 (CCM): 2 year familiarity advance, 2024 - 2034

4.4 Rebates and feebates

For consumers that do not prioritise 'green' values or who do not have a comparison of life cycle costs between EV and ICEV ownership, the upfront price difference can dissuade them from investing in EVs (Gardner et al, 2011). Financial incentives help overcome the actual or perceived gap in payback periods of EVs verses ICEVs (Usher et al., 2012). Additionally, financial incentives help account for unpriced external costs of ICEVs. Within the model, rebates impact the Upfront Cost variable.

Rebates equal to 50% of the cost difference between EVs and ICEVs were modelled, albeit with two different maximums: AU$3,000 and AU$7,500. There is a considerable range in the price of EVs, depending on their size (large and small) and technology type (PHEV and BEV) in comparison to ICEVs. Additionally, the projected cost decrease in EVs varies based on the technology. A rebate based on the percentage difference in cost to ICEVs more equitably incentivises the range of EV types, manufactures and sizes. These two rebates were modelled with varying durations, including a 20-year time frame (2014 – 2034) and 5-year time frames (starting in 2014 and 2019, respectively), which equates to six rebate scenarios in total.

Scenario	Description	Start year	Duration (years)
110:	50% of difference up to AU$3000	2014	20
111:	50% of difference up to AU$3000	2014	5
112:	50% of difference up to AU$3000	2019	5
114:	50% of difference up to AU$7,500	2014	20
115:	50% of difference up to AU$7,500	2014	5
116:	50% of difference up to AU$7,500	2019	5

Nine feebate scenarios were also modelled. A feebate policy is one in which fees and rebates are coupled to make a more budget neutral policy. Specifically, fees are charged against the purchase of ICEVs while rebates are provided for EVs and therefore put pressure on the vehicle market from both sides. Rebates equal to 50% of the cost difference between EVs and ICEVs, up to AU$3,000 were modelled with a fee of 1%, which increased by 1% per year. Similarly, rebates of 50% of the cost difference up to AU$7,500, and AU$12,000, were modelled with fees to the vehicle owner of 2% (increasing by 2% each year (e.g. 4% in year 2)for the duration listed below) and 3.5% (increasing by 3.5% each year), respectively. These three feebate policies were also modelled for the same durations as the rebates.

Scenario	Description	Start year	Duration (years)
118:	Fees 1%. Rebates 50% up to AU$3,000	2014	20
119:	Fees 1%. Rebates 50% up to AU$3,000	2014	5
120:	Fees 1%. Rebates 50% up to AU$3,000	2019	5
122:	Fees 2%. Rebates 50% up to AU$7,500	2014	20
123:	Fees 2%. Rebates 50% up to AU$7,500	2014	5
124:	Fees 2%. Rebates 50% up to AU$7,500	2019	5
126:	Fees 3.5%. Rebates 50% up to AU$12,000	2014	20
127:	Fees 3.5%. Rebates 50% up to AU$12,000	2014	5
128:	Fees 3.5%. Rebates 50% up to AU$12,000	2019	5

4.5 Combined policies

In order to model the impact of concurrent policy implementation, seven variations of combined policy scenarios were modelled. Four of the combined policy scenarios include a mix of two or three policies. In order to illustrate the potential objective of grouping certain policy instruments, we have given these combined policies a qualitative descriptor as well.

Scenario 130: Aimed at environmental early adopters (RE-EV + Feebate [123])

Scenario 131: Aimed at technology early adopters (RE-EV & CCM)

Scenario 132: Address the price gap between ICEVs and EVs (CCM + Feebate [126])

Scenario 133: Least cost to government (CCM, RE-EV, ToU)

The other three combined policy scenarios are variations of implementing the non-financial policy instruments with three different financial instruments. Specifically, in the following scenarios, RE-EV, CCM and ToU were modelled with:

Scenario 134: Feebate [123]

Scenario 135: Feebate [126]

Scenario 136: Feebate [118]

These three scenarios were chosen as they appeared to maximize the uptake of EVs at the lowest cost to society and government against a larger set of combined scenarios modelled.

