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WOULD QUÉBEC REACH THE ELECTRIC VEHICLE ADOPTION TARGET? – A GAME THEORY APPROACH

Orenga Panizza, R.[1], and Nik-Bakht, M.[2]
Concordia University, Canada
[1] Rafaelapanizza@gmail.com
[2] Mazdak.nikbakht@concordia.ca

Abstract: As the awareness to decrease greenhouse gas (GHG) emissions rises, so do the Québec action plans to improve its own rate of emission. One of the main plans is the "Transportation Electrification Action Plan", which directs the government into new targets for electric vehicle (EV) adoption with a combination of programs. With 4 years of plan, the trend does not look promising to achieve the first set target (100,000 EVs by 2020). This study is modeling the Québec market as a game of strategy, played two main players (government and consumer) each aiming to maximize their own utility. This game is being analyzed for evaluation of feasibility of action plan targets, and the costs associated with it. The game is a perfect information extensive game that analyzes the EV consumers' response to a change in financial incentive programs. The moves and payoffs of the game were based on available data. Results of this study showed that the government has multiple alternatives to reach the final 2026 target however, the time for making changes is crucial when analysing the economic benefits that the government can acquire. Finally, due to the limited reported experiments that Québec consumers have with the EV market; the simulation of EV adoption has its limitations. This is an initial effort to simulate the EV market in Québec, following steps of this work include the analysis of different segments of prospective users, so that in the future more accurately effective incentives can be known.

1 INTRODUCTION

With the rising concern of climate change, the world has been taking actions to ensure environmental protection. The government of Québec itself also has a mission to ensure environmental protection as well as sustainable development in its territory. One of its focus is the transportation sector, which was then and still is one of the main sectors producing greenhouse gas (GHG) emissions in the province (The 2030 Energy Policy 2015) (Canadian environmental sustainability indicators: Greenhouse gas emissions 2017). Oil has dominated the transportation sector for many years and Québec does not produce its own (The 2030 Energy Policy 2015). In order to tackle the elevated concentration of GHG emissions in Québec and at the same time decrease the amount of oil imported, the province started a "Transportation Electrification Action Plan" to promote the adoption of electric vehicles (EVs), instead of conventional, to the population as well as the public transportation sector (Transportation Electrification Action Plan 2015).

The province began to encourage the adoption of EVs in 2012 by creating a program called "Drive Electric" (now called "Drive Green"), this program created purchase rebates to the population, businesses and organizations that were interested in buying new low emission vehicles and chargers (Transportation Electrification Action Plan 2015). Later in 2015, the government started a new and more elaborated plan, the “Transportation Electrification Action Plan”, to provide a set of objectives and its directions. This plan is directing the province into creating initiatives to encourage electric transportation in all sectors, from the industrial base of the technology to the infrastructure and incentives to assist in reaching the set targets and encourage the change (Transportation Electrification Action Plan 2015). The main objective of this plan is to achieve a target of 100, 000 electric vehicles by 2020, which is the first step to the 300, 000 electric vehicles goal set for 2026 (Transportation Electrification Action Plan 2015).

Today however, with about 7 years into the “Drive Green” program and 4 years of the creation of the action plan, the province has reached 31.5% of the total expected value for 2020 (based on third quarter of 2018 data). Which means that in a little less than two years, the “Transportation Electrification Action Plan” expects to have about 80,000 new electric vehicles driving around the province and, based on the growth rate from the past 6 years, the goal will not be reached by 2020.

The goal of this paper is to propose and evaluate new strategies to be used by the government in terms of financial incentive offered. These government strategies along with consumer’s response are being analyzed in a game theoretic model with respect to their resulting adoption, benefit to cost ratio and their risks.

2 WORKS DONE

Electric vehicles, depending on where they are being charged, can have many economic and environmental benefits over the conventional gasoline vehicles (Al-Alawi and Bradley 2013). However, they are a new technology and consumers are not used to or comfortable with. For that reason, it is important to try to predict how the market will evolve to help manufacturers and policy makers when taking decisions (Valeri and Danielis 2015).

The decision to buy or not an electric vehicle depends on a set of criteria. Many studies that were taken place in various countries, including Canada, and between 2005 and 2015 collected data, through surveys, on important attributes taken into consideration when adopting an electric vehicle (Valeri and Danielis 2015). Surveys, however, mostly show the rational thinking of a person. Even though consumers are becoming more aware of how their practices can influence the environment and/or their savings, many of them still fail to take the necessary actions (Frederiks, Stenner and Hobman 2015).

