Team Control Number

10147

Problem Chosen

A

2019

HiMCM

Summary Sheet

0.1 Summary

To answer the question of money flowing out of businesses due to charging, we developed an analytical model using Newtonian physics and basic applications of math, as well as analytical statistics to back up our claims. We split our model into two scenarios: one for electric vehicle charging, and another for mobile device charging. In our electric vehicle model, we analyzed the economic advantages and disadvantages of different types of electric vehicles. We concluded that type one chargers are much more cost efficient for businesses but are less convenient than type 2 or type 3 chargers. For our mobile device chargers, we analyzed the cost of charging of any given day for a company with a 24 hour schedule. The 24 hour schedule was to maximize the cost of charging of mobile devices. We concluded that even with these extreme conditions and perpetual use of chargers, the cost of using these chargers is negligible compared to the other costs of operations for the business. Using the results of these scenarios, we developed an economic model for the impact of increased demand of charging outlets and the possible implications of this increase in costs to business, specifically using the time value of money. Overall, the cost of changing the way that businesses are regulating chargers right now is much greater than the amount saved from changing the current methods, and therefore would be inadvisable to most businesses.

0.2 Article

"Free" Electricity: The Hidden Costs of Charging in Public Areas

Imagine walking into your local coffee shop. The scent of coffee is fresh in the air as you walk in, the tiny golden bell jingles as you gently close the door. At every table around you, people have their laptops plugged into an outlet and are typing away furiously on a document or being mesmerized by the computer screen. Get used to it, because this phenomenon is becoming drastically more prevalent in today's society. People probably don't think about it, but the electricity that is used when you plug in your mobile device to the seemingly free outlet costs the business. Our team has extensively researched what economic effects this common occurrence has had on businesses and have developed models to help better understand these costs.

To begin with, we developed several models for different electronic goods to better estimate the costs of "free" public charging: One for electric vehicles, and one for mobile devices. From our electric vehicle model, we concluded that there is a trade-off between business costs and customer satisfaction, and it would be beneficial for business to switch from type 2 charging stations, which are the most prevalent type of charging station, to type 1 charging stations because we calculated that it would take less than half a year to reimburse the initial investment.

In addition, we deduced from our calculations that the best way for businesses to reduce their cost of providing "free" electricity to the public is to decrease the number of outlets inside public facilities because decreasing the number of outlets results in a decrease in the cost of outlets in a day. These costs are likely to be negligible compared to the company's electric bill for daily operations.

In summary, we recommend that businesses do not worry too much about the cost of charging caused by mobile devices. It is not these costs that are causing big troubles for businesses. Businesses should therefore focus on more important costly matters and make sure that they do not lose valuable customers and money. More important than charging costs is the cost of things such as keeping the lights on in a store, which uses up more than 3000 kilowatt hours.

Contents

Chapter 1

Introduction

1.1 Problem

As society progresses, people use electronics every day wherever they go. As we all know, it is necessary to charge our electronics in order for them to function. Usually, people charge their electronics at home through an outlet and then pay an electrical bill to the company that provides their electricity. However, the vast majority of people have to spend time away from their homes due to various circumstances, so they would need to charge their electronics in areas away from home such as in public places. This is where electrical outlets, charging stations, and electric vehicle charging stations come into play, which are some of the most prevalent, non-domestic means of charging. While many of these methods require no payment from the consumer, nothing in life is free. Someone or something needs to pay for this ”free” electricity and oftentimes, it is the individuals and businesses that supply this system that faces its consequences. Nevertheless, even though it creates an additional economic burden on businesses, it is almost expected in today’s society to provide customers with this basic commodity.

1.2 Background information and Prefatory Discussions

Electricity plays an immense role in how our society functions and communicates today. As a reliable source of clean energy and safe light, electricity allows us to ”plug in” to our electronic devices every single day, enabling us to communicate with billions of people around the globe with only a few taps. According to a study performed by the International Energy Agency (IEA) in 2018, less than 12% of the world population did not have access to electricity, which illustrates that electricity has become a widespread commodity in our society. Moreover, further technological innovations have only increased the already skyrocketing worldwide demands for electrical energy.

For many individuals today, it can be mind-boggling that only a few centuries ago, the power of electricity was unknown to human kind, and to the people of the past, it is practically unimaginable how drastically this simple concept has altered our society.

