A Behavioral Economic Analysis of Cryptocurrency Markets [1]

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A Major Qualifying Project Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science in Economics.

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[1] This report represents the work of one or more WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on the web without editorial or peer review.

Abstract

Cryptocurrency is a modern decentralized medium of exchange that offers unique inflationary protection. Using traditional microeconomic tools, a new utility function of three goods - cryptocurrency, cash, and traditional assets is selected. Income effects, price effects, and consumer preference effects are then investigated through endogenous shifts in parameters and values. Consumer preferences based on perceptions of asset characteristics yielded the largest shifts in the price of cryptocurrency. Particularly, regulatory bodies should further investigate these markets to quell speculative trading and fraud.

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Background

Cryptocurrency is an ever growing market, seeing as Americans had nearly no holdings in cryptocurrency over a decade ago, while now over 8% of the population has at least some cryptocurrency in their portfolio. Moreover, electronic banking and investment software include the ability to purchase cryptocurrency, even offering robo-advisors, which are registered with the Securities and Exchange Commission, to buy and sell cryptocurrency. Contemporary economic structure, policies, and institutions revolve around currencies and money, and in particular, the idea of fiat currencies. These fiat currencies are mediums of exchange that are not backed by an inherently valuable commodity, nor do they possess or yield any intrinsic value to the agents in which they are used and exchanged. Value is then predicated on good faith and trust in a centralized power, which does not inspire any reasonable amount of credence for some individuals. This then motivates the creation of cryptocurrencies, which provide a decentralized repository of value and medium of exchange agreed upon by economic agents, rather than a centralized authority providing regulation.

These currencies often have complex transaction verification schemes that are tied to the minting of new coins, but each one typically takes a different approach. The most prominent cryptocurrency is one of the oldest in the market, inspiring the creation of thousands in the subsequent years after its creation, and this is none other than Bitcoin. Bitcoin has been extensively investigated in the past several years, and it has a notable exponential price trend which moves independently in comparison to other traditional asset classes. Bitcoin's electronic and decentralized nature allows for more power in a currency in comparison to traditional fiat currencies, allowing for more public verification of transactions, but also more opportunities for felonious behavior. However, regulation in these markets is still quite infantile and inconsistent, with some regulation from the SEC, as it is technically classified as a security. More policy implications follow from the results outlined below.

The Model

The general approach for the modeling procedure is that of comparative statics, or simply the analysis of a snapshot in time given a change in a single parameter. Variables for three assets are utilized in this analysis: Cryptocurrency (X), Cash (Y), and Stocks, bonds, and all other traditional financial assets that provide regular returns (Z). Recalling traditional microeconomic theory, Cobb-Douglas utility functions of the form $U(x, y) = x^{\alpha}y^{\beta}$ are analyzed along side Quasi-Linear utility functions of the form $U(x, y, z) = ax^{\alpha} + by^{\beta} + cz$.

Marshallian Demand functions are used to reflect real consumer sentiments within their portfolio allocations, namely maximizing utility over a given budget constraint. Lagrange multipliers then provide the framework to extend traditional two-good utility functions into three-good counterparts, where the symmetric polynomial form is selected due to its ability to yield demand in all three goods that exhibit income and price effects and substitution across goods. Specifically, the utility function that was selected was of the form: $U(x, y, z) = \alpha x^{\lambda} + \beta y^{\lambda} + \gamma z^{\lambda}$, with behavioral parameters α, β, and γ. These parameters reflect consumer sentiment for each asset class by quantifying the characteristics of each asset, such as inflation protection and its ability to satisfy the functions of money. In particular, these give numerical weight to the effects of each variable such that they reflect real world asset distributions in consumer portfolios. Cryptocurrency has α to quantify the protection against inflation and fulfillment of the functions of money, cash inherits β to reflect the attraction felt by consumers due to its perfect satisfaction of the definition of money, and traditional assets have γ to reflect inflation protection and regular returns. The functional form for both supply and demand for cryptocurrency are modeled after Bitcoin for simplicity sake, since each crypto can offer vastly different price and demand structures.

Analysis

Through the function specification for utility, and subsequently Marshallian demand, three different effects are analyzed: Income effects, price effects, and consumer preferences. When income doubles, demand in the markets for each good subsequently increase in price and quantity. Due to differing elasticities of supply and demand for each good, the percent changes in quantity and price differ as well. Most notably, cash generated the largest percent change in price, followed closely by cryptocurrency. Then, the relative prices of each good were doubled in the investigation of price effects in the model. In this section, cryptocurrency exhibited the largest price swing in percentage terms with a relatively small increase in quantity demanded, where its price increased over 30% while cash and other traditional assets appreciated in price by less than 10%.

Then remains the analysis of shifts in consumer preferences, which are indeed the most interesting, since large, sudden shifts in consumer sentiment are quite possible in real markets. Examining shifts in the parameter α, cryptocurrency nearly doubles in price while the other goods decline in price by approximately 25% or less, revealing the intense volatility in this market, which is of particular interest to regulators and investors. