

EVS29 Symposium

Montreal, Québec, Canada, June 19 - 29, 2016

A Socioeconomic study into the Demand for Electric Vehicles

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Summary

The importance of electric vehicles (EV), from an economic perspective, is rooted in their superior operational efficiency in mobilizing labour and capital when compared to current available alternatives. The use of EVs ensures that the most efficient means of mobilization, from both the consumption of resources and externality generated, is adopted. The challenges facing the mass adoption of EVs will be critically assessed from a socioeconomic standpoint to gain a better understanding of the demand determinants of consumers. Understanding the mind of the vehicle consumer, the autoist, is paramount to accelerating the mass adoption of EVs globally. The consumer's perception and willingness to purchase the vehicle is the fundamental change that is required to advance the new technology to a level of economic normalization. It is evident that a consumer's propensity to adopt the new technology will only increase sufficiently if the following criteria are met: 1 - It is equivalent, or superior, in performance and functionality; 2 - It is equivalent, or superior, in safety and comfort; 3 - It is equivalent, or superior, in initial acquisition cost; 4 - It is superior, in the cost of operating the vehicle

Keywords: Maslow's Pyramid, demand determinants, electric vehicle, elasticity, mass adoption, supercharging

1 Introduction

It at times seems the tendency of a consumer to purchase a new technology is embedded with a subconscious disdain to adopting the unknown. It is the uncertainty and lack of information or misinformation surrounding the technological advancement that results in it being removed as an option. This seems true, even if the improvement is assessed, to be beneficial to the consumer.

The focus of this paper is to address the demand determinants that affect the decision making process when purchasing an automobile. Subsequently how these demand determinants then explain the lacklustre demand for EVs as a viable option. The theoretical assessment of demand of the automobile will initially be addressed from of an intrinsic value proposition. The final section will undertake an econometric assessment of an autoist to determine the current state of elasticity of demand, substitutability and complementation of other vehicles. Viewing the automobile for what it is – a means of transportation – will allow

for a better understanding of how a consumer makes the decision to choose a mode of mobility. Understanding these conditions will shed light on how an EV can truly increase market share and ascertain a level of normalization in the future.

An EV is functionally the same as its internal combustion engine (ICE) vehicle, barring a few fundamental differentiating factors; the means of powering the motor to turn the wheels and externalities generated. Therefore, an EV needs to address all the demand determinants of a consumer to truly be considered as a viable substitute to the ubiquitous ICE vehicle.

2 The Automobiles' Significance: Adapting Maslow's Pyramid

The propensity of a household choosing to purchase an automobile has drastically increased as a result of both mass suburbanization, and technological progress catalysing globalization. The decision made to migrate and reside in less urban areas has increased significantly over the last several decades. Using the USA as a test case and adjusting for population growth, we have measured the average miles driven by a household increased by more than 50% over the past 30 years [9].

What this implies is that the significance of the automobile has increased drastically since its introduction more than a century ago. In vast areas of the developed and developing world, households are nearly solely reliant on the automobile as a means of transportation to ensure the wellbeing of their family. In many respects the automobile, under the auspices of mobility, has truly assimilated into Maslow's pyramid.

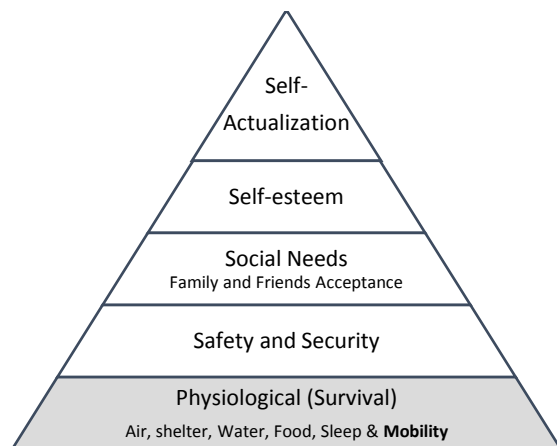


Figure 1 Maslow's hierarchy of needs (adaptation) [1]

As shown in figure 1 above, Abraham Maslow developed a theory that illustrates the basic hierarchical structure of a human's needs. This psychological concept was first developed in 1943 in his paper entitled "A Theory of Human Motivation". At the time of putting forward this theory, it excluded the need for mobility however, given the urban sprawl experienced in the latter part of the 20th century. It is evident that the first core precondition – Physiological Needs – of this theory, in many cases, requires the human being to be mobilized to achieve many of the survival objectives. For the focus of this paper, an adaptation to this theory has been made whereby mobilization of a human being is added to the first physiological tier in Maslow's pyramid.

It has become more prevalent over the past several decades that in order for a human to succeed in living a comfortable fulfilled life from a socioeconomic perspective, the first core needs of survival require efficient long distance mobility.