Most studies focus on financial, infrastructure, technical and policies (Fanchao Liao 2017). In the technical aspect side, most studies have shown that driving range is a very important aspect to be considered when buying an EV. In the infrastructure sector, the density of available public chargers was the unit used. Increase in the density was found to positively impact adoption of EVs since it helps with the range anxiety of the drivers. The financial section on the other hand, had two main criteria: purchase and operational cost. Both appeared to be very significant to consumers. Lastly, in the policy section, five different policies were taken into consideration and the policies one-time reduction policies were found to be effective in most of the studies (Fanchao Liao 2017).

There are many methods used to try to understand impact of a decision made by a management position or policy makers. In the alternative fuel vehicle market, the Monte Carlo Simulation has previously been used to evaluate market penetration of different vehicles (Valeri and Danielis 2015). However, game theory has shown great effectiveness in many science and economic fields with consumers and policymakers (Kelly 2003).

3 PROPOSED CHANGE

Based on the attribute options summarized by the literature review, some scenarios were created in this study, for the market simulation. Since enhancing the public charging infrastructure is already in the agenda of the government (as well as other private networks), and technical attributes depend on technology development, the created scenarios do not focus on such areas of incentive. The focus of this paper is merely on policies placed to decrease the inverse impact of EV purchase price on the adoption.

When analyzing the financial incentives of other comparable countries and provinces during the years of 2015 and 2016, it was noticeable that Québec is placed in the middle range of offering EV purchase rebate incentives. That raises questions such as “What if Québec invests in offering more financial incentives?”; “Would adoption increase at a faster pace in result of such increases?”; “Would it be worthwhile from the perspective of government?”; “What about the possible inverse impacts of offering less incentives on EV adoption, and consequently on reaching the set target?” In order to answer such questions, the present study is analyzing adoption scenarios of maximized and minimized incentive levels within the existing ranges, as well as maintaining the current incentive level.

4 METHODOLOGY

4.1 Structure of the model

Based on the system described, a two-player game theoretic model was built. The game is an extensive form game starting in January of 2019 and going until December of 2025, which is when Québec wants to have reached 300,000 EVs. The government has the first move at the beginning of each year and the group of consumers responds at the end of the same year with the total amount of new adoptions. That cycle repeats until the end of the game.

The government has three possible moves: increase incentive to USD17, 900, maintain the existing incentive or completely remove the incentive. However, as a rule of the game, once incentives are changed, they cannot be changed again during the game period. Based on these moves and rules, the government has a total of 15 strategies. A representation of these strategies can be found in *Figure 1*.

Time of move / Strategies	2019	2020	2021	2022	2023	2024	2025
1	Increase						
2		Increase		Maintain Increased Incentive			
3			Increase				
4				Increase			
5					Increase		
6						Increase	
7							Increase
8		Maintain Current Incentive					
9							Remove
10						Remove	
11					Remove		
12				Remove			
13			Remove				
14		Remove		Maintain No Incentive			
15	Remove						

Figure 1: Summary of government strategies

4.2 Estimation of model parameters

Apart from the time when EVs were first introduced to the Québec market, the local consumer never experienced a change in financial incentive provided by the government. So, the simulation of possible market responses to variations of incentives in Québec was based on the historical data from other locations with high similarity level. At the beginning of this analysis, 15 countries and provinces were considered; however, after completing an analytical hierarchy process (AHP), only 10 remained with a 50% or higher similarity to the current case study. The similarity was evaluated based on multiple criteria, including annual and purchase cost parameters, income and education level, time of introduction of EV to the market, available infrastructure and level of market maturity, each of which with its associated impact weight, estimated through the AHP.

The moves for the group of consumers, in this model, depend on the baseline adoption growth rate (due to the normal technology development), as well as the combination of a change in incentives and maturity of the market with respect to the existing policies. The baseline growth rate is the growth that will happen every year independently from the changes in available incentives. Electric vehicles are divided into battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV). And the baseline equations for BEV and PHEV were estimated through the best-fit analysis of Québec data over years 2013 through 2018 (Figure *2*). The resulting regressions for BEV and PHEV can calculate the yearly adoption for each type of vehicle based on the EV market age in Québec (year 0 being 2012 because that was when EVs were first introduced in the market).