5. Results

The modelled outcomes of the policy scenarios are presented below, including their impact on PHEV and BEV market share in comparison to the base case (defined as an additional EV on the road for one year), EV sales, and carbon emissions. Economic performance is also discussed in terms of including net government impact (AU$B), net consumer impact (AU$B), government gross cost effectiveness (AU$/additional EV year) and the societal benefit cost ratio (BCR).

Table 3. Analysis of policy performance

Scenario #	BEV market share at 2034 (%)	PHEV market share at 2034 (%)	Carbon savings (Mt)	EV market share at 2034 (%)	difference from base case	Net government impact (AU$B)	Net consumer impact (AU$B)	Government gross cost effectiveness (AU$/additional EV	Societal BCR
100	11.2%	27.2%	-	38.4%	0.0%	-	-	-	-
101	13.8%	28.7%	1.3	42.5%	4.1%	-0.1	0.9	110	2.8
104	12.0%	30.4%	1.0	42.4%	4.0%	0.0	0.4	0	1.9
108	12.2%	30.3%	2.0	42.5%	4.1%	0.0	0.4	0	1.4
Rebate									
110	11.3%	33.5%	1.8	44.8%	6.4%	-2.7	3.3	1705	1.8
111	11.2%	27.5%	0.3	38.7%	0.3%	-0.2	0.4	891	3.8
112	11.3%	28.6%	0.7	39.8%	1.4%	-0.6	0.9	1004	2.1
114	10.8%	37.4%	3.4	48.2%	9.8%	-4.6	5.6	1594	1.7
115	11.2%	28.1%	0.9	39.2%	0.8%	-0.7	1.2	1013	2.4
116	11.2%	29.8%	1.4	41.0%	2.6%	-1.2	1.7	1052	1.8
Feebate									

118	11.6%	36.6%	3.7	48.3%	9.9%	0.4	0.5	1205	1.4
119	11.2%	27.6%	0.5	38.8%	0.4%	0.4	-0.2	715	1.9
120	11.3%	28.9%	1.0	40.1%	1.7%	-0.2	0.5	852	1.8
122	11.1%	43.6%	7.1	54.7%	16.3%	-0.1	1.6	1152	1.4
123	11.1%	28.4%	1.4	39.5%	1.1%	0.4	0.0	882	1.6
124	11.2%	30.5%	2.0	41.7%	3.3%	-0.4	0.9	899	1.6
126	11.1%	47.1%	9.6	58.2%	19.8%	1.3	0.4	1034	1.4
127	11.1%	28.8%	2.0	39.9%	1.5%	1.0	-0.5	876	1.4
128	11.2%	31.0%	2.4	42.2%	3.8%	0.1	0.5	822	1.6
Combined									
130	13.6%	30.2%	3.0	43.8%	5.4%	0.1	1.0	497	1.9
131	14.3%	31.0%	2.8	45.3%	6.9%	-0.2	1.1	148	1.6
132	13.7%	41.0%	9.2	54.7%	16.3%	2.0	0.0	1114	1.5
133	15.1%	32.9%	3.6	48.0%	9.6%	-0.1	1.4	53	1.9
Balanced									
134	14.3%	31.2%	4.1	45.6%	7.2%	-0.1	1.3	515	1.6
135	16.6%	43.6%	11.3	60.2%	21.8%	0.3	2.7	954	1.6
136	15.9%	38.5%	6.6	54.4%	11.9%	-0.8	2.8	836	1.7

Implemented individually, RE-EV, ToU and CCM each had similar impacts on EV adoption. The RE-EV scenario had the greatest impact on the BEV market share in 2034, both in comparison to the non-subsidy scenarios (Table 3) and the subsidy scenarios. ToU and CCM had a greater impact on PHEV market share than the RE-EV scenario and all 5-year subsidy scenarios (except [124] and [128]).