3 The Demand Determinants of an Automobile

There are four fundamental requirements that need to be satisfied by an automobile if it is to be viewed as an option of mobilization by a human being. Each of the determinants are defined below and are further analysed in how they pertain to the demand for EVs in section 5.

3.1 Performance and Functionality

Vehicle consumers (autoists) have come to demand a high degree of performance and drivability of the automobile. The vehicles driven in the 21st century are able to travel vast distances and able to be refuelled with relevant ease within a short period of time. The drivable spectrum (range) of a vehicle and relative high degree of accessibility to fuel, therefore ensuring continued driving, have become normalized performance expectations of private transportation.

Assessing the driving habits of most autoists, it is evident that 96% of the Vehicle Miles Travelled (VMT) daily are below 100 miles. What current ICE vehicles satisfy is both the *actual* and *expected* demands of an autoist. That is 100% of their daily commute constituting 96% less than and 4% greater than 100 miles of VMT daily [2] [3].

This level of normalization has created a benchmark of driving that is non-range bound due to the infrastructure available and ease of refuelling.

3.2 Safety and comfort

Technological advancements in the design and materials used in the manufacturing of vehicle have shaped a heightened level of expectation by autoists. Vehicles need to offer a high degree of comfort and safety, which meet these new benchmarks.

Average driving speeds, VMT and the number of vehicles on the road have increased significantly in the 21st century. These have all led to more traffic related incidents, increased driving time and congestion. It is therefore imperative that automakers do everything to mitigate against these negative externalities experienced. Vehicles are expected to not only perform their functional duty of mobilization, but do so offering a safe, ergonomically efficient cabin that allows autoists to drive with confidence.

3.3 Vehicle Acquisition Cost

The affordability of the vehicle is generally one of the first factors accounted for when purchasing a new vehicle. Comerica bank in the USA has tracked this data for the US market and looks at the affordability of an automobile in relation to wages earned. It is evident, that over the past several decades' vehicles have become more affordable to the average consumer, even as the price of a new vehicle increased annually by almost 3% over the same period [4].

The purchase price is one component that makes up the 'total cost of ownership' of a vehicle. The price of the vehicle is a short term variable that is estimated to play the largest role in determining a consumer's willingness to purchase. In many occasions the 'sticker shock' of higher priced vehicles overshadows the long run benefits of efficiency, comfort and safety.

3.4 Vehicle Operational Costs

The other component of the cost of ownership of a vehicle is that of the on-going expense in operating the vehicle. It is expected that consumers tend to not fully evaluate the 'total cost of ownership' when researching a new vehicle purchase. This is classified more as a

variable expense with its main components being:

1. Maintenance and repairs
2. Fuel expense
3. Insurance coverage expense
4. Opportunity Cost

Given the unpredictability in maintenance and repairs as well as the uncertainty in fluctuating fuel prices, it is not surprising that many consumers overlook these variable expenses as inconsequential as they discount these costs as a 'given' expense regardless of the vehicle purchased. Essentially, these costs are outside the realm of control of autoists, so it doesn't matter what vehicle is inevitably purchased.

The financial expense of insurance coverage is required by the governing authorities within most countries. Given the lack of control over this variable it is viewed more as a fixed expense no matter what vehicle is purchased.

The opportunity cost of maintaining and refuelling an automobile is somewhat of a non-monetary disbursement therefore, in many cases overlooked. This is measured in the utility loss in terms of the value of 'time spent' when refuelling. Given that this value is difficult to quantify, and that there is no option outside the normalcy of going to a gas station to refuel, the majority of autoists simply overlook this cost.

4 The Global Demand Dilemma

The global population continues to grow at an astounding rate; see figure 2 below.

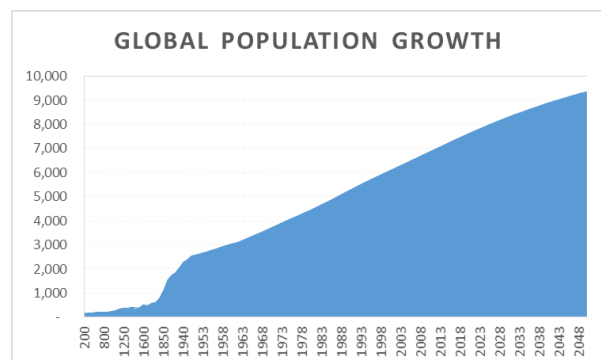


Figure 2: Global Population Growth [15]

As expressed in section 3, the 'physiological needs' of a human now includes that of mobilization. It reasons, that the vast majority of these new entrants into the global market will be

looking at options to mobilize themselves more efficiently. The enhanced affordability and new found independence rooted in the technological innovation of the automobile will compel people to purchase one for themselves. This increased demand for mobilization will likely be experienced largely in the developing world; see figure 3 below.