1.2.1 Recent Changes in Consumption and Demand for Electricity

Over the recent years, the world consumption of electricity has generally been rising every year according to data gathered by the World Bank that is displayed in **Figure 1.1**. An important

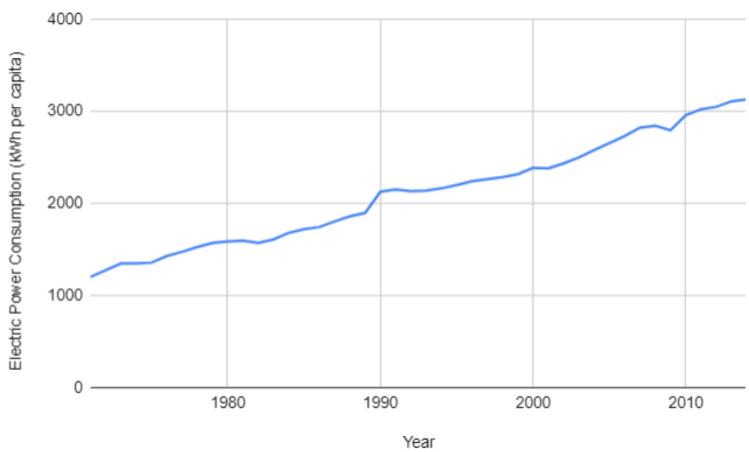

Figure 1.1: World Electric Power Consumption from 1978 to 2019

fluctuation shown by the graph is the subtle spike in electric power consumption per capita around 1989; this was due to the World Wide Web being invented by Tim Berners-Lee, a British scientist at CERN. In addition, another important fluctuation displayed by the graph is the sudden decrease in electric power consumption per capita around the late 2000s, which could be attributed to the global financial crisis of 2007-2008 or the subprime mortgage crisis, which was triggered by the collapse of the US housing bubble and later the US real estate market. A common misconception among the general public could be the belief that there is an exponential relationship between worldwide electric power consumption per capita and the year due to the recent and annual increases in technological innovations. However, a crucial component in technological innovations is that the energy efficiencies of these new devices are getting better every year, and it is essentially the defining factor of why the relationship between electricity consumption per capita and the year is linear.

On the other hand, we believe that in the future, this relationship will not last forever. According to the second law of thermodynamics, every energy conversion results in a loss of energy to the environment in the form of low quality waste-heat. Therefore, the energy efficiencies of our electrically-powered goods can theoretically approach but can never reach or exceed 100% efficiency. Thus, the rate of our improvements in energy efficiencies of electrically-powered goods will decrease as time passes and eventually begin to plateau at a percentage extremely close to 100%. However, the demands for electricity will continue to skyrocket as our society becomes more and more dependent on electricity, and the slowing improvements in efficiency will not have as large of an effect as they once did. As a result, the relationship illustrated in **Figure 1.1** will begin to resemble an exponential function, which indicates that the derivative of the curve will become dependent on the year since the year is the response variable.

In addition, the recent growth of the electric car industry is an important variable that has immensely impacted the consumption of electricity Since 2011, over one-million electric vehicles (EVs) have been sold, but the number of EV charging ports barely numbers in the thousands, according to study done by the US Department of Energy.

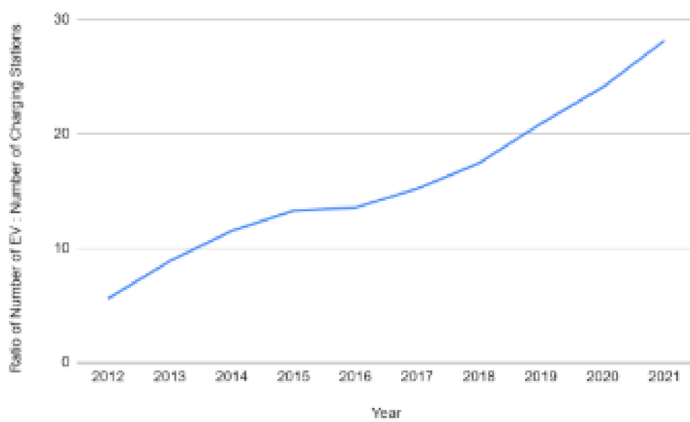

Figure 1.2: shows and predicts the ratio of the number of EVs sold to the number of charging stations in the US

Figure 1.2 is a prime example of how the demand for electrical energy is increasing; the number of EVs being sold is skyrocketing compared to the number of charging stations being installed. The recent increase in demand for charging stations has had many macroeconomic effects that will be discussed later in this chapter.

Furthermore, the population of the world has to be taken into consideration because the electric power consumption in **Figure 1.1** is expressed in kWh per person.

