“Supply and Demand Below Zero”

Introduction

The law of demand, first introduced by John Locke, simply stated that “the price of any commodity rises or falls, by the proportion of the number of buyers and sellers.” [1] Building off of Locke’s theory, Alfred Marshall introduced the supply and demand curves to the world in 1890, bringing a graphical representation to our conceptual understanding of the law of demand. The graph hasn't changed much. Price remains on the vertical axis while the quantity demanded remains on the horizontal axis.

However, perhaps it is time for a change. A graph created in 1890 about a law conceived in the 17th century does not necessarily fully reflect the conditions of supply and demand in the 21st century.

This paper will first discuss a two-part theory regarding a necessary extension of the demand curve, the evidence to support the extension, and the applications of the extension. This paper calls for the demand curve to be extended to include “demand below zero” - instances in which consumers are paid by producers to use a given good.

Demand below zero is somewhat logical. Certainly a consumer But an obvious question arises: will there ever be supply below zero?

The paper will outline three basic instances of supply below zero: that of inferior goods, nonphysical goods/services and surplus. In the short term, we increasingly see examples of supply below zero. In fact, in late April 2020, crude oil was being supplied at a price below zero.[2] The price dropped into negative territory, meaning oil producers had to pay consumers to take oil, due to several factors: oil producers did not slow production and demand disappeared as a result of decreases in travel during the COVID-19 outbreak.[3] This incident describes an instance of short-term supply below zero. With respect to inferior goods, we will see long-term instances of supply below zero. The latter half of the paper will focus on the graph of supply below zero, why supply below exists and when supply below zero can be an effective economic strategy.

Finally, we will discuss the relationship between supply and demand below zero.

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[1] Locke’s paper: Some Considerations on the Consequences of Interest and Raising the Value of Money was published in 1691 as a letter to Parliament

[2] West Texas Intermediate crude oil futures reached -$40.32 per barrel on April 20, 2020. https://markets.businessinsider.com/commodities/news/us-crude-oil-wti-falls-to-21-year-low-1029106364

[3] The https://www.nytimes.com/2020/04/21/upshot/negative-oil-price.html#:~:text=The%20coronavirus%20pandemic%20has%20caused,States%20fell%20to%20negative%20%2437.63.

I

The current graph of the demand curve is simple. Price lies on the vertical axis, the quantity of the given good demanded by the set of consumers lies on the horizontal axis. The demand curve is downward sloping to represent the fact that as the price of any given good falls, the more that given good is demanded, or purchased.

Of course, there are exceptions to this basic form, including staple goods, which experience an increase in demand as price rises, in addition to goods that experience perfect inelasticity of demand or perfect elasticity of demand. However, for the vast majority of goods, the standard, downward-sloping demand curve accurately represents demand.

However, two categories of goods are not currently accurately reflected in the demand curve: free goods and goods that consumers are paid to accept or use.

On the standard demand curve, there is only a marginal increase in the quantity demanded of a good when the price decreases from a negligible amount to free. As demonstrated in Graph A, the demand curve continues on its normal path. However, in reality, this is inaccurate; in practice, there is a far larger increase in demand. One need look no further than online movies or videos, where the quantity of goods demanded is far higher amongst free goods. Some research has been conducted on the significant increase in demand when the price of any given good is lowered to exactly free, leading some to coin the term Zero Price Effect.[4] An accurate demand curve would represent this significant increase in demand by graphing the demand curve as a piecewise function, with a significant increase as a discontinuity, as shown in Graph B.