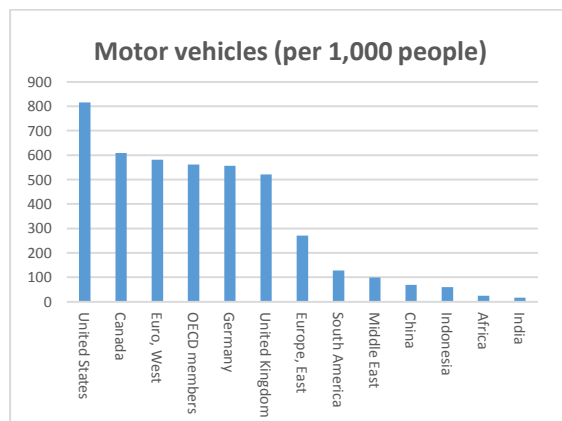


Figure 3: Motor Vehicles Per Capita [13]

The true case for sustainable transportation is made when the total growth and compound annual growth rates (CAGRs) are assessed over the last 15 years, see table 1 below:

Table 1: 15 year growth in new vehicles [15]

Country Name	Total % Growth	CAGR %
China	1259%	20%
India	469%	12%
United States	6%	0%
Indonesia	214%	8%
Brazil	50%	3%
East Asia & Pacific	90%	5%
South Korea	71%	4%
Europe & Central Asia	33%	2%
High income	19%	1%
United Kingdom	11%	1%
High income: OECD	9%	1%

As is shown in table 1 above, two of the largest counties, in terms of population size, – China and India - have yet to even begin to add vehicles to their national fleets. The size of their vehicle fleets have grown annually by 20% and 12% respectively over the past 15 years. It is a matter of time until the negative demand push effects of these markets are felt globally. Vast segments of

their new sizeable middle classes remain immobilized in their personal capacity disallowing them the autonomy experienced in other developed nations.

Table 2: Vehicle Fleet Inequality [13] [15]

Country Ranking	% of Global Population	% of Worlds Vehicle Fleet
China	18.9%	7.7%
India	17.5%	2.0%
United States	4.4%	23.6%
Indonesia	3.6%	0.9%
Brazil	2.8%	6.8%

Table 2 further re-iterates that there is an unjustified imbalance in the current global vehicle fleet. As vehicles have increased in necessity and affordability. Swathes of market entrants in developing parts of the world namely China, Indonesia and India have begun to purchase and experience this sought after independence and physiological need requirement. From the above table, we can see that 40% of the world's current population currently operates just over 10% of the global vehicle fleet. It is a matter of time until parity is reached in these growing nations with untold demand push ramifications on resources and dire implications to our global ecosystem.

5 The Electric Vehicle

Visually, an EV is the same as an ICE vehicle in the sense of it being a privately operated motorized metal transportation vessel. One of the defining factors that differentiates an EV from an ICE vehicle is that it is fuelled by a locally, cost effective and abundantly produced energy source. From an efficiency standpoint, an EV offers a considerably higher 'well to wheels' ratio, with only a 10% loss in energy via entropy when turning the energy stored on-board into work to turn the wheels. This is calculated to be approximately 60% more efficient than an ICE vehicle [7].

5.1 EV Performance and Functionality

From a performance (speed and acceleration) standpoint it is difficult to compare, as both

categories of vehicles offer very unique driving experiences across a broad spectrum of options. It is not fitting to compare top driving speeds due to legislature requiring all autoists, regardless of vehicle, to abide by the legal speed limit, therefore annulling any required comparison. It is when evaluating the responsiveness and overall performance from an acceleration perspective that a fundamental improvement is noted. When comparing an EV to an ICE vehicle, an EV delivers instantaneous torque and smooth power delivery which is 100% spooled at 0 mph [9]. What this entails is a vehicle far more responsive with greater levels of acceleration at almost every level of speed with a heightened level of drivability. Therefore justifying the substitutability of EV when comparing it to an ICE vehicle from a performance perspective.

When assessing the functionality of a vehicle, thus the efficiency of transporting a human from point A to point B. Two primary factors are assessed, the total driving spectrum (range) and refuelling process. As previously stated, 96% of the daily VMT by an autoist are less than 100 miles in range [3]. This is classified as the *actual* range and is easily satisfied by an EV. However, it is not sufficient to have a vehicle that can only be driven 96% of the time, after which an inefficiently prolonged period of time needs to be spent refuelling. The opportunity cost (disutility) experienced in the protracted refuelling process and uncertainty in accessibility in supply required for the remaining 4% *expected* range, outweighs the benefits of the lower operating costs. During a study undertaken by Deloitte Touche (Electric vehicle realities versus Consumer expectations) it was shown that the vast majority of autoists are comfortable with refuelling their vehicles in 5 to 10 minutes. It further shows that more than a third of autoists surveyed would be happy with a refuelling time of up to 30 minutes if driving an EV. [2]