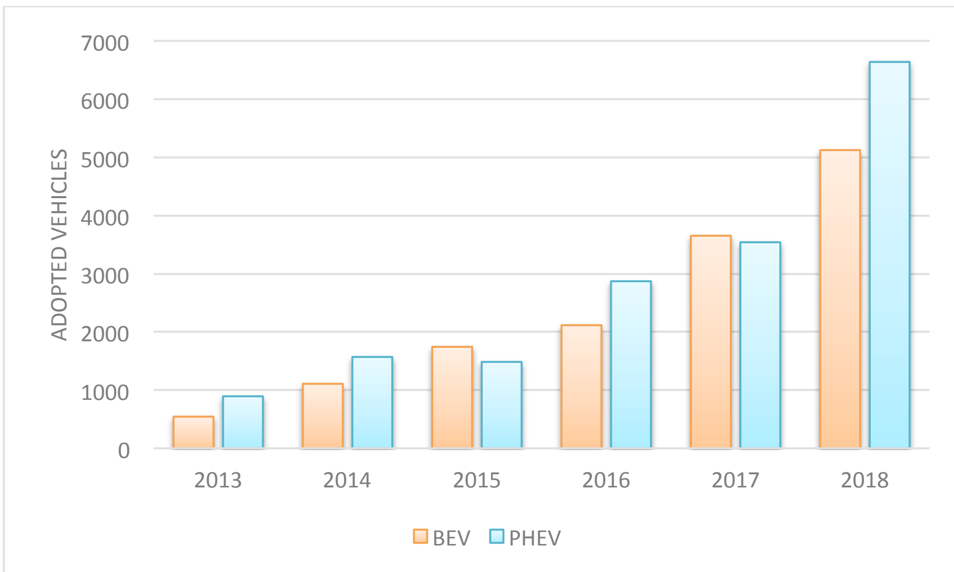

Figure 2: EV Yearly Adoptions

Due to the limitations associated with the available data, a normal distribution with a variance proportional to the existing variance over the years in Québec was assumed to model the uncertainty for all the evaluated data points. The correlation between normalized marginal growth of adoption and normalized existing incentive for BEV and PHEV in the countries that had a change in their incentive were studied separately. This relationship enabled the formation of a model that can calculate the growth in the number of adoptions due to a change in the value of incentives based on the value of the already existing financial support. The process leading to this calculation is being represented in Figure *3*. This growth will then be multiplied by the previous year's adoptions to provide the amount of adoptions that are a result of the incentive modification.

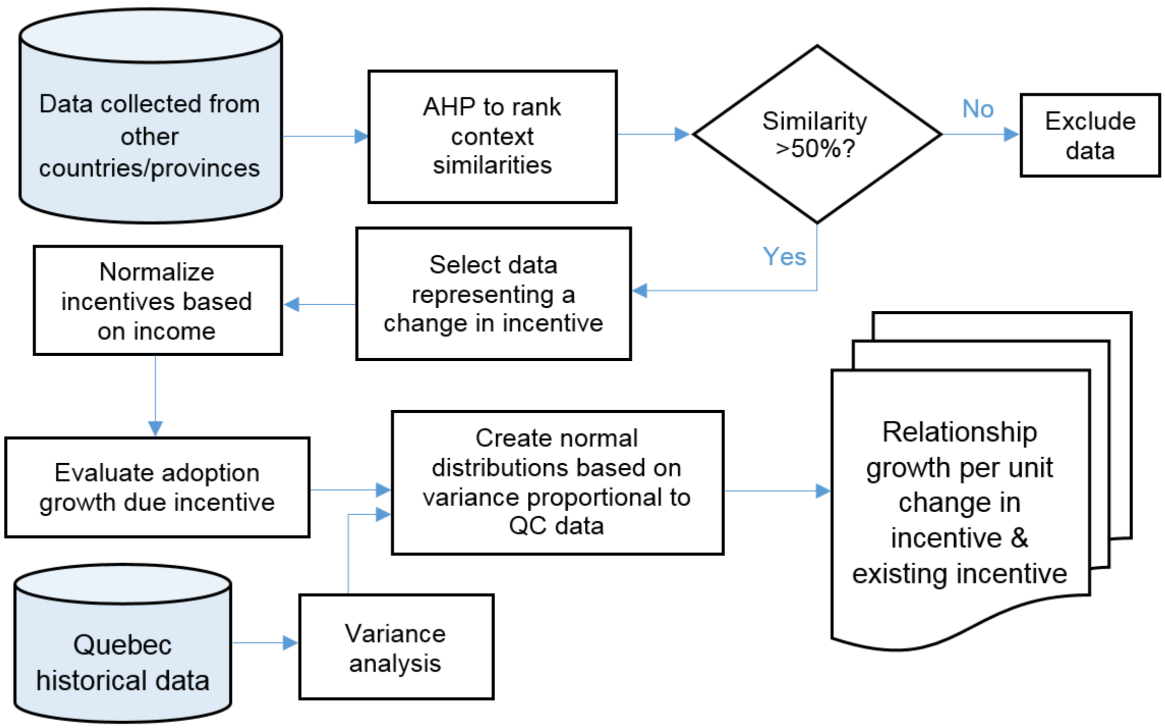

Figure 3: Data processing method used for calculating the number adoptions after changing financial incentive

4.3 Evaluation of payoffs

The strategy for Québec government aims to maximize two major outcomes: adoptions of EVs (at least reach the set target for 2016) and, benefit to cost analysis (BCR – to guarantee a justifiable investment). For the first aspect, the payoff is based on the summation of all consumer adoptions before and throughout the analysis period. The goal is to achieve a total of at least 300,000 electric vehicles in the province, and if possible, achieve 100,000 EVs by 2020 on the way. The second aspect aims to maximize the monetary benefits, for every dollar paid as incentive. In this analysis, the cost is the present value of all rebates provided by the government throughout the analyzed period.