According to **Figure 1.3**, it is evident that in the majority of the projections, the human population will eventually begin to plateau at a certain point, most likely at the carrying capacity of the Earth, which scientists have not found a definite estimate for. Nevertheless, whenever the human population begins to plateau, this may compensate for the decrease in the rate of improvements of energy efficiency, and may eventually decrease the derivative of the world consumption of electricity

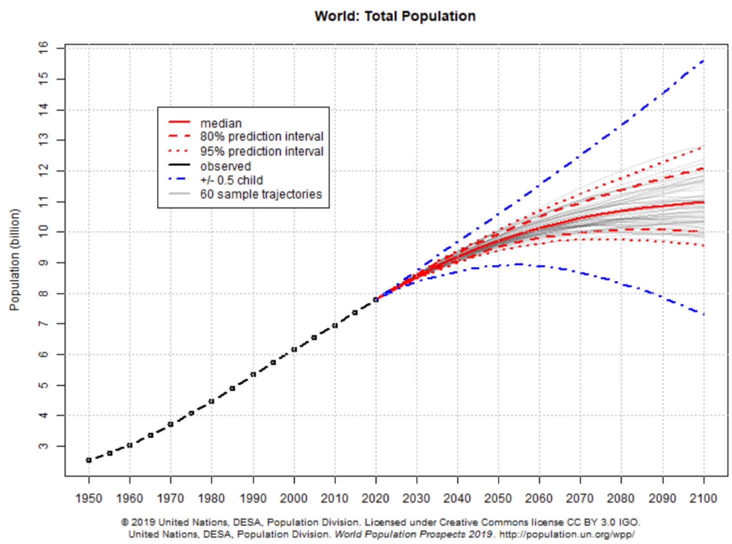

Figure 1.3: shows the projected human population according to the UN DESA

vs. time graph. To sum it all up, we predict that the total electric power consumption in the world per year will continue to increase in the future, but the linear relationship in **Figure 1.1** will change in the future depending on what variables are changed.

1.2.2 Impacts and Requirements of Businesses

To begin with, the drastically increasing consumption of electricity as well as the growing demands for electrical energy has created an assumption in our society that the vast majority of businesses should provide free energy for customers and the general public to use. As a result, it is possible that some businesses, especially small businesses, may view this belief as an extra burden to not only provide electricity for their facilities, but also for their customers who wish to charge their devices inside stores. They may do this in fear of losing these customers who believe that businesses are required to provide free electricity for their customers. However, this presumption has drastically altered the marketing strategies of different businesses. Specifically, these businesses have created an incentive for customers to charge their devices in stores, which increases the probability that a person entering a store will purchase a good. For instance, in the average Starbucks in the US, there are numerous chairs, tables, and outlets that essentially encourages customers to charge their electronic devices as they relax, which increases the probability that a new customer will purchase something and maybe become a regular customer. This marketing technique may be a key factor that has made Starbucks such a successful business.

In addition, the recent increases in the demand and consumption of electricity has increased the public pressure on businesses to receive their electricity from renewable sources of energy such as solar panels and windmills. Today, the majority of electricity is produced by the combustion of nonrenewable fossil fuels, such as coal, oil, and natural gas. When burned, fossil fuels can release toxic pollutants as well as greenhouse gases that contribute to global warming. However, over the past decade, the environmental movement has been picking up speed and support, and a growing percentage of the public is realizing that the ways in which we derive our electricity from are not sustainable and are detrimental to the health of the planet. They are also recognizing that electricity consumption is increasing and the demand is growing, and are urging businesses to retrieve their electricity by environmentally friendly means.

1.3 Initial Assumptions and Justifications

We first made some general assumptions that would make our model more simple and practical.

1. Energy gain while charging and energy loss while using for each device changes negligibly during the time in which the person is charging. Due to the longevity of a business, in the long run, small to medium fluctuations (which is the vast majority of the case when considering energy gain or loss while charging or using) will average out to a certain value; we will try to develop models to find the value.

2. The battery health of each device is negligible. It is impractical to estimate the average battery health of each device, and it has little to no impact on the overall cost.

3. Damage done to outlets or batteries while charging is negligible. This assumption comes down to the fact that the only way a battery or outlet could be damaged is through improper voltage or current going through to the devices. We are assuming that damages done to these objects are so infrequent that it will not affect the cost of charging in any major way.

Chapter 2

Analytical Models

2.1 Overview

We will be using an analytical model when considering the effects of the increased demand for charging devices, we split the different types of energy consumption into two categories:

1. Electric Vehicles
2. Phones, Laptops, iPads, and other devices that a person carries into public places. We will refer to these devices mobile devices for the rest of the paper.