In the same study, it was noted that there was a misconception by autoists that the required range should be more than 200 miles. Whereas in reality these same autoists only drive, on average, around 31 miles on any given day, with 96% of their daily driving being under 100 miles. It will take time for autoists to gain the same level of confidence in EVs as they currently have in their ICE vehicles. The fundamental factors that will shift their anxiety will be ensuring the average range of an EV is greater than 200 miles

with easy access to a charging infrastructure that can charge up to at least 75% of their range (150 miles) in less than 30 minutes. It is also required that the charging stations are within 100 miles from each other, therefore ensuring continuity of travel; round trip. In time, it is anticipated that their perceived daily commute of 200 miles will be altered and redefined to a more realistic 100 mile driving spectrum.

5.1.1 Keeping the Station - The Depot Model

There are two fundamental strategies when EV charging infrastructure buildout is being planned. One, the 'scatter model' where a wide network of single or double charging stations are distributed within dense urban areas. And two, the 'depot style' model of centrally located, multiple access charging ports, mimicking current gasoline stations. If range anxiety is truly to be removed from the thought process of all autoists, a combination of both will be required.

When assessing the refuelling process of an EV, the core differentiating factor is that fuel has been substituted from the standard liquidized fossil fuel with electricity. It is already demanding enough to get households to understand the new system of charging their cars with electricity rather than conventional gasoline. It is in the best interests of all to maintain the process of how we go about refuelling, therefore, keeping the depot model of multiple refuelling access points at one centralized charging station. This gives the EV autoist the look and feel of a conventional gasoline station thereby, maintaining a level of comfort. However, the urban scatter model, conveniently placing level 2 chargers in urban localities, will play a role in bridging the range paradigm.

5.1.2 The Top-up

One factor that is precluded from many studies is the fact that the majority of EV autoists start their daily journey with a full charge. Generally, an EV autoist will charge their vehicle at home overnight, giving them 100% available range for the following day; every day. This, in fact, is impossible to be experienced by an ICE vehicle autoist who needs to refuel at an offsite location.

Using the current technology readily available across the USA, EV autoists are able to get around 25 to 60 miles of range per hour when plugged in. The 'Top-Up' approach will likely become more of a normalized activity. What this entails is an EV autoist will make a quick stop at a charger

within the normal 5-15 minute timeframe to gain an additional 5-20 miles of range. The vast majority of these public chargers are located at areas of convenience (stores, restaurants, place of work etc.). In light of this fact, this form of charging is a secondary thought process and not the primary goal of the commute. These top-ups will simply be a convenient, complementary addition to an already planned trip. Given that it was the intention to frequent the locality for other reasons than charging, the opportunity cost of topping up is zero. In time, the autoists' commute will encompass this new refuelling process. Complete recharging at home or workplace will be supplemented with short stints at public recharge stations.

5.1.3 Realising 100% Vehicle Miles Travelled

From a functionality standpoint an EV must satisfy the *expected* driving needs of an autoist to qualify as a viable substitute to the ICE vehicle. At present, the EV does have an advantage over an ICE vehicle as its primary source of refuelling is the point of departure (Point A – The autoists dwelling) whereby an ICE vehicle will need to drive an additional 5-15 minutes to get to the nearest offsite refuelling station [13].

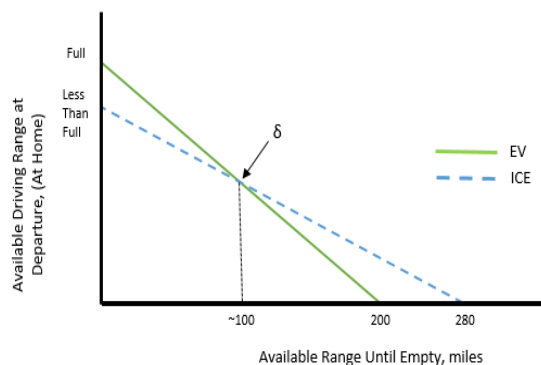


Figure 4: Achieving Parity: Pump to Charger

The graph above illustrates the mile equivalence range point (δ) where an ICE vehicle and EV are in parity. The area beyond this point constitutes the driving time when an autoist will drive more than 100 miles. Beyond the point δ , the uncertainty of refuelling and lesser drivable spectrum create what is known as 'range anxiety'. Beyond this point will require a recharge outside the household, and be subjected to high opportunity cost in the time it takes to

sufficiently charge the EV. At this point, a top-up will not be sufficient in terms of efficiency.