With regards to incentivized goods[5], there lacks even an inaccurate representation within the current demand curve; there's no representation at all. As the evidence will show, goods that would not be purchased, even if they were free, will be purchased if they cost a "negative amount" ie. consumers will use goods if they are paid to do so. If a consumer doesn't particularly like, or even dislikes a good, they will not use the good even if it costs them nothing. Take, for example, a free subscription to a newspaper that an individual strongly disagrees with. She is completely uninterested in the newspaper and thus will not take the subscription even if the service is free. However, if the newspaper were to offer her coupons for other goods that she desires, she might take the newspaper subscription. If the demand curve were to accurately represent this, there would need to be a segment below the price point of zero, thus reflecting

[4] The zero price effect definition

[5] I am defining incentivized goods as goods that consumers use after receiving an incentive to do so. Specifically, I am using incentivized goods as a term for goods that cost consumers negative amounts of money, or colloquially, goods they are paid to use.

the amount of money (or value) paid to the consumer for the trouble of accepting the unwanted product, as demonstrated in Graph C.[6]

This segment of the demand curve would also be downward sloping to reflect the following: *as incentives to purchase a product increase, the demand for that good increases*.

Thus together, the two-part extension can be represented in Graph D.[7] This graph takes into account both the jump in demand when a good becomes free and the increasing demand for a good as incentives rise.

II

In observing society, one can find numerous examples of free goods that are not accurately represented by the demand curve.

First, I will discuss an observation I made about a particular free item[8], music, and the significant increase in demand experienced once music becomes free.

A. Observation

Until relatively recently, the only forms of free music were those that were illicitly recorded over the radio and stored on home discs. With the advent of the internet, music began to become easier to access and easier to illegally obtain. YouTube fundamentally changed the demand for music by allowing for free consumption of music. Still, this music could not download and thus was of inferior quality. However, new services like Spotify and Apple Music allow for the free downloading of music.

In a study titled “Changing Their Tune: How Consumers’ Adoption of Online Streaming Affects Music Consumption and Discovery,”[9] Datta et al. studied the effects of the adoption of a free music streaming service, Spotify, on total consumption of music by consumers.

> “The first questions we address are whether adopting Spotify leads to extra music consumption and how long these effects last… In the week of adoption and the week after, the number of plays grows by 132%. Total consumption is 63% higher in the medium run, from two weeks until 24 weeks after Spotify adoption. Even more than 25

[6] Graph C represents the incentivized good demand curve for an item in which no demand exists at a price above zero

[7] This graph intentionally shows greater elasticity of demand below zero to reflect the greater change in demand due to a marginal increase in incentives when compared to a marginal increase in price.

[8] Traditionally, the definition of a free good is one that is not scarce, and is thus available without limit. When defined this way, “free” means having no opportunity cost to society. However, in this context, I am using the phrase free good in its colloquial sense, meaning that there is no cost to the individual consumer.

[9] Hannes Datta, George Knox, Bart J. Bronnenberg (2018) Changing Their Tune: How Consumers’ Adoption of Online Streaming Affects Music Consumption and Discovery. Marketing Science 37(1):5-21. https://doi.org/10.1287/mksc.2017.1051

> weeks (nearly six months) after adoption, overall consumption is still 49% higher than before adopting Spotify.

The study demonstrates that a marginal decrease in price, from mere cents to free, results in a significant increase in demand in both the short and long run.

Were a graph of the demand curve to be accurate, the graph would have to look like Graph E.[10]

2. Previous Research

Following my observation, I found that there was research on the zero price effect completed in 2006.[11]

In their paper titled *How Small is Zero Price? The True Value of Free Products,* Dan Ariely and Kristina Shampan'er conducted several experiments, in which there was a significant increase in demand for free goods.

In their paper, they describe a series of experiments involving consumers having the choice to purchase a Hershey's Bar or Lindt truffle.

> There were 398 participants in the experiment. The two products used were a Hershey's as the low-value product and a Lindt as the high-value product. There was a free condition (0&14), a cost condition (1&15), and a second free condition (0&10). In the 0&14 and 0&10 conditions, the price of Hershey's was 0¢ in both conditions, and the price of Lindt was 14¢ and 10¢, respectively. In the 1&15 condition, the price of the Hershey's was 1¢ and the price of the Lindt was 15¢.
>
> A booth was set up at MIT's student center with two cardboard boxes full of chocolates and a large upright sign that read "one chocolate per person." Next to each box of chocolates was a sign lying flat on the table that indicated the price of the chocolate in that condition. The flat signs could not be read from a distance, and the prices were visible only to those standing close to the booth. We used the flat signs because we wanted to measure the demand distributions, including the number of people who considered the offer and decided not to partake. By placing the price signs flat next to the chocolates, we could count the people who looked at the prices but did not stop or did not purchase, classifying them as "nothing."