These non-subsidy policy scenarios, which were all modelled with a 20-year duration from 2014 – 2034, increase both the BEV market share by 1-2.5% and the PHEV market by 1.5 to 3%. In contrast, the rebate incentives shown in Table 3 had minimal impact on the BEV market share.

When comparing the relative impact of the rebate scenarios to one another (Table 3), the two rebate scenarios with the 20-year duration [110 and 114] had the largest impact on PHEV market share and carbon savings, although 114 actually decreases the BEV market share. Both scenarios that offer rebates for only five years from 2014 to 2019 have a very small negative impact on PHEV market share [111 and 115]. A delayed five-year rebate, starting in 2019, performed only marginally better than the base case [112 and 116].

Of the rebate scenarios with a 5-year duration, Scenario 116 has the greatest overall performance in terms of PHEV market share and carbon savings.

Similar to rebates, the feebates (fees for ICEVS and rebates for EVs) had little to no impact on the BEV market share and scenarios implemented for the first five years [119, 123, and 127] have the smallest impact on PHEV market share out of all feebates (Table 4).

Combining the fees with the rebates achieved a higher market share than modelling the rebates alone. For example, the PHEV market share in 2034 from a '50% rebate up to AU$3,000' [110] for 20 years is 34%, versus 37% when adding a 1% fee to ICEVs with the same policy [118], a difference of 3.1%. The difference between '50% up to AU$7,500' [114] is double that, at 6.2%, when compared to its feebate counterpart, '2% fee/50% rebate up to AU$7,500' [122].

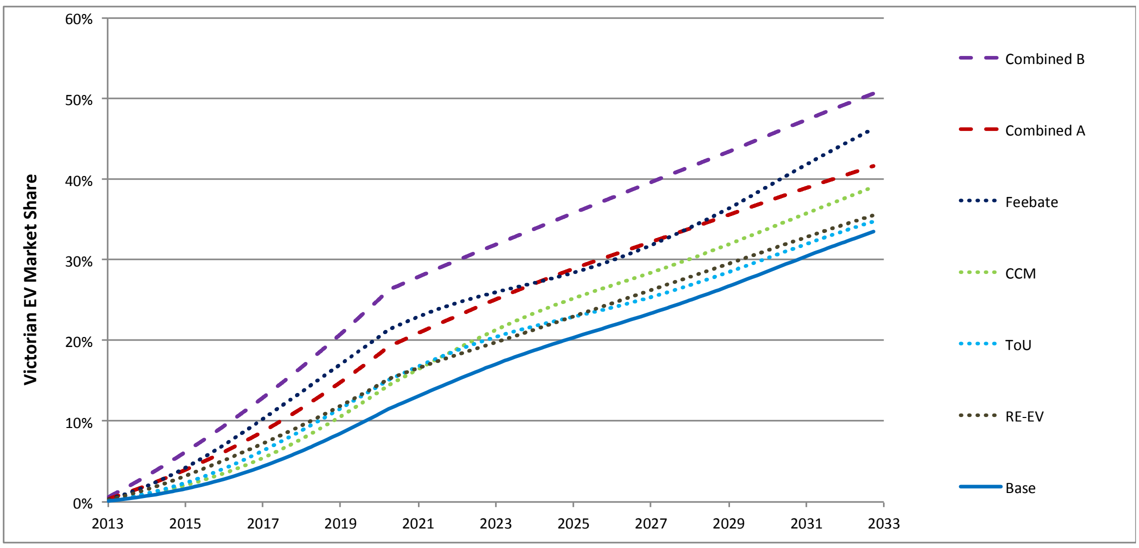
When comparing the results for the 20-year feebate scenarios, there was a much greater increase in PHEV market share when jumping from the '1% fee/50% rebate up to AU$3,000' [118] to the '2% fee/50% rebate up to AU$7,500' [122], than from [122] to '3.5%fee/50% rebate up to AU$12,000' [126]. The difference in PHEV market share in 2034 is 7% and 3.5% respectively.