Encouraging people to use electric rather than conventional vehicles does not directly bring an economic benefit to the government. However, to perform the BCR analysis, the benefits were the savings related to the cost of importing crude oil into the province that will be saved per vehicle. The benefit was also analyzed as present worth and took into consideration the cumulative adoptions throughout the analysis period. The calculations were based on an average driver annual mileage (15,000 km/year) and on a 7.01 L/100km driving range (2018 Honda Civic LX, which is among the most popular vehicles in Québec).

5 RESULTS AND DISCUSSION

5.1 Adoption-oriented strategy

To analyze the resulting adoptions of the studied strategies, the Extended Swanso-Megill (ES-M) method was used. ES-M is a discrete three-point approximation method, and in this case was used to separate the final adoption continuous distribution into three possible outcome values. The approximation values were categorized as 'worst-case scenario' (10% percentile), 'median scenario' (median value of distribution), and 'best-case scenario' (90% percentile).

As expected, the strategies with an increase in financial incentive had greater adoption rates than strategies maintaining or decreasing financial incentives. Strategies that maintain rebates also showed greater adoption rates than decreasing strategies. When increasing incentives, the highest number of adoptions comes with the strategy that makes the change during the last year of analysis; and when decreasing incentives, the highest adoption number comes with the strategy that makes the change during the first year.

As a result of this game, all the best-case scenarios would allow Québec to reach the set target for 2026 (300,000 EVs on the roads of the province by 2026). The worst-case scenario on the other hand, showed that all but 2 strategies would still reach the target. The variation between best and worst cases represents the uncertainty related to the behaviour of consumers. In between those two scenarios is the median scenario, also known as most likely. In that case, all strategies but one would allow the province to accomplish its objective when combining the new adoptions with the already existing ones. The target adoption quantity set to be accomplished by 2020, on the other hand, will not be reached independently of the strategy chosen.

These results show that the province has a wide range of options to reach its 2026 objective. However, a large portion of the adoption, in all cases, will happen due to the growing market share of EVs every year, in the result of technology advancements and maturity. The limitation of our method, however, is that the market saturation is not being represented, which may have a significant impact on the results.

5.2 Cost-oriented strategy

When focusing on cost-oriented payoffs, it was observed that the time chosen to make a move is critical when trying to maximize the government's payoff. It was seen that, when removing an existing incentive, it is always best to do it as early as possible. And, when adding more financial discount, it is best to do so in the later phases of the game. When it comes to increasing the rebates, if the government needs the greatest amount of benefit by the time the game ends; it is more lucrative to choose to add the incentive during the second to last year. That is because the government depends on savings from the following year to recover and overcome the expenses caused by the previous year's provided rebates, causing the last year to have a much lower benefit to cost ratio than other alternatives for rebate increase.

The strategies which were based on providing less incentives, resulted in less adoptions; however, the fact that less incentives were given out, allowed for a greater financial benefit for the government. The strategy based on maintaining the current situation, remained in the middle in terms of adoptions and paybacks trade-off. Finally, the group of strategies that increased financial discount for customers resulted in an overall lower benefit for the government.

6 CONCLUDING REMARKS

This study represents initial efforts to estimate and simulate the consumer response to financial incentives in the electric vehicle market in the province of Québec, Canada. With the idea to support decision-making, this paper showed two different perspectives of providing incentives, along with the risks involved with respect to behavior of potential customers. According to the results of this paper, there are thirteen different combinations of choices that, in a worst-case scenario, will provide the province with 300,000 EVs or more by 2026 (the set-target of Québec government). The choice between increase or decrease incentives will then depend if the government prefers a greater financial benefit or higher number of adoptions.

The game theoretic model proposed by this paper allowed us to have a general understanding of the relationship between government policies and consumers in the EV sector. This game however, relied on several assumptions and generalizations, mainly imposed due to the data availability limitations. Even-though similarity comparisons were made to choose from which countries and provinces to use data; consumers have different tastes and habits in different countries. Hence, using their data to predict Québec adoption is a major limitation of this study. We are performing field studies and market analyses to overcome this limitation in the future steps of the study. Also due to the lack of data, this model was not sensitive to effects such as market saturation, and only focused on the incentives offered. After filling the gaps associated with data limitations, the future steps of the study will analyze different segments of the population as prospective EV users, and examine the readiness of the infrastructure (chargers, digital and physical platforms, roads, etc.) for accommodating the sought-out adoption increase of EV's in the province of Québec.

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