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[10] The quantity demanded was chosen arbitrarily. However, the increase in percentage of quantity demanded is consistent with the findings of the study in the long-term scenario which dictated a 49% increase.

[11] The Research was completed by Dan Ariely and Kristina Shampan'er of MIT. https://www.bostonfed.org/-/media/Documents/Workingpapers/PDF/wp0616.pdf

While this methodology is undoubtedly a poor reflection of the macroeconomic market, it does show an indication that the trend exists. Using this methodology, the experience achieved the following results:

> The share of Hershey's increases from 27 percent in the 1&15 condition to 69 percent in the 0&14 condition, and to 64 percent in the 0&10 condition. The demand for Lindt shows a complementary pattern, decreasing from 73 percent in the 1&15 condition to 31 percent in the 0&14 condition, and to 36 percent in the 0&10 condition.
>
> Together these results show that the reduction of a price to zero is more powerful than a five-times-larger price reduction that is within the range of positive prices.

Ariely and Shampan'er's experiment establishes that a significant increase in demand is experienced by decreasing the price from 1 cent to free. At the very least, this study indicates that there is a significant zero-price effect. This adds more support to the increase in demand represented graphically in Graph B.

III

As I and others have established, when price decreases to "free," there is a noticeable jump in demand. However, an area that has been explored far less is that of incentivized goods.[12]

Incentivized goods have become increasingly common in the digital age, perhaps due to the globalization of markets. Globalization has caused an increase in competition, which has forced individual competitors to differentiate themselves and their products. Differentiation can be achieved in many ways including through the creation of a brand name (ie. Coca Cola) or through offering consumers incentives to use an individual product or service over another similar product. The goal is that eventually consumers grow accustomed to using the product and don't switch to another product when prices return to their normal state.

Incentives often take the form of discounts or entry into contests. Most of these incentives, empirically, cut down on profit margins, ever so slightly. However, a new, seemingly economically unwise, method of incentives has arisen: companies have been offering incentives at a loss.

A recent anecdotal example can be found in my use of the Postmates app. Postmates is a food delivery platform whereby independent couriers are contracted by Postmates to pick up food from numerous restaurants and deliver it to consumers who placed an order through the app. In exchange, Postmates receives a fee, some of which goes toward paying for the courier with the remaining income for the company.

[12] As I previously stated, I am defining incentivized goods as goods that consumers are paid to use.

I recently placed an order with Postmates, although I would not have done so had one thing not happened: Postmates paid for my dinner. That's right. I paid a total of $0 to have food *delivered* to my door. Had I walked the 20 blocks myself it would have been more expensive! In essence, their method accomplished part of its goal: I used Postmates when I would not have otherwise. However, I didn't stick around as a long-term customer. We'll return to the motivation of companies, and the supply side in general, in section V of this paper. From the demand side, this strategy seems to be effective in increasing demand.

The problem with describing this kind of economic incident graphically is that no demand curve exists at a price point below zero. Most demand curves stop short of zero, or at the very best, hit the x-axis and then stop. Even a graph that accurately represents the increase in demand at a price point of zero through a discontinuity lacks accurate representation for incentivized goods.

As described in part I, there are two changes necessary to the demand curve that will result in a more accurate reflection of markets. The first change, which was explained in part I, is the discontinuity at the price point zero. Second, the demand curve continues from zero to "negative" price points, ie. amounts that companies are willing to pay consumers to use their goods.

IV

While there are plenty of instances of incentivized goods that appear throughout society, finding statistics on incentivized goods is significantly more difficult.

While companies such as Uber and Postmates do provide incentives goods, statistics on the success of these endeavors is unavailable. However, there are readily available statistics on the electricity industry.