Currently the most widespread and efficient technology available is the Tesla supercharger network, delivering up to 120 kW of direct current (DC). A 30 minute recharge at a supercharger station is able to recharge a vehicle up to 168 miles of range [12]. Using this data along with information from the US Energy Information Administration (EIA), we can calculate the following:

Table 3: Time Spent Refuelling an ICE vehicle at gas station [14]

Average Fuel Economy, MPG	23.3
Average Distance per Gas Tank (12 gallons)	279.6
Daily Commute, miles	50
Left in tank at refuel (20%), miles	55.92
Refuel every, days	4.4736
Total number of refueling stops, annual	82
Average time to refuel, minutes	5
Driving to offsite fuel station, minutes	10
Total Time Spent Refueling, minutes	1230

Table 4: Time Spent Recharging an Electric Vehicle at supercharger station [3] [10] [12]

EV Range	210
Daily Commute	50
Replenish daily (96% of daily trips)	
# Long Distance Trips (4% > 100 miles)	15
Charge Time, minutes	30
Miles added 80% charge	168
Total Time spent Recharging, minutes	450

The surveyed analysis by Harris Interactive of households in the USA, shows that only 4% of the time the total VMT exceeds 100 miles in a given day. It can then be determined that on average, *ceteris paribus*, an EV autoist will frequent a supercharger 15 times per year. This equates to 450 minutes per year compared to 1230 minutes an ICE vehicle will spend getting to and at the pump. This should negate the hypothesis that an EV autoist will be subjected to longer refuelling times when driving.

It is the goal of Tesla Motors and other level 3 fast charging providers to build out their network coverage to ensure every household in the US is within a 100 miles of a station. At this stage,

given the hypothesis in figure 4, range anxiety is no longer an imminent concern and an EV ascertains parity with an ICE vehicle in regards to the ratio of VMT to recharge time. It is evident that the opportunity cost of replenishing the fuel for an ICE vehicle exceeds that of an EV due to the cross utilization of time spent refuelling. It can be concluded that an EV does in fact offer an equivalent, and in many cases superior, level of functionality when compared to an ICE vehicle.

5.2 Safety and comfort

Comparing safety standards of available EVs to equivalent ICE vehicles in the National Highway Traffic Safety Administration in the USA and The European New Car Assessment Programme. It was shown that by all accounts the EVs achieved all satisfactory levels of compliance and safety required to be operated in the public domain. In one instance both rating agencies awarded the maximum rating (5 stars) to the Tesla Model S. It is one of only three vehicles to achieve this rating certification post the introduction of the new 2011 guidelines [12]. The International Standards Organization (ISO) is a secondary organization that has rigorously verified the safety specifications of EVs. The following standards under ISO 6469 were used: on-board rechargeable energy storage system (RESS), vehicle operational safety means and protection against failures, protection of persons against electric shock and post-crash electrical safety. It too awarded EVs the accreditation required to be used by autoists as a mode of transportation in the public domain.

From a logical perspective and comparing the number of moving parts within the vehicles, an EV, having roughly 75% less components in its build, offers a higher level of safety. There is simply a lower probability of something going wrong with the vehicle as there are fewer moving parts to create a problem. Part of the definition of an ICE vehicle includes the phrase, “*burning a volatile liquid fuel with ignition initiated by an electric spark*” [5]. In finality, it can be deduced that an EV is indeed equivalent, and in many cases superior, than its ICE vehicle counterparts.

5.3 Vehicle Acquisition Cost

One of the largest obstacles to current EV adoption is the sticker price shock experienced by most customers when reviewing their options

to purchase a new vehicle. The lack of economies of scale in the production processes of EVs and the misinformation in the current sales models have resulted in high acquisition costs of EVs.

A cross comparison report generated by Plug-In America showed that in the US marketplace, which is indicative of worldwide pricing, an EV is around 42% higher in purchase price than its ICE vehicle equivalent. The majority of adults surveyed in the Harris Interactive Poll stated price to be one of the most significant deterrents when deciding upon an EV. It was evident that the younger generations were less impacted by price when deciding. When breaking it down into generational segments, it is clear that Echo Boomers (18-35) and Gen X (36-47) consumers are around 10-15% less concerned about the price than those over the age of 48 [3]. Therefore, future generations that will make up the core of the marketplace will be more open to going beyond this initial hurdle, namely the purchase price, when deciding on a vehicle.

From this it becomes evident that for an EV to remove the ‘sticker shock’, significant improvements in component and build costs need to be experienced. As will be shown in section 5.4, if a consumer is able to move past the initial purchase price, they will realize a superior operational cost of the vehicle. This offsets the initial purchase price of an EV, resulting in the net total cost of ownership over the lifetime of a vehicle being lower than an ICE vehicle. However, as it stands today, an EV is not in parity with the ICE when it comes to acquisition cost. Strategic marketing and consumer education pertaining to the other benefits of an EV need to be emphasized if mass adoption is to be achieved.

