Maximizing Profit through Optimizing Production of Electric, Hybrid, and Traditional Cars Using Game Theory

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Abstract

As the global supply of petroleum dwindles, interest in alternative energy sources grows. This trend has manifested itself in the automotive industry through the growth in high-mileage and hybrid vehicles. Now many car companies are beginning to release fully electric vehicles. Thus it is a vital time for car companies to decide how much they wish to invest in new, unproven technologies. This project seeks to optimize the profit for one or more car companies when they are faced with the choice of whether to focus on traditional gas-powered, hybrid, or electric vehicles using game theory. Utility functions are created for both the consumer and the company, and a game is created with the company and the consumer as players. A framework is then laid out for how these utilities can be used in creating a single- and multi-year model.

Section 1: Introduction

On the whole, over the past years, gas prices have slowly been climbing upward. Simultaneously, sources like the film “An Inconvenient Truth” have been revealing to the world the effects of pollution on the climate and global warming; this has led to a widespread environmental movement and the popularization of sustainability and going green. The result of these two movements has been to see a push for vehicles with better gas mileage. The success of this movement is exemplified by the Toyota Prius hybrid. The Prius, with its distinctive design, has grown over the past 15 years to become the third best-selling vehicle in the world (Ohnsman, A. and Hagiwara, Y., 2012). Now car-makers are looking toward producing plug-in hybrids and fully electric vehicles. With these new options, car-makers are trying to figure out where they should invest their time and money: in traditional gasoline vehicles, hybrid, or electric vehicles.

Through this paper, game theory is used to begin analyzing this problem. Since game theory was created to analyze economic problems, it is a fitting tool in this situation (Davis, M.D., 1970). A game is created where the two players are a car company and a consumer. Through repeating this game many times, probabilities can be found for when consumers will buy certain types of cars and the car company can produce their vehicles in corresponding proportions. The paper will then expand on this model by exploring multi-year forecasts.

Section 2: Game Theory Introduction

As was mentioned previously, game theory plays a part in the remainder of this paper. Thus, it is necessary to discuss some basic game theory before continuing further. First, the concept of a game is central to game theory. A game is a setup where there are one or more acting agents, called players, who each have a set of actions, or strategies, that they can use.

Game theory analyzes which action players will take and what the resultant outcome will be (Davis, M.D., 1970).

Consider the following example game: the recording artists Panda Bear and Avey Tare each want to release an album. If they collaborate on a project, they will each make $100,000. Panda Bear will make $80,000 if he makes a solo album and Avey Tare will make $50,000. If one approaches the other to collaborate and the other is doing a solo project, the potential collaborator will get nothing. This can be easily represented by what is called a *payoff matrix* . The payoff matrix for the example is given in Figure 1. In the figure, Panda Bear is what is known as the row player, and Avey Tare is the column player. In each order pair of the matrix, Panda Bear's payoffs come before Avey Tare's do.

		Avey Tare	
		Collaborate	Solo Project
Panda Be	Collaborate	($100000, $100000)	($0, $50000)
	Solo Project	($80000, $0)	($80000, $50000)

Figure 1. A payoff matrix for Avey Tare and Panda Bear's recording options

In this situation, there are two Nash Equilibriums in the top left and bottom right squares of the matrix. A *Nash Equilibrium* occurs when neither player can do better given the other player's decision. For example, if Avey Tare does a solo project, Panda Bear cannot make more than the $80,000 he would make if he did a solo project. He would have no incentive to try to collaborate. Similarly, if Avey Tare wants to collaborate, Panda Bear has no incentive to do a solo project because he would make less money.

This example situation hinges on an implicit assumption: all players are rational. That is, each player will choose the strategy or execute the action that will earn them the best payoff. In this case, the best payoff is determined by money. However, humans are not fully rational. In order to represent irrational human preferences, utility functions are created for players. The point of a utility function is to quantify individual preferences. This is no simple task; trying to completely model an individual's preferences is nigh impossible. As a result, utilities often are relatively subjective and weighting comes from surveys and stated preferences. This can lead to inaccuracies, as people do not always do what they say they will.

For an example of what utility might look like, consider again the scenario laid out with Panda Bear and Avey Tare. Perhaps the money has no meaning to Panda Bear, and he values recording by himself at 5 utils, recording with Avey Tare at 7 utils, and being rejected for collaboration at -10 utils. Avey Tare, on the other hand, only cares about the business prospects and weights collaboration at 10 utils and a solo album at 5 utils. The corresponding matrix is shown in Figure 2.

Avey Tare

Pa nd a Be

	Collaborate	Solo Project
Collaborate	(7, 10)	(-10, 5)
Solo Project	(5, 0)	(5, 5)

Figure 2. The payoff matrix with utilities

In this paper, an interval scale is used for utilities. Interval scales are transitive, and as the name suggests, the values of the intervals between utilities is what is important. This means that almost any value can be normalized to zero. For example, for Panda Bear, we could normalize the utility of being rejected to zero and accordingly the utilities of doing a solo project or collaborating would be 15 and 17 respectively. This is convenient for setting utilities to manageable values and is done throughout the remainder of the paper.