An important note: the supply and demand below zero described as occurring in the electricity industry is that of surplus goods. As described in the introduction, there are three instances of supply below zero. An assumption being made is that surplus goods have a similar graph for supply below zero to that of incentivized goods.

1. Electricity Markets

Without delving too much into the supply side, which is more thoroughly covered in section V, the electricity industry occasionally experiences supply below zero.

In Europe, electricity is traded in multiple different markets. Day-Ahead markets are operated through a blind auction that takes place once a day, every day of the year. The traded electricity is delivered on the next day. An alternative is Intraday markets, a standard open-market, in which consumers and producers can see all available bids.

Intraday markets create an hourly price, which reflects the market equilibrium. As data from electricity think tank Agora Energiewende shows, in 2017, there were 146 hours in Germany where electricity traded at a negative price.[13] The average price during these hours was -26.47 Euros per MWh. Graph F represents a full chart with hourly prices (market equilibrium) for electricity in Germany over the course of 2017. Graph G is a chart that shows the amount of hours the electricity market has operated at an equilibrium price point below zero, with average price during those hours.

An observation of the electricity industry establishes with certainty the existence of demand and supply for goods at a price point below zero and provides graphical representation.

V

Establishing demand below zero is not exactly striking. Logically speaking, consumers certainly don't mind being paid to use a particular good or service. However, this remains a moot point unless supply below zero can be established.

Supply below zero exists in three significant instances: incentivized goods, surpluses and inferior goods.

A. Incentivized Goods

Anecdotally, supply below zero is increasingly common. With the advent of digital marketplaces such as Uber, Postmates and many more, companies with nearly identical products find themselves in a constant struggle to acquire a demanding consumer base. Some have turned to paying their customers.

As I relayed in Section III earlier, I experienced this unusual form of supply while using the food delivery app Postmates. Postmates paid for my meal so that I would use their food delivery service for free. Naturally, I obliged. I paid a total of $0 to have food delivered to my door, a no-brainer. However, what could have motivated Postmates to engage in this, seemingly, economically-unwise endeavor? Why pay for my dinner?

While there are multiple possible motivations for Postmates' strange behavior, I would like to suggest a reason for other companies to engage in this course of action from an economic perspective.

By paying for my Wednesday night dinner, Postmates received many benefits, three of which I will discuss briefly.

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13 https://www.agora-energiewende.de/fileadmin2/Projekte/2018/Jahresauswertung_2017/Energiewende_2017_-_State_of_Affairs.pdf

While I would like to use Postmates' financials to demonstrate the following economic justification, Postmates was acquired by Uber Technologies in July of 2020. I will instead use Uber Technologies' financials as of the third quarter of 2019.[14]

1. Acquisition Costs

By paying for my dinner, in the case of UberEats or Postmates, or my car ride, in the case of Uber, the company uses its customer acquisition financing effectively. Over the first nine months of 2018, Uber spent $2.177 Billion on Sales and Advertising. As of December 31st, 2018, Uber had 91 million users, which it says was a 35% increase year-over-year.[15] Mathematically speaking, this would give Uber 67.5 million users as of December 31st, 2019, growing the platform by 23.5 million users. By taking the sum of money Uber spent over the first 75% of 2018 and dividing that sum by 75% of Uber's gain in customers over 2018, we can find Uber's customer acquisition cost. That calculation results in a $92.64 acquisition cost per new customer.

When taking all of this into account, paying for a meal with a $15 maximum doesn't sound too bad. Giving away free meals to customers, in terms of acquisition costs, might not be economically illogical. In the long run, the trust built with the average consumer and the potential money saved on acquisition costs might end up generating far more revenue than the price would dictate.

2. Establishment Bias

Since that Wednesday when Postmates paid for my meal, I have ordered food to be delivered six more times, as my order history on the app reveals.

Not once have I ordered on UberEats, despite them offering promotions that would have made it cheaper for me to use their platform.

This phenomenon is easily explainable: When I ordered food those 6 times, I was in a hurry and looking for the most convenient option available. Postmates, which was already downloaded onto my phone, was the easier option. The opportunity cost of my few minutes to save a minimal amount of money simply wasn't worth it.