5.4 Vehicle Operational Cost

There are several cost variables that make up the ‘operating costs of ownership’ of a vehicle. The list below may not comprise all of the costs associated with maintaining and operating a vehicle however, these are regarded as some of the core variables making up this cost.

5.4.1 Maintenance and repairs

As stated, there are significantly fewer moving parts in an EV than in an ICE vehicle, roughly 75% less, which in most cases are frictionless. The law of probability reasons that the overall cost and time spent in maintaining an EV will be lower as there are fewer moving parts, therefore

possibilities, of mechanical problems existing. Repairs are subjective and can vary depending on the severity of the incident, therefore non-comparable. Overall, it was calculated, that EVs are around 45% less expensive to maintain than ICE vehicles [10].

The most significant problem for EV adoption is the mind-set of the consumer. Harris Interactive measured that 55% of autoists were wary of maintenance and repair costs associated with an EV. To a large degree this is primarily based out of not knowing the facts about operating an EV. Surveys conducted by the author further showed that in many cases, consumers were unaware of the fact an EV did not even require an oil change. Something as simple as questioning where the engine was or how often the oil had to be replaced were asked approximately 79% of the time. EV manufacturers have a long way to go to educate the nearly one billion autoists currently operating vehicles across the globe.

5.4.2 Fuel Expense

The fuel savings experienced by an EV autoist have been extensively covered in a vast number of reports and studies. To summarize, comparing similarly priced and built EVs to two equivalent ICE vehicles, using annual VMT, fuel efficiency and a gasoline price of \$3. It was calculated that on average a household could save approximately \$1750 to \$2500 annually [13] [14]. This is approximately an 81% reduction in the fuel cost of operating the vehicle. Given that long distance trips could be done on the supercharger network which is free, this becomes even more advantageous.

The 'buy local' symbolic gesture is common practice when fuelling an EV with electricity. Every watt that is directed into the vehicle was generated in the country the autoist resides in, and in most cases made locally. Using the USA and Tesla Motors as an example, the Tesla Model S is both made in America and fuelled by 100% American made electricity. There are currently no ICE vehicles that can claim this accolade.

5.4.3 Insurance Expense

As stated earlier in this paper, in most countries around the globe this is a financial expense that is required by law. No vehicle operated on the road can be driven without adequate insurance coverage. It is for this reason, insurance is

completely overlooked by an autoist as it is a fixed expense no matter the vehicle they drive. Further research showed, that this is currently the case for EVs where the cost of adequate insurance coverage for an EV is on par with an equivalent ICE vehicle.

5.4.4 Opportunity Cost of ownership

One of the most ignored costs is the value of time spent by the autoist when refuelling a vehicle. The primary reason being it is measured in utility before it is quantified, which makes it complex and very subjective when accounting for it. Using a simplistic approach to valuing time based upon wages earned, the following can be inferred.

Assuming the autoist stops at a gas station to refuel 82 times per year accounting for an average total of 1230 minutes (410 minutes fuelling + 820 minutes driving time to station – see table 3 above). In many cases, these fill-ups are last minute affairs spent either on route to or from home, work or another task. This averages out to around 15 hours a year that is used to simply safeguard sufficient mobilization of the household.

When reviewing an EV in the same context, the majority of 'filling up' is done at home with no real engagement by the autoist, the vehicle is simply plugged in when home. The following morning, the autoist has a full charge – 100% range – to start the day with no fear of needing to head to a refuelling point. Given top-ups are generally done when available at a locality that has sufficient infrastructure, these do not constitute any additional time allocated by the autoist to complete this recharge. The only time an EV autoist will likely experience opportunity cost, therefore disutility, is when they frequent a supercharging station. It was calculated, in table 4, that an EV autoist will stop at a supercharger around 15 times per year for a total of 450 minutes (if stopping for a 30 minute charge).

Comparing the time used to refuel an ICE vehicle and EV it shows that the ratio of disutility experienced by an ICE autoist compared to an EV autoist is almost 3:1 ratio. Given that the average household income in the US is \$51,939 per year [16]. We can infer that the value of an hour is ~\$25. Using the logic of one labour hour equating to one util (a measure of utility) we can calculate the total disutility experienced, therefore opportunity cost of refuelling their ICE vehicle, is an additional \$513 per year. There are a vast

number of other factors that could be accounted for to achieve a more accurate value of disutility. The exercise above is a theoretical method of measuring the value of time, therefore cost of life, experienced by a human in ensuring they can mobilize themselves.