The reason for this is that electric vehicles have a much larger battery capacity and a higher power of charge compared to mobile devices. In fact, the power of charge can be higher up to a factor of 1000. In addition, the models are slightly different because for electric cars, the charging places are always sedentary and don't move around. However, most of the time mobile devices require the holder to bring a charger with them in order to use the outlets in public places.

2.2 Electric Vehicles (EVs)

First of all, we will be considering the bigger device and model electric vehicles. EV charging stations are either located at home or in public places. Since we're only considering the cost of using public charging stations, the EV charging stations used at home will be ignored in this model. Public charging stations are typically located in public on-street facilities and built by electrical companies. They can also be located at restaurants, shopping centers, and parking places. As demand for EVs increase, these private companies need to be able to account for the costs associated with the charging stations. This analytical model will try to accomplish that by defining variables and writing equations in terms of those variables. Later on, the economic model for electric cars will address a more quantitative model for the costs associated with electric vehicles.

2.2.1 Assumptions:

1. Electric cars will start charging at around 15 percent. We are making this assumption because cars typically will notify the driven when the car reaches a battery of 15 percent. As a result, we can assume that the user only needs to charge 85 percent of the car's battery capacity measured in kilowatt-hours.

2. The availability of these charging stations would be across the entire day. In other words, the charging stations will be assumed to always be used. This is due to the fact that according to our introduction, there is a projected increase in demand for electric vehicles. As demand increases, the more charging stations that will be demanded by consumers. As stated in the problem, our model needs to model the increased demands for public charging places, so we account for that by saying that all charging stations are occupied at all times.

2.2.2 Types of Plugs:

For charging electric vehicles, there are different types of plugs that output various currents and voltages. These various currents and voltages result in varying power outputs, which allow the consumer to have a variety of options for charging. Each type of plug would also have varying costs for businesses. For the case of our model, there are 3 types of charging plugs:

1. Type 1: This type of charging uses 120V AC current. This is the equivalent of charging your electric car using the power supplied by a standard 120V outlet inside a house. This type of charging is the least common among the three types in public places. Since the power of charge is so low, the time that it takes to finish charging would be high. This type is the least expensive to install for businesses.

2. Type 2: This type of charging uses 240V AC current. The two most common types include one with 16A and one with 30A of current. The two most common power supplies are 3.3kW and 7.2kW. Type 2 is the most common and popular among public places. Compared to type 1 charging stations, the cost for installing the station is greater, but the time it takes to complete charging a car would be shorter.

3. Type 3: This type of charging uses 480V DC current. This form of charging is also called DC fast charging. The current supplied by the charging station varies depending on the private company responsible for installing the station. This type of charging is by far the most expensive and quickest to get to full charge. For businesses, this is the most expensive form of EV charging. In fact, some cars aren't able to handle type 3 charging or don't have the ability to connect via DC charging.

2.2.3 Variables:

These variables are variables that will be used when addressing electric vehicles. The purpose of these variables is to organize the information relevant for the cost of public EV charging stations.

1. d: The current average size of electric vehicle batteries that are measured in joules. As shown in chapter 1 of our paper, the prevalence of EVs and the demand for electricity to charge is increasing over time. Therefore, keep in mind that this variable is assumed to be a certain value for now, but will change and affect costs for businesses in the future.

2. P_1: The power of charge from a type 1 charging station.

3. P_2: The power of charge from a type 2 charging station.

4. P_3: The power of charge from a type 3 charging station, or DC fast charging.

5. c: Cost per kilowatt-hour of battery used. This value varies depending on the location of the place of charge. For example, Louisiana has a cost per kWh of 8 cents whereas Massachusetts has a cost per kWh of 22 cents.

6. C_1: Cost to install one type 1 charging station.

7. C_2: Cost to install one type 2 charging station.

8. C_3: Cost to install one type 3 charging station.

2.3 Mobile Devices

Mobile Devices are the next type of electronics that we will be considering. Many times, people will need to charge their phones in places such as the airport and a coffee shop. As electricity demand increases, businesses need to be able to provide outlets in order to attract customers and stay in business. By modeling how people may act in public places, businesses can estimate how much they need to charge consumers based on the demand for charging. We will now try to model the power consumption of charging each device. When making this model, we made reasonable assumptions to make the model less clogged up and more easily understandable.