Section 3: Prior Work

Though this analysis is believed to be a novel approach, there have been many attempts to model consumer acceptance of electric vehicles. Most have used stated preference data gathered through various consumer surveys to model when consumers are likely to purchase electric and other alternative fuel vehicles. Hidrue et al. (2011) mention seven other attempts other than their own. Their own model uses stated willingness-to-pay data to create a random latent class model for all of the consumers. This model then led to a prediction that electric vehicles are not going to become popular anytime soon without subsidies.

The model laid out in this paper differs from previous attempts in that it takes a game theoretic approach; moreover, this model considers the business prospects for car companies who would be producing electric vehicles. The “electric car revolution” is unlikely to take place if it is not profitable for car companies to facilitate. Thus, the analysis in this paper is believed to be unique.

Section 4: Main Results

In order to analyze what types of vehicles companies should produce and what attitudes consumers had, the first step was to create a utility function for both the car company and the consumer. The assumption was made that the business's main concern is to make a profit. Thus, the following utility function was created for the car company:

(Equation 1)

where is the utility for company *C* of selling vehicle *v*, is the income for selling said vehicle, and is the cost of manufacturing the vehicle. Advertising and marketing costs are not included in this estimate, as modeling the effectiveness of marketing is beyond the scope of this paper.

The utility function for the consumer was slightly more difficult to create. What should be included in a utility function is relatively suggestive and is a mix of what seems to be most important for consumers in buying a vehicle and what factors one wishes to analyze the effect of. That is, what the consumers value and what the author wishes to see the effects of. For this reason, the following utility function was initially created for the consumer:

(Eq. 2)

Where is the utility of buying vehicle *v* for consumer *k*, is what percent less vehicle *v* pollutes than a comparable gasoline vehicle, is the fuel costs to go 25 miles in the vehicle, is the range for vehicle *v*, and is the upfront cost of the vehicle. The coefficients , , and are all weighting coefficients dependent on the values of consumer *k*. One important aspect of equation (2) to note is that for all categories, the value for the gasoline vehicle was normalized to zero, and the values for hybrid and electric vehicles were taken relative to the gasoline vehicle. Next, the upfront cost of the vehicle is not weighted. This is because the scale of the utility function is in willingness to pay. Willingness to pay simply means that dollar values are attached to preferences. For example, a consumer might be willing to pay $1000 for one extra mile per gallon. Obviously, a consumer's willingness to pay for the cost of a car will just be the cost of the car.

After creating the utility functions, the next executed step was to create a program that would find the utilities for many different customers, as utilities will differ on a person to person basis. A simple version of the program was created in the java programming language, but due to errors in the code and the unsuitability of the programming language, the project was abandoned in lieu of creating a similar, working program in Matlab. This step is included in future work. The progress that was made on the java program is included in the appendix.

Once the program was abandoned, the consumer utility function was tested and refined. For the weighting coefficients, willingness to pay data was taken from Hidrue et al. (2011). That survey only considered several discrete options for reduction in pollution and range, so the points were plugged into an excel spreadsheet and regression lines were made for each, with the slope of the regression equation being used as the weighting coefficient for the consumers. During this process, it was noted that the relationship for pollution reduction was much closer to exponential than it was linear. Thus, the first refinement to the consumer utility function was made:

(Eq. 3)

where is the function, , for consumer *k* based on the percent less pollution of vehicle *v* compared to a comparable gasoline vehicle. After this refinement was made and the willingness to pay data was plugged in for the "average Joe" consumer *j*, the equation was:

(Eq. 4)

It is noteworthy that in this equation, the range of the vehicle is normalized to zero when the range is 75 miles.

After creating equation (4), the utility function was tested on the 2011 models of the Nissan Versa sedan(gas), Nissan Altima Hybrid, and the Nissan LEAF (electric). It was decided to test the utility functions on a gasoline, hybrid, and electric vehicle made by the same car company. This decision was made for two key reasons. First, if all vehicles are produced by the same car company, it is possible to give suggestions to the company on what is likely to be the most profitable for them. Second, by choosing the same company, the difficulty of factoring in brand loyalty is avoided. The values for fuel costs, range, and pollution were all obtained from fueleconomy.gov (2012) which is maintained by the Department of Energy and the Environmental Protection Agency. The upfront cost of the vehicle was set as the Kelley Blue Book fair purchase price (Kelley Blue Book, 2012). After plugging in these values, the following payoff equations were found, where *V* stands for Versa, *A* for Altima, and *L* for LEAF:

(5)

(6)

(7)

Currently in the United States, there is a federal tax credit for consumers who purchase electric or plug-in hybrid vehicles of up to $7500. If this is treated as upfront cash, the utility for the average person for the LEAF is only -45.61.