When companies like Postmates offer to pay for my dinner, they hope this exact scenario repeats itself ad infinitum.

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[14] These were the most recent statistics at the time. A pdf of the report can be found here: http://d18rn0p25nwr6d.cloudfront.net/CIK-0001543151/53066efb-e08f-43fe-b5ff-0850cf3cd7ba.pdf
All statistics referencing Uber's financials can be found here unless otherwise noted.

[15] Uber released 4th Quarter financials in its IPO filing, which can be found here: https://www.sec.gov/Archives/edgar/data/1543151/000119312519103850/d647752ds1.htm#toc647752_1

3. Marketing

The third reason is perhaps a bit obvious, but necessary to state nonetheless: marketing.

As a marketing strategy, paying consumers is brilliant. I heard about the promotion from a friend of mine, who had overheard a stranger talking about it. Free things are exciting. Getting paid to use things is newsworthy.

The amount of people who must have downloaded Postmates that night to get free food is most likely shocking. As a marketing strategy, then, this promotion was extremely successful.

There are likely many additional reasons why Postmates decided to pay for my dinner. These three alone certainly justify what may have appeared to be an economically-unwise decision.

B. Surplus

Supply below zero can be established using the same case study of the electricity industry. As explained previously, electricity producers are occasionally left with surplus electricity and are thus placed into a position of having to pay to export electricity.

The market for electricity is unique in many ways, not the least of which is that occasionally producers pay consumers to use their electricity. Before we get into the actual market, and the specifics that come along with it, we must first briefly explain why there is a negative price in the first place.

When electricity plants operate, they produce a given amount of electricity per hour. Like any motor, thermal power plants, which convert heat to electricity, cannot immediately accelerate to its optimal pace. To ensure they operate at their optimal production during peak hours, thermal power plants mist start operating hours before they must start supplying power. As a paper by the Toulouse School of Economics explains[16]:

> The economic cost of MWh produced during the night is, therefore, lower than the immediate marginal cost, as we need to deduct the expected gains at peak hours thanks to the ramp-up during the night. This deduction can be so significant that the economic cost of night-time hours becomes negative. It is this value - lower than the immediate marginal cost, and possibly negative - which will be presented as a bid by the operator of the thermal power plant. We can, therefore, interpret the negative price offered during off-peak night-time hours as an investment intended to increase gains during peak morning hours.

Due to their increased production during the night, power plants produce a significant surplus. The electricity industry has a particularly difficult time getting rid of surplus as large scale

[16] https://www.tse-fr.eu/negative-prices-electricity

storage is currently unavailable and surpluses can only be sent to places that do not already have a surplus.

The question now becomes what to do with the surplus. In their paper studying the industry, the Toulouse School of Economics suggests the following:

> In any industry, when the price goes below the production costs, the producers halt operations. If this interruption does not stop the product flow - which, for example, is the case for crops which are linked to natural cycles - it is stored to wait for better days, or the production surplus is simply destroyed. But storage and destruction have a cost. If we can find consumers willing to increase their consumption for payment lower than the cost of destruction (or the cost of storage, net of future expected sales), it is in the interest of the producers to pay these consumers.

Of course, this results in a negative price. And, as the economically sensical arguments would suggest, many electricity producers in Europe have turned to this method of exporting their surplus.

This culminated in an equilibrium price point in which producers were paying consumers to use electricity in Germany.

Graphically, supply below zero currently doesn't exist on the standard supply curve, which can be found in Graph H. Before graphing supply below zero, a disclaimer has to be made: supply below zero only exists in the short run when dealing with incentivized goods and surpluses. In the long run, any given company would likely be better off shutting down operations than continuing to supply at a loss.

With that said, an appropriate graph of supply below zero would represent a standard supply curve temporarily shifting to the right. An appropriate graph would look like Graph I.

The supply curve only partially dips below zero, to reflect the incentives that a given firm offers consumers. The supply curve still maintains a portion above zero to accommodate any potential increase in demand that would bring the supply price point above zero.