2.3.1 Variables

- m: The maximum capacity of a mobile device; this is measured in milli-amp hours, a measure of charge.
- P_a: Power lost while using device; measured in joules per second, or watts
- P_c: Power gained by charging device; measured in watts
- P_p: Power lost without the user performing any action, such as calling or texting, on a device; measured in watts
- t_o: The total time someone spends with their device in a day; this changes depending on the location and industry of the venue in question and is measure in hours. For public places, this value would be equal to the amount of time the business providing the outlets are open for in a day.
- ΔC: The percent change from full charge at which a person starts charging his or her mobile device; this changes from person to person and is measured as a percentage (i.e. If a person only charges their phone once it reaches 30% charge, their ΔC would be 70%)
- V_{cell}: This is the voltage of the battery cell. for lithium ion batteries, this value is 4.2 volts.

2.3.2 Assumptions

1. P_p, the power a handheld electronic device uses passively, or while the phone isn't doing anything, is negligible. The reason for this is that the passive power used is so small compared to P_a and P_c that leaving off the passive power does not change the outcome of the model in any way.
2. the outlets at each location where the electronic devices are being charged are all occupied at any point. This assumption is made because in most places, such as coffee shops and airports, there are more people than charging stations, which means that most of the time, more chargers are being used than there are people. As it is impossible to model the number of outlets at each location where this model is applicable, we will leave that as a variable for the individual companies to change.

3. P_a is constant for any mobile device. This assumption is made because it is almost impossible to determine a function for the amount of power a mobile device uses, because there are so many things that a mobile device can be using that it would be impractical to assume otherwise. In reality, P_a will vary for each device.

4. Battery use within any device within a category is the same when normalized to battery efficiency. For example, an iPhone 8 and a Samsung Galaxy S8 will perform the same when normalized under the maximum battery capacity.

2.3.3 Period

Now we will begin the model by finding the bounds of the period of each charging cycle. Charging cycle is the time it takes for a phone to use up energy equal to $m\Delta CV_{cell}$ and then to charge it back up.$m\Delta CV_{cell}$ is the point at which a person will start charging because that is when the battery percentage is at the point where this person will charge the phone. At the point at which a person with the mobile device reaches $m\Delta CV_{cell}$, they will do one of two things: charge their phones without using the phone, or charge their phones while using it at the same time. Now we will define 3 new variables:

- t_a: the time, in hours, it takes for a person to use up $m\Delta C$ amount of energy
- t_b: the time, in hours, it takes for a device to charge back up to full from its charge value if the owner of the device is also using the phone at the same time
- t_c: the time, in hours, it takes for a device to charge back up to full from its charge value if the owner is not charging the device.
- E_{tot}: the total amount of energy used in a given period of time. This is measured in joules.

We can set up bounds for our period T, which is the amount of time needed for a cycle of a phone losing battery, and then gaining full battery while charging. Here, we are utilizing our assumption that a person will charge to full before taking out, given that he or she has enough time to charge to full. In our worst case scenario for the amount of time taken for full charge, the person will be using the mobile device while charging the entire time. T will then be

$$t_a + t_b.$$

However, the best case scenario will be when the person in question does not use the mobile device while it is charging. T will then be

$$t_a + t_c.$$

This creates a bound for T, in all it's simplicity:

$$t_a + t_b > T > t_a + t_c.$$

Now that we established a bound for T, we will now try to make t_a, t_b, and t_c a more relatable idea.

$$m\Delta CV_{cell} = t_a P_a.$$

This equation, seemingly simple, has a lot of implications. The most important part of this is that we can relate $m\Delta CV_{cell}$ with time and power, which will be important later when we relate the different times and powers.

Similarly, $m\Delta CV_{cell} = t_b(P_c - P_a)$ and $m\Delta CV_{cell} = t_c P_c$.

We can set all of these equal to each other to cancel out the $m\Delta CV_{cell}$:

$$t_b(P_c - P_a) = t_c P_c$$

$$t_b(P_c - P_a) = t_a P_a$$

$$t_c P_c = t_a P_a$$

Assuming that P_c and P_a are constants, we now have 3 equations and 3 variables. However, as we will go over soon, P_c is not constant; P_a, however, can be seen as constant on an individual basis. The extra degree of freedom can be taken into account by using our bounds for T. We will try to normalize the variables to a single variable, t_a.