The fundamental message that should be taken from this exercise is that to operate an ICE vehicle refuelling must be done to ensure mobility. Even an ICE vehicle that is driven infrequently will at some point have to be refuelled at an offsite location. When operating an EV it is very possible to drive without ever having to experience any disutility at all if 100% of the driving done by the autoist is less than 200 miles daily. On average, at least once per week, an ICE vehicle will result in a certain amount of disutility being experienced, whereas at the worst case scenario, an EV autoist will experience this once per month and in many cases, never at all.

When finally assessing the total cost of ownership, it is evident that an EV is superior to that of an ICE vehicle. Surveys found that 44% of the consumers would choose an EV if, and only if, the lower operating cost would not change their driving habits or expectations [3]. A substitution effect in demand for an EV will emerge if it realises the following:

- 200+ mile range,
- access to a fast charging infrastructure within 100 miles from their departure,
- fast chargers offer a charge of at least 150 miles within 30 minutes
- The depot charging station offering multiple connection points of accessibility

Given these attributes, range anxiety will be removed from the thought process of autoists. It is expected that an EV is superior to an ICE vehicle in the cost of operating the vehicle if the above are satisfied.

6 Econometric Analysis of Demand

An empirical assessment of the elasticity and substitutability in demand for fuel, namely gasoline, was undertaken to gain insight into the decision making process of an autoist. Historical transportation, energy, macroeconomic and alternative vehicle time series data were used to

simulate models estimating the change in gasoline demand.

An uncompensated demand function was stipulated to estimate the change in demand for gasoline given changes in the determinants and propensity to drive an additional mile. The following functional form was specified:

$$\text{Gasoline Demand} = GD(V_t, O_t, VMT_t, MPG_t, E_t, PCE_t, DI_t) \quad (1)$$

Where GD was Gas demand, V the number of vehicles in use, O is the operating cost per mile, VMT is Vehicle Miles Travelled, MPG is the miles per gallon (efficiency), E is the number of households employed, PCE the Personal Consumption Expenditure of Households and DI the Disposable Income and where t indicates values over time t.

The Explanatory Variables to be assessed:

- Cost of Ownership: Energy prices and operating cost per mile
- Expenditure Effect: Total income, disposable income and PCE
- Usage: Vehicle miles driven, age of vehicles, and total number of registered vehicles
- Efficiency: Miles per gallon (MPG)

Ordinary Least Square (OLS) Linear Regression models with Robust Standard Errors were used with the following linear regression specification:

$$\text{Gas Demand} = \alpha + \beta_1 \text{Opt. Cost} + \beta_2 \text{Efficiency} + \beta_3 \text{Usage} + \beta_4 \text{Income} + \epsilon \quad (2)$$

In all four models the change in disposable income and median age of vehicles were significant at the 5% level. PCE was significant at the 10% level with all other variables being statistically significant at the 1% level. The data and models were estimated to all be a good fit with R-squared values above 0.63 and a D-stats' calculated to satisfy the presence of no autocorrelation between the variables.

6.1 Empirical Results

Model one, estimated the changes in gasoline prices, vehicles in use, VMT and MPG. *A priori* signs on the coefficients for gasoline prices and MPG were in line with the models results. It was

shown that a \$1.00 increase in the price of a gallon of gasoline would yield a 0.05% decrease in the demand and consumption of gasoline. This validates the expected high price inelasticity of demand. MPG showed that a 1 MPG increase in the efficiency of a vehicle would result in a decrease in gasoline consumed of 0.9%. This clearly indicates how significant the role of vehicle efficiency is in regard to the consumption of gasoline.

Model two regressed the variables of gasoline price, VMT, MPG % change, PCE and Median Age of Vehicle on the change in gasoline demand. Gasoline price inelasticity is expressed in this model where a \$1 increase in gas prices would result in a 0.05% decrease in gasoline consumed; the coefficient's sign was also in line with *a priori* expectations. The VMT coefficient showed that an increase of 1 million VMT resulted in a 0.013% decrease in gasoline consumed. Reasoning for this decrease was that the majority of additional miles driven were freeway miles. This would imply that, on average, VMT on highways would reach higher levels of efficiency (MPG). The result shows diminishing marginal consumption in gasoline as VMT increase. A 1% increase in MPG would result in a 0.27% decline in gasoline consumed, a rather significant decrease in consumption for a modest increase in vehicle efficiency. PCE along with the median age of a vehicle showed to positively affect the consumption of gasoline. A \$1,000 (per household) decrease in PCE would result in 0.00258% decrease in gasoline consumption. Therefore an almost 2% decrease in income would result in 0.2% decrease in gasoline purchased. This validates the high income inelasticity of demand for gasoline. A 1 year increase in the age of a car resulted in a 2.3% increase in gasoline consumption. The age of a vehicle plays a pivotal role in gasoline demand as it is reasoned the older a car the more inefficient it would tend to be.