C. Inferior Goods

An interesting case-study in supply below zero arises in the form of inferior goods. In a similar manner to surplus goods, inferior goods are goods that consumers are paid to consume. However, one notable difference is whether supply below zero will exist in the long run: for surpluses and incentivized goods, supply is limited to the short term as companies would be better suited to shut down rather than supply at a loss. Inferior goods, however, can sustain supply below zero in the long term.

One such conceptual example can be plastic waste. Municipalities generally have several options for how to deal with waste: burning the waste, polluting the natural environment or

creating landfills. All of these options cost money, perhaps more than they would have to pay an outside entity to get rid of the garbage themselves. An outside company that converts waste into energy would, in this case, get paid to take the waste from the municipality. Perhaps they would not take the waste for free, as there are significant labor and energy costs involved in the handling of waste. But, when paid to use the item, these entities will “demand” the good.

An interesting case study can be found in the global recycling industry. Sweden is unique in that less than 1 percent of household waste finds its way to landfills, according to Avfall Sverige, the Swedish Waste Management and Recycling association. In Sweden, about 49 percent of household waste is recycled, and roughly 50 percent of garbage is incinerated in power plants. Along with its domestic production, Sweden also imports trash from Norway and Britain each year to fuel power plants. These countries pay Sweden to accept their trash because it can be cheaper than paying landfill taxes...[17]

Britain and Norway are supplying the waste at a price below zero for a sustained period of time. The United Kingdom, Norway, Ireland and Italy are willing to pay 43 USD for every tonne of waste that Sweden imports to this end.[18] Sweden is also reported to have imported 2.3 million tonnes of waste in 2016 alone.[19] Based on these figures, we can create an estimated supply and demand graph showing the market for waste in Sweden, depicted in Graph M.

Graph M shows a sustained, long-term instance of supply below zero for the instance of an inferior good. The fact that there is an equilibrium price below zero shows with certainty that supply and demand exist below zero, necessitating a change to the supply and demand curves.

VI

Now that we have established supply and demand exist below zero, we must show how they relate to each other.

Graphically speaking, the incentivized supply instance is shown in Graph J. Graph J summarizes the three-part graphical theory of supply and demand below zero for incentivized goods. The demand curve is drawn to reflect both the zero price effect and increasing demand as price falls further below zero. The supply curve is drawn post-rightward-shift in which the company has experienced a surplus or is running a promotion that results in supply below zero.

Graph J is only applicable in the short run during a promotion run by a company. In the case of a company running a promotion, the anticipated long-term supply and demand curves will look more like Graph K. The graph depicts the supply curve returning to its original levels with the increased demand as a result of the promotion also depicted. The result is an increase in

[17] https://www.nytimes.com/2018/09/21/climate/sweden-garbage-used-for-fuel.html
[18] https://www.blueoceanstrategy.com/blog/trash-treasure-sweden-recycling-revolution/
[19] https://www.trtworld.com/europe/swedish-recycling-so-successful-it-is-importing-rubbish-24491

quantity demanded at a higher price when compared to the equilibrium price before the promotion.

In the case of a company running a surplus of production that needs to offload excess, Graph L will represent their anticipated long-term demand curve. Demand in this instance likely remains the same while the supply curve experiences a leftward-shift.

In the case of a market for an inferior good, the long-term equilibrium will look similar to the estimated graph of the Sweden Waste Market depicted in Graph M. Demand and supply are depicted as intersecting at a price below zero, reflecting the market price for that market.

Conclusions

Through our analysis of prior research and observation of the music streaming industry, we successfully demonstrated the existence of a zero price effect. We also suggested a graphical representation of the zero price effect.