$$t_b(P_c - P_a) = t_a P_a \Longrightarrow t_b = \frac{P_a}{P_c - P_a} t_a$$

$$t_c P_c = t_a P_a \Longrightarrow t_c = \frac{P_a}{P_c} t_a$$

Combining these new values of t_b and t_c, we get:

$$\frac{P_a}{P_c - P_a} t_a + t_a > T > ta + \frac{P_a}{P_c} t_a$$

gathering all the variables into one denominator,

$$\frac{P_c}{P_c - P_a} t_a > T > \frac{P_c + P_a}{P_c} t_a$$

. However, we don't want t_a, we want our bounds to have less variables. To solve this problem, we will now look back at one of our assumptions: at any given point, all outlets are being used. This assumption is basically stating that $t_a P_a \frac{t_o}{T}$ is the total energy being used in a given day. We can now plug these values in for our lower and upper bounds of T:

$$t_a P_a \frac{t_o}{T} = t_a P_a \frac{t_o}{\frac{P_c}{P_c - Pa} t_a} \implies \frac{t_o P_a P_c - t_o P_a^2}{P_c}$$

$$t_a P_a \frac{t_o}{T} = t_a P_a \frac{t_o}{\frac{P_c + P_a}{P_c} t_a} \implies \frac{t_o P_a P_c}{P_a + P_c}$$

This is just plugging in our upper and lower bounds for T into our equation for the total energy being used. Now we have the upper and lower bounds for the total energy used in a given day in terms of P_a and P_c; we just need to find models for P_a and P_c.

2.3.4 P_a

P_a was defined before as the power that users of mobile devices use to use up ΔC battery level. This is entirely measurable by experimental data. To do this, we gathered a variety of phones with known maximum battery capacity and normalized this capacity as a function of the energy that was spent. Our results gave us a clear linear relationship between time spent using device and energy expended, as seen in figure 2.1. From this data, we fit a least square regression line,

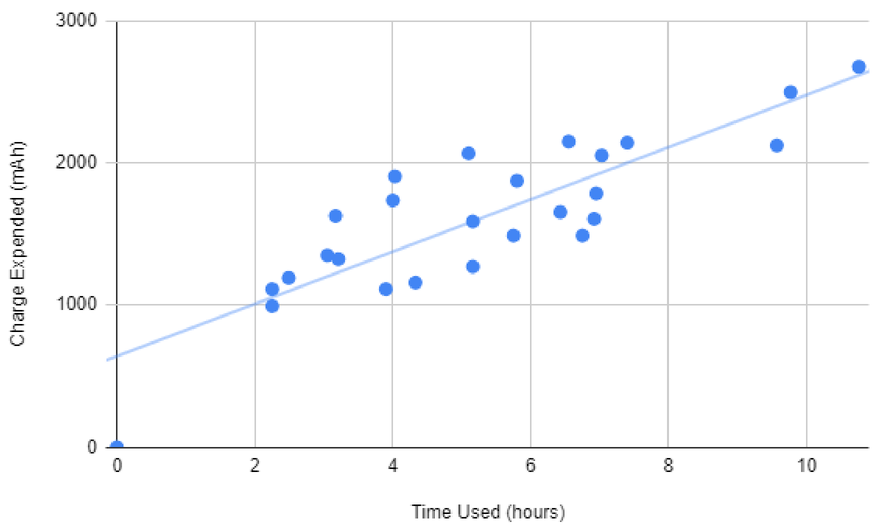

Figure 2.1: Charge Expended as a Function of Time

with an R^2 value of . Showing a moderate linear relationship between time and Energy expended, we can now find the power as a function of time through a simple slope of the graph. The only drawback to this model is that there is potential for a lot of extrapolation, which limits our data to the time frame seen in figure 2.1.

This linear relationship between time and Energy expended proves a constant P_a, one we can plug into the equation to find the bounds of T. This is a specific bound for phones, and does not apply to any other mobile device. Similar measurements can be made for other mobile devices with the same results to determine the model.

2.4 P_c

P_c is defined as the amount of power gained by charging a mobile device. None of our assumptions, however, assumed that P_c was constant over any period of time. However, because of one of our assumptions that a person will charge to full if they have the time, we can find the average amount of power needed to charge a mobile device up to 100% and assign this value to P_c. The fact that P_c is not constant does not matter for our model, as we do not need instantaneous values of P_c, but rather an average value.

2.5 Data Collection

In order to find the values of P_c and P_a for phones and laptops, we used real life data by taking a small sample of devices and measuring their charge consumption.