Each of the combined policy packages in Table 3 increased the BEV market share by 2-3%, more than any of the individual rebate or feebate scenarios (except for RE-EV). The scenario that addresses payback gap [132] had the greatest impact on the PHEV market and carbon savings, out of all of the combined policies in. Note this combined scenario used the most progressive feebate modelled in this report.

The 'balanced' policy packages, or the scenarios that model all four types of policy interventions measures, all have the greatest impact on BEV market, compared to any scenarios discussed thus far. Similar to the scenario modelled above [132] which use the most progressive feebate, the scenario [135] with the same feebate had the greatest impact on BEV and PHEV market share in 2034, and the greatest of all policy scenarios modelled. The balanced policy package [136] with the smallest 20-year feebate achieved almost double the additional EV uptake above base case than the balanced policy package with a 5-year, but more progressive feebate [134].

The impact of selected policy scenarios on the Victorian EV market share are in Figure 1. The non-subsidy incentives all have a very similar impact on EV market share, bringing the percentage to 42%, or 4% greater than the base case. The selected feebate [118] and Combined [133] also have very similar impacts on market share (an increase of almost 10%). Comparing [133], which is the "Least Cost to Government" to the non-subsidy scenarios demonstrates how implementing CCM, ToU, and RE-EV together can achieve a greater market impact that implementing any of them individually (an increase of almost 6% market share).

Figure 1. Victorian EV Market Share, 2014 - 2034



5.1 Economic Performance

The economic performance of the policy scenarios is compared on four indicators, including net government impact (AU$B), net consumer impact (AU$B), government gross cost effectiveness (AU$/additional EV year) and the societal BCR. See Usher et al., (2012) for further explanation of the cost and benefit estimates, and the methodology for the economic analysis.

The non-financial scenarios had little or no government costs and were therefore relatively cost effective for government (Table 3). Table 3 also contrasts the non-financial scenarios to three indicative rebates ([110], [111], [116]) and two feebates ([118] and [123]).

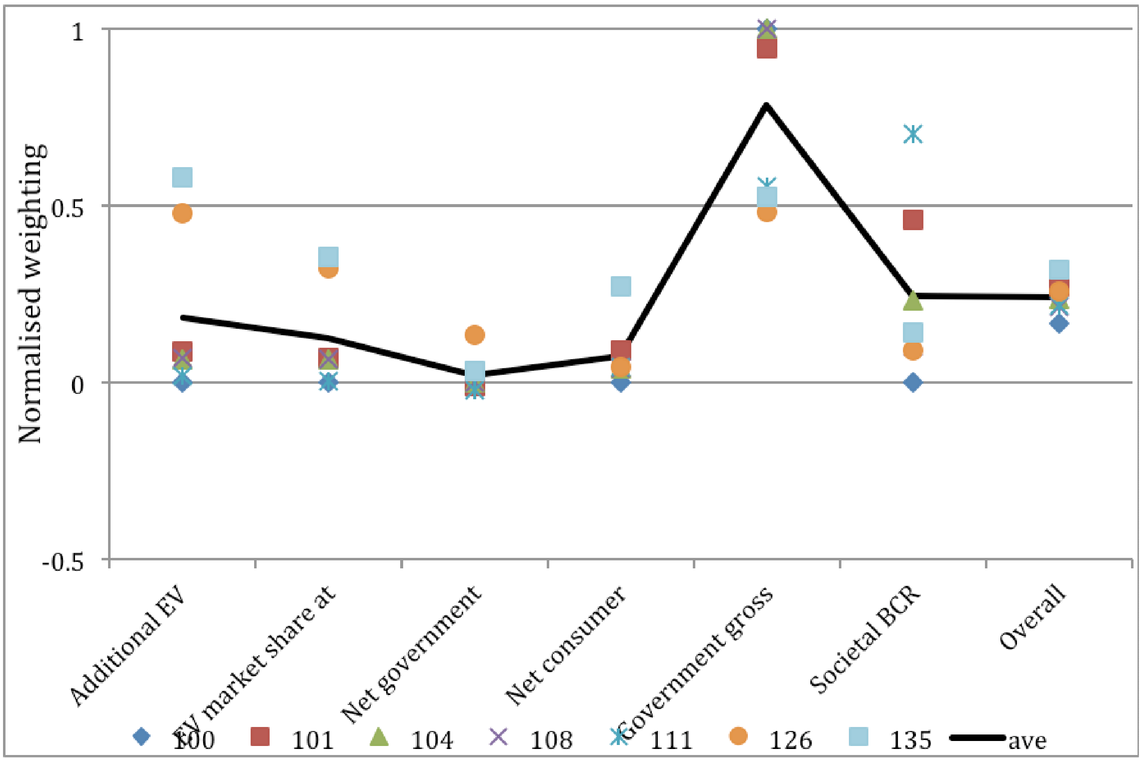
Rebate [111] and the RE-EV policy have the greatest societal BCR of all modelled scenarios (3.8 and 2.8). The scenarios with the greatest government cost effectiveness (aside from ToU which does not involve government funding) are CCM, RE-EV, Feebate [123], and Rebate [111].