Another refinement to the utility function seemed in order at this as the average consumer would have no incentive to buy any of these vehicles. Because all aspects of the gasoline vehicle had been normalized to zero, there would be no incentive for any consumer to buy the gasoline vehicle; they would receive the same utility from buying no vehicle at all. However, the author assumes that only the pool of potential car buyers is being considered, thus a driving coefficient was added to the consumer utility function. This is simply a value that gives value to owning a vehicle. This variable is equal for all vehicles considered and is just the flat utility of having a car to drive. If the driving coefficient is set to an even 1000, the new utilities for the vehicles would be:

(8)

(9)

(10)

When considering the accuracy of these utilities, a couple of aspects jump out. First, the Altima's utility is very low. This is a result of multiple reasons, including that power and cargo room were not considered as part of the consumer utility. Yet even though this value is quite low, it does not mean that the value is to be thrown out. In fact, the 2011 Altima hybrid was far from successful. There is no 2012 Altima hybrid for that very reason. Thus, a low utility seems fitting. A second aspect of the utilities that sticks out is that the government subsidies for the LEAF make it a much more desirable car. Without the tax breaks, only extreme consumers would be buying the LEAF.

Though this example case was created to test the consumer utility function, it is hard to be concrete in the analysis of the function. This is because widespread sales data is not readily available for the LEAF. Since it has only been produced and released in small numbers, there is little data to test this equation against. The results are within a reasonable range, but as empirical data becomes available, it should be used to refine these utility functions.

After it was decided that these utility functions were workable for the time being, a payoff matrix was created using them (see Figure 3). In this payoff matrix, it is assumed that if a customer desires a car that Nissan is not producing, they find a vehicle of similar utility elsewhere. Thus, a Nash Equilibrium will occur in whatever column has the highest utility for the consumer and the corresponding row with Nissan producing the vehicle the consumer desires. This is intuitive in that a car company will produce cars that meet consumers' demands. If the aforementioned java program had worked, this game would have been played many times over and one would have an idea of what proportions vehicles should be produced in so that the company maximizes their profits.

Consumer

	Buy Traditional Gas	**Buy Hybrid**	**Buy Electric**
Versa	(,)	(,)	(,)
Altima Hybrid	(,)	(,)	(,)
LEAF	(,)	(,)	(,)

Figure 3. A payoff matrix for Nissan and a consumer.

Future Work

There are many extensions and expansions that can be done as a result of this research. The first that has been partially explored is to create a multi-year model for the company. A multi-year model analyzes what production decisions the car company should make in order to be profitable long-term. An example of how the multi-year model would work follows. The goal is to play the single year game and find the payoffs for producing only gas, hybrid, or electric. Then the game is played again for the next year. The changes from year to year would include the company gaining (or losing) a reputation for being "green" and the price of battery and other electric technologies declining. After playing a number of years, backwards induction can be used to discern the company's best long-term course of action. Figures four through six give an example of backwards inductions applied to a multi-year model. To execute backwards induction, one simply starts at the final cluster of values and works backwards from the greatest value in each cluster. The pictures make this clear.

Figure 4. An example of values in a multiyear model

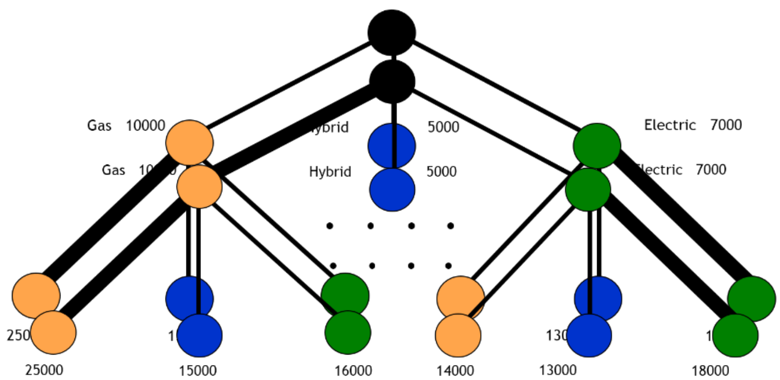

Figure 5. Choosing the greatest value from the bottom cluster

Figure 6. The path to the maximum profit is by producing gas cars both years

Further future work includes creating a program that calculates the utilities for many consumers and applying the original model with that program. This could then be expanded to a model with two car companies, for example Ford and Nissan, who are competing against each other, both in a single year and in a multi-year model. The utility functions used in this paper could continue to be expanded upon and tested as empirical data becomes available. Finally, the random latent class model from Hidrue et al. (2011) can be applied using this game theoretic model and results can be compared with the original model. There are certainly a lot of possibilities for what this work can lead to.

Section 5: Conclusion

Throughout this paper was laid out utility functions for both a car-buying consumer and a car company. These functions were tested using a sample case involving Nissan. Due to lack of empirical data, extensive analysis is inhibited using these functions. A framework has been laid for single- and multi-year models that can be used to analyze where car companies should focus their efforts in order to maximize their profits. This research can lead to many other models that can give the American community a better idea of what electric car integration into everyday life might look like.

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The appendix needs to be included prior to the references.