2.5.1 Phones

We calculated the power gain of phones while charging and their power loss while being used through the battery page in the phone settings. We recorded our percentage-wise charge consumption $\%U$ and usage time t_U in terms of hours everyday for a week, and normalized the charge using the formula

$$C_C = \%U Q_B m$$

Where Q_B is the percentage of current battery capacity relative to when it was new, given in the battery page in the settings. m is the max intended capacity of the device in mAh, found through research about each type of phone model, and C_C is the normalized charge consumption, also measured in mAh. We then graphed C_C in a scatter plot against t_U and obtained the graph in Figure 2.1 We found that the least squares regression line between the two variables was

$$C_C = 182.46 t_U + 642.31$$

with a correlation coefficient of .847, which indicates a strong relationship. The slope of the least squares regression line, 182.46, tells us that for each extra hour someone uses their phone, about 182.46 extra mA is consumed, or .18246 amperes. We then multiplied that by the nominal voltage of lithium-ion batteries which is 3.7V to obtain our value of P_a for phones: .675 Watts.

The P_c is found by multiplying the amperage of phone chargers: 1 amp by 3.7V, which gives us 3.7 Watts as the P_C for phones.

2.5.2 Laptops

The process of finding the P_a for laptops was a much easier task. We used windows power shell to generate a battery usage report that included the intended energy capacity of each device in mWh and estimated battery life in hours. We divided the energy capacity for each of the devices by the battery life to approximate the energy consumption per hour for laptops. We averaged all of the laptops' energy consumption to find 7.2 Watts as the value of P_a for laptops.

To find P_c, we used 19V as the standard voltage of laptop batteries, and multiplied it by an average amperage of the laptops which is 2.32 amps to obtain our value of P_c for laptops of 44.08 Watts.

2.6 Cost of Charging

Now, to combine the 3 models in this section, we will refer back to the bounds of the energy used in any given day.

Our upper bound is $\frac{t_o P_a P_c - t_o P_a^2}{P_c}$, where t_o is the number of hours a business is open for. which we assume to be a constant, we can plug these values in to find the total energy spent at 1 outlet in a given day. Then, we multiply by the cost of electrical energy, which we assume to be 11 cents per kilowatt hour. Finally, we multiply by the number of outlets, and make sure our units are in terms of kilowatts and hours. So the max costs to provide charging for a business day at each outlet is about 6.07 cents times the number of business hours for phones, and 66.26 cents times the number of business hours for laptops, both relatively inexpensive.

2.7 Strengths of our Models

The strengths we have in this model to determine the cost of energy expended while charging is that it all simplifies into 2 variables that the company controls: business hours and number of outlets; This is a very good strength because businesses can understand and properly implement this model in a good way. Additionally, our model is very flexible, allowing businesses to use the variables in different ways depending on the situation. For example, businesses can account for audiences with phones and audiences with tablets interchangeably without completely destroying the model. Furthermore, the more time passed, the more accurate our model is, because our model largely deals with averages, and by the law of large numbers, the more time passed, the closer data is to the mean, which means that the model gets only better with time.

2.8 Weaknesses of our Models

Even with strengths, however, our weaknesses also show in this model. Because of the assumption that P_c, our model loses a bit of accuracy. P_c decreases as batteries charge to full in real life, but by taking an average, we mostly counteracted this weakness, except for the early stages of the implementation of the model. Additionally, we only consider extreme cases in our model. We are assuming that phones and laptops are the extreme cases of power output and charging power. Subsequently, everything in between these two values will not be exactly calculated. This, while giving autonomy to businesses, possibly makes it cost more for businesses to obtain the data necessary to give an accurate cost of charging mobile devices.

Chapter 3

Economic Models

Now that the conceptual models have been developed, we can now calculate the quantitative costs businesses face with the increasing demands for electricity. For this model, we created a theoretical business Company X, who specializes in producing and installing EV charging stations. This model will calculate the theoretical economic costs for Company X. By combining both the analytical and economic model, we can prove the model and give a more real life view on the costs of electric vehicles.

3.1 Assumptions

1. Real interest rates stay constant over time. This assumption is made because it is impossible to predict the real interest rates if we did not assume this. Because of its complexity and the many variables affecting it, real interest rates must stay constant in order to avoid a myriad of variables in the model.

2. Nominal interest rates adjust to inflation. This is a safe assumption as the nominal interest rates will not be tied directly to real interest rates. This assumption is made to keep real interest rates constant.

3.2 Values of Variables

1. P_1 is $1.5kW$. This is for the sake of normalization, and $1.5kW$ is the average power of type 1 charging stations.

2. P_2 is $5.2kW$. Similar to our first assumption, this is for the sake of normalization, and $5.2kW$ is the average power of type 2 charging stations.