The policy package with the highest societal BCRs, in terms of all combined scenarios, did not include financial incentives [Least cost to government]. The policy package aimed at early adopters performed well across all indicators (in the top five for all indicators accept net consumer impact).

6. Discussion

The number of registered HEVs in Victoria has increased by 26% from 2009 to 2012, with a total of 4,125 HEVs registered in 2012. This number can be contrasted with the expected number of EVs in the base case scenario, beginning 2014, of 89,000 EVs. While the model was calibrated to Graham et al (2008), the base case may have a higher prediction than what can be expected without any policy interventions. However, several interesting performance comparisons can be made amongst the modelled policies, both in terms of EV market share increase and economic performance. To enable the comparisons, the key performance indicators have been normalised (as shown in Table 3) and the highest value results are presented in Figure 4.

Figure 4. The key performance indicators for the various policies scenarios, specifically the non-subsidy scenarios with the best subsidy scenarios for rebates, feebates and combined/balanced policies (defined as the scenario with the highest overall value).



6.1 Subsidies versus non-subsidy scenarios

By comparing the performance of individually implemented, non-subsidy policies (RE-EV, CCM, ToU) versus subsidy policies, the model predicts that non-subsidy incentives have a greater impact on the EV market than the subsidy incentives in several ways. The RE-EV scenario had the greatest impact on BEVs by 2034 compared to any other rebate or feebate, regardless of the size, timeframe or duration of the subsidy scenario (total BEV market share of 2.6% greater than base case). Conversely, rebates and feebates had negligible impact on BEV market share, regardless of the policy start year or duration (+/-0.4% from base case). Additionally, RE-EV, ToU and CCM were predicted to produce an EV market share of at least 42.4% (4% greater than base case), which is greater than the impact of all individual rebates and feebates with a 5-year time frame (which had a range of 0.3% and 3.8% greater than base case). What this suggests is that non-subsidy policy instruments can be an important policy lever for government in supporting the uptake of EVs, especially in the case of encouraging BEV adoption.

6.2 Rebates versus feebates

Feebates (coupling EV rebates with fees for ICEVs) were more effective overall than implementing rebates alone and can lead a positive net financial impact for government, suggesting that if governments are investigating EV rebate incentives, a fee counterpart should also be investigated. Feebates in particular outperform rebates in net government impact and Government gross cost effectiveness; however rebates perform better Societal BCR and net consumer impact. Feebates also have better EV market share.

Feebate [118] had a 3.5% greater market share of EVs in 2034 (9.9% above base case) than Rebate [110] (both were 20- year scenarios with rebates up to AU$3,000). The net government impacts of AU$0.4B for [118] versus -AU$2.7B for [110] highlights the difference in government financial outcomes of a rebate verses feebate policy. Similarly, Feebate [122] had a 6.5% greater market share of EVs in 2034 (16.3% above base case) than Rebate [114] (both were 20-year scenarios with rebates up to AU$7,500). In both comparisons, carbon savings more than double moving from equivalent rebates to feebates.