Model three estimated the effect a % change in number of non-ICE vehicles in market and the % change in operating cost per mile would have on gasoline demand. Due to limited data being available of non-ICE vehicles, only 12 years of observations were utilized and all non-ice vehicle types were included. Both signs of the coefficients in question were in line with *a priori* expectations. It was shown that a 1% increase in non-ICE vehicles entering the vehicle fleet would

decrease gasoline consumption by 0.043%, further bolstering the case for the electrification of transportation. It is important to note that at the time of this study, a portion of non-ICE vehicle fleet included biofuel, plug-in hybrid EVs and other non-pure electric vehicle types. Even though this statistic is not a unit elastic change in demand, mass adoption of pure EVs could drastically intensify the impact. Operating cost per mile was assumed to possibly suffer from endogeneity due to gasoline costs being incorporated in the variable. It was shown however, that a 1% increase in operating costs would result in an increase in gasoline consumed of 0.23%. This result further validates the significant role gasoline plays in the operating cost of an ICE.

The fourth model was a modification of regression model one, now incorporating the number of licensed drivers and the change in disposable income of adults in the US. VMT were adjusted for a one period lag on the data set. This was to assess whether there was a delay in the demand for gasoline as the number of miles driven changed. A change in MPG and gasoline prices were used to determine the effectiveness of these variables in an alternate model specification. The gasoline price coefficient was relatively unchanged from models 1 and 3. A \$1 increase led to a 0.04% decline in gasoline consumed. A 1% increase in MPG was estimated to result in a 0.29% decrease in gasoline demand, very similar to the estimated results in model 2. The lagged effect on VMT, resulted in a decrease in gasoline consumed as VMT increased. This result, even though significant, needs further attention as it could possibly suffer from multicollinearity or a severe case of endogeneity with the dependant variable. An increase of 1,000,000 drivers would increase demand for gasoline by 0.0279%. It was also estimated that a 1% increase in disposable income would lead to a 0.53% increase in gasoline demand, which is in line with economic theory. As disposable incomes rise so will the propensity to drive, positively affecting the demand for gasoline as shown in the model.

Both the OLS regression and the theoretical models are externally valid across all non-ICE technologies. In each case, models were constructed using sound economic judgment and theory. It would be impractical to include every variable as this would essentially lead to biased estimators. The best possible models and variables

were specified and estimated to give the results above.

7 Concluding Remarks

The following theoretical and empirical study into the demand determinants of an automobile (and fuel) validated the requirements *expected* by a consumer before it is chosen. To summarize a few of the socioeconomic benefits derived by operating an EV, beyond the well-known environmental and economic benefits, would be the following:

- Full available driving spectrum every day at departure.
- Minimal, or in some instances, no opportunity cost suffered by an EV autoist due to no primary offsite charging required.
- Significantly low cost of ownership and refueling if less than 200 miles driven daily
- Almost non-existent cost of maintenance due to lower probability of a problem existing
- Fuel is 100% locally produced resulting in stable supply and pricing as well as a degree of patriotic symbolism

When further assessing the empirical findings it was found in the third regression, giving options that are non-ICE vehicles, consumers are willing to make the switch. This was also expressed in models 1, 2 and 4 where the level of efficiency comprehensively affected the demand for gasoline.

Further assessment of demand showed that present day EVs satiate all but one of the determinants required. It is equivalent, and in the case of the Tesla Model S, superior, in performance, functionality and safety. It is superior in just about every aspect in the cost of operating the vehicle. The only determinant that was not met satisfactorily was the initial acquisition cost. However, when combining both determinants 3 and 4 to derive a 'total cost of ownership' it is shown that an EV will over the life of the vehicle yield a lower cost. Given the early stages of economies of scale in the production processes of EVs, it is expected that the acquisition price will decrease overtime. It is envisioned, at the time of this study, that the year 2020 will be an inflection point for the purchase

price of an EV. Given the models entering the market at favourable price points and saturation of the fast charging network, both *actual* and *expected* consumer needs will be met.

Realising that mobility is a prerequisite to the fundamental wellbeing of a household as per the adaptation of Maslow's Pyramid. Acknowledging the growth in the global vehicle fleet as developing nation's populations improve their standard of living. Further emphasizes the absolute requirement that a new sustainable form of mobility is required. At present, EV technology capable of a driving spectrum greater than 200 miles and access to a fast charging network to satiate the total *expected* needs, is already available. The final hurdle facing the complete transformation of the vehicle fleet is bringing both manufacturing and consumer confidence of the EV in line with current market expectations.

Early adopters have paved the way to allow these technologies to emerge and solidify themselves as viable forms of mobility. Achieving mass appeal through the alignment of an autoists' *expected* and *actual* mobility requirements will allow for the complete normalization of electric transportation and mass adoption.

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