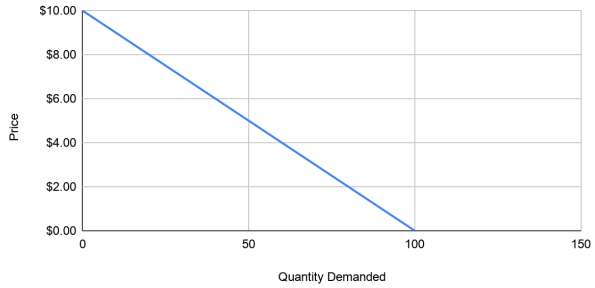
Our analysis of the food delivery industry and electricity industry, in Europe specifically, showed the existence of real-world demand and supply below zero in the short-term for incentivized and surplus goods. A case study of the waste market in Sweden demonstrated long-term supply and demand below zero for inferior goods.

Graphically speaking, the three-part theory can be summarized by Graph J.

Graphs and Charts

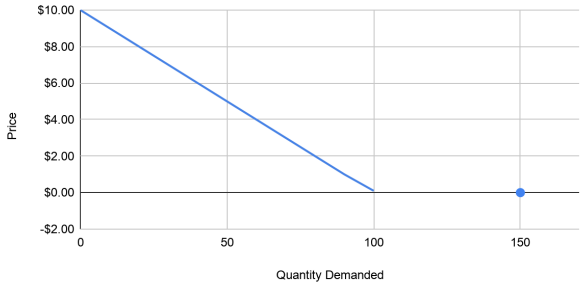
Graph A

Standard Demand Curve



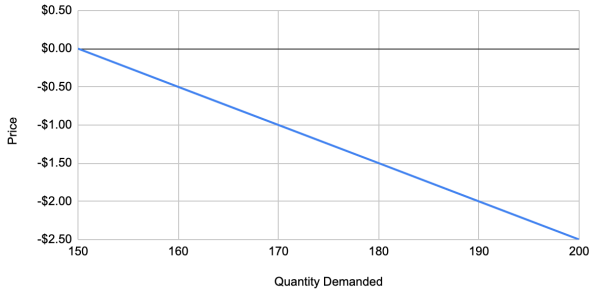
Graph B

Zero Price Effect Demand Curve



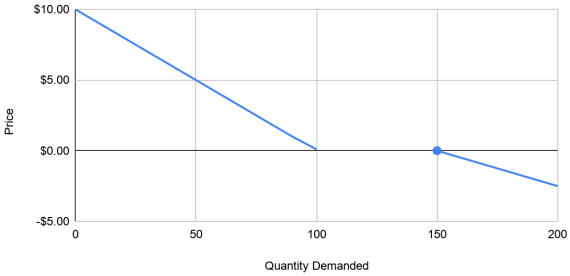
Graph C

Incentivized Good Demand Curve



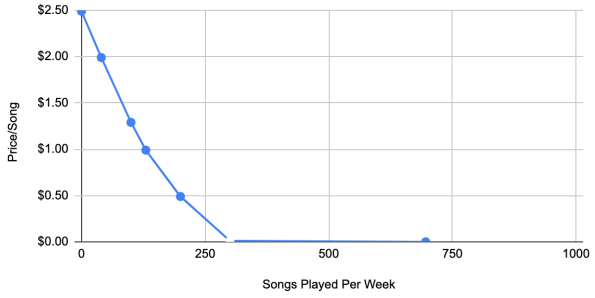
Graph D

Full Extension of Demand Curve



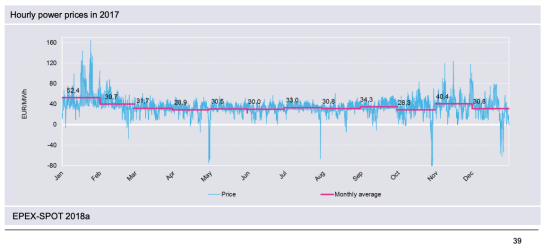
Graph E

Increase in Song Consumption Week After Spotify Adoption



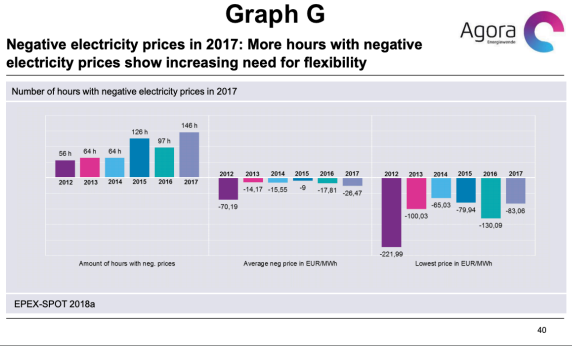
Graph F

Hourly prices over the course of 2017: Power is cheaper when it is sunny (April–August) and windy (October, December), and more expensive when RES generation is low (January)