However, increasing the amount of rebates and fees will not have a proportional impact on the EV uptake. In comparing Feebate [118], [122] and [126], which are all feebates with a 20-year duration, the increase in EV market share from [118] to [122] was much greater than [122] to [126]. Scenario [122] had a 6.4% greater impact on EV market share in 2034 than [118], but Scenario [126] only had a 3.5% greater impact than [122].

6.3 Combined and balanced versus feebates and rebates

Combined and balanced policies are substantially more effective than feebates or rebates. In particular combined/balanced polices have a normalised average of 0.25 compared to 0.16 for feebates and 0.15 for rebates. Across all the key performance indicators, combined and balanced policies outperformed feebates and rebates with the exception of net government balance compared to feebates and net consumer impact and societal BCR compared to rebates.

6.4 Best subsidies scenarios versus non-subsidy scenarios

By comparing the performance of individually implemented, non-subsidy policies (RE-EV, CCM, ToU) versus the best subsidy policies, the model predicts that non-subsidy incentives performance is mixed compared to the best subsidy scenarios. In particular the best feebate and combined/balanced policy subsidies significantly outperform in terms of EV uptake and net government impact, but performs below average in societal BCR and worse in terms of government gross cost effectiveness. For net government and consumer impact the best subsidies are mixed, with the best combined/balanced policy performing above average but the feebate was significantly better in net government impact but below average in net consumer impact. The best rebate scenario scored highest in terms of societal BCR, but across all other indicators performed well below average. This indicates that rebates in isolation do not produce good results. Overall if economic and societal indicators should be considered more important, then the best performing policy is RE-EV, however if EV market share indicators are more important than the [135] combined policy scenario which includes RE-EV is the best policy. In either case RE-EV should be implemented either as a standalone instrument or as part of a balanced package of policies.

6.5 Start time and duration of financial subsidies

All rebates and feebates that start in 2014 and have a 5-year duration were predicted to create the smallest amount of change in the EV market share by 2034 (all scenarios are < 1.5% greater than the base case). Rebates and feebates beginning in 2019, with a 5-year duration all lead to greater EV uptake by 2034 than the same scenarios implemented for 5-years starting in 2014, albeit the increase is minimal (between 1.3% and 2.3% greater impact uptake of EV, relative to each other), however the later time period also decreases the net government postive impact. Rebates operating from 2014 – 2034 increased the EV market share but significantly decrease the net government positive impact. By comparison for feebates, the net government impact was variable and in the case of the 3.5% fees and rebates of up AU$12,000 the 20 year scenario outperforms either of the 5 year feebate scenarios. Overall, best results were achieved if rebates are applied for 5 years starting in 2014, whereas for feebates, the best results are achieved if the subsidy is applied for the full time period (2014 – 2034).

7. Conclusions

This paper explored the relationship between electric vehicle policy and market uptake using an innovative diffusion model developed by ISF and the CSIRO incorporating features of multi-criteria analysis and choice modelling. Four policy scenarios are tested in the model, including Coupling 'Electric Vehicle Sales-Renewable Energy Purchases', Financial Subsidies, Smart Charging Incentives and creation of a Common Cost Metric. The RE-EV scenario had the strongest performance in terms of economic and societal indicators, suggesting non-subsidy policy instruments could be an important policy lever to support the uptake of EVs, especially in the case of encouraging BEV adoption. The modelling and analysis suggests the feebates were a more effective policy than rebates. Rebate scenarios with the time frame 2014-2019 compared better than other rebate scenario timeframes. Similarly, the feebates with the 2014 – 2034 time frame performed better than feebate scenarios with shorter durations. The combined policy scenarios and balanced policy scenarios (with all four policy types) perform better than implementing just a feebate policy.

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