3. P_3 is $32kW$. This assumption is the same as our first and second assumptions.
4. The cost of installing a type 1 charging station counting for labor and parts is \$1800 based on research.
5. The cost of installing a type 2 charging station counting for labor and parts is \$2200 based on research.
6. The cost of installing a type 3 charging station counting for labor and parts is \$5650 based on research.
7. We assume c to be \$0.11, as it is a reasonable value of the cost per kilowatt-hour.

3.3 Costs and Benefits of Changing to Type 1

Type 1 chargers are cheaper for companies to use compared to type 2 chargers or type 3 chargers, because of the less efficient power input of type 1 chargers. To model this, we will look at the cost of charging for both type one and type two chargers. For any type of charger, the cost of charging in a given year is:

$$C_1 = P_1(24hr)(365days)(c)$$

$$C_2 = P_2(24hr)(365days)(c)$$

$$C_3 = P_3(24hr)(365days)(c)$$

As determined in section 3.2, we determined that the cost of energy consumed is \$0.11 per kilowatt hour. Substituting this value in, and all the values of P_1, P_2, and P_3 in we get:

$$C_1 = (1.5)(24)(365)(0.11) = \$1445.40$$

$$C_2 = (5.2)(24)(365)(0.11) = \$5010.72$$

$$C_3 = (32)(24)(365)(0.11) = \$30835.20$$

This is the annual cost for a company when charging electric vehicles, assuming that the electric vehicle charging stations is used at the same amount. We see that the type 1 charger uses \$3563.32 less than type 2 chargers, and \$29389.8 less than type 3 chargers.

There is a considerable cost for the replacement of the Type 2 charging stations to Type 1, which ranges from \$1000 - \$1700 for each charging station. However, we can also calculate how long it will take for the replacement cost to be reimbursed by calculating the time value of money vs. the money Company X will save with the equation

$$I = S\left(\frac{1-(\frac{1}{1+r})^n}{1-\frac{1}{1+r}}\right)$$

where I is the initial investment cost of replacing the type of charging station, which we will take to be the maximum \$1700. S represents the yearly savings the company receives from the change in terms of dollars, which as we calculated, is \$3563.3. r represents the real interest rates Company X could have gotten if they invested their money instead of using it to change the type of charging station, we take this to be 2.21% and assume that it stays constant over time. The variable we are calculating: n is the number of years it's gonna take for the savings the company will experience to make up for the initial installation cost. Plugging the values we outlined above into the formula, we find n to be approximately .465 years, or about 168 days. So it would take less than half a year for Company X to make back its initial cost of replacing the Type 2 chargers through savings even assuming the highest cost of installation, so it would be extremely advantageous to the company economically to switch to Type 1 charging stations.

3.4 Changes We Can Make to the Phone/Laptop Model

Reducing cost for companies in the phone/laptop model is much easier, as we modeled the cost for companies per outlet used. We can simply reduce the number of outlets at a public place, as it directly subtracts from the annual cost of the company while requiring little to no initial investment, taking off an average of about \$3168.3 off the company's electrical bill per year for each outlet, assuming each outlet is used an equal amount by phones and laptops. However, it does come with its trade-offs, which we will outline in the next section.

3.5 Trade-offs

For our model for phones and laptops, we decided that removing a certain amount of outlets will allow the company to save a lot of money per year, but it comes with its own disadvantages, such as lower customer satisfaction, leading to a potential decrease in long-run revenues. For the electric vehicle model, using type 1 chargers versus type 2 chargers will save costs because of less power input per unit of time; however, type 1 chargers are far less efficient and will cause customers to wait around more to charge, also decreasing customer satisfaction. In a capitalist society companies are always facing similar trade-offs between monetary benefits and customer satisfaction, but our model is only concerned with reducing costs for the company, which, however much it lowers the real-life applicability of the model, strives to make the model better for the company.

Chapter 4

Different Public Places

The term public places is very broad and general in that every public place is different. Our model is dependent on variables that will change based on different locations and type of public places.

4.0.1 Variables that change

1. t_o is the largest variable that changes depending on the public place. For example, airports are open all day, whereas coffee shops and businesses are only open for a fraction of that. As a result, t_o changes for public places. Also, places such as airports would have distractions that limit the value of t_o even further. Airports would have people going through security and a lot of congestion. That isn't seen in libraries, where all you have to do is simply sit down and get straight to charging.

2. Depending on the place, the number of outlets will change. Our model for mobile devices concerns the cost per day per outlet. Therefore, to calculate the total cost of the business spent on charging in day, multiply the cost for one outlet by the number of outlets.

These variables can all be controlled by the business, since the business have control over the amount of outlets they supply and the hours that they are available.

Chapter 5

References

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