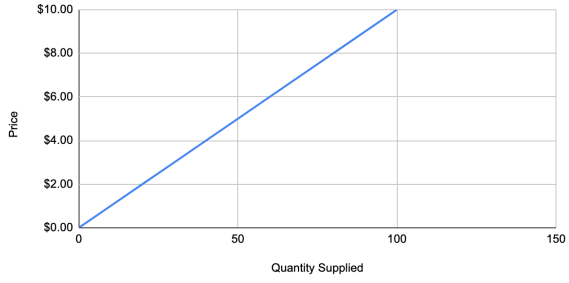
Graph G

Negative electricity prices in 2017: More hours with negative electricity prices show increasing need for flexibility



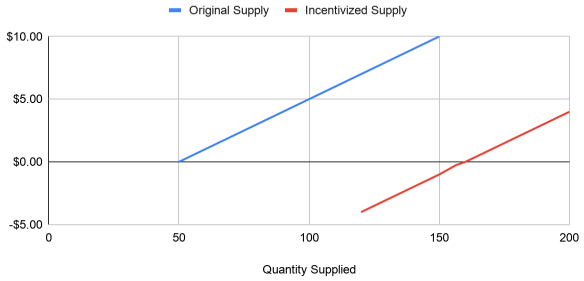
Graph H

Standard Supply Curve



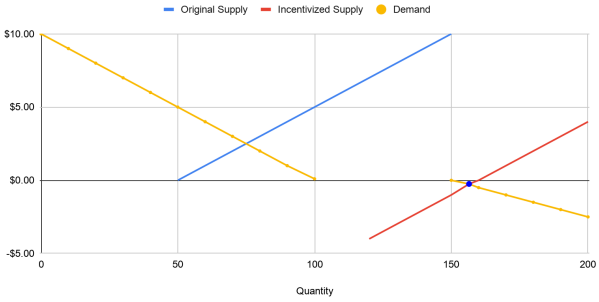
Graph I

Incentivized Goods Supply Curve



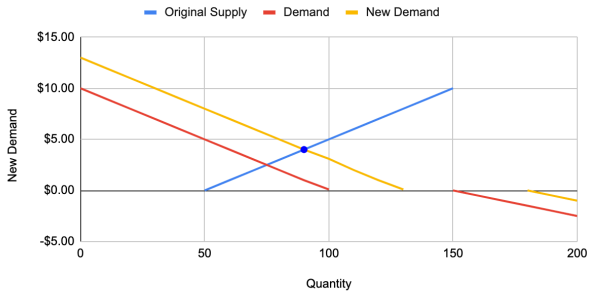
Graph J

Supply and Demand Curves Below Zero



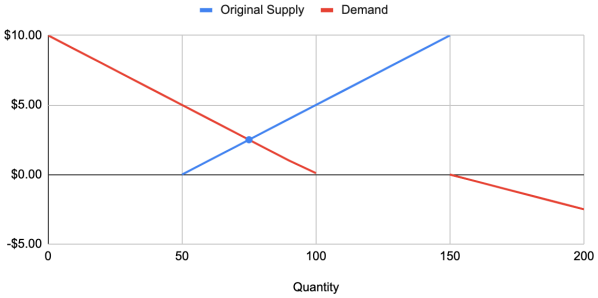
Graph K

Anticipated Long-Term Equilibrium of Incentivized Goods



Graph L

Anticipated Long-Term Equilibrium of Surplus Goods



Graph M

Sweden Waste Market (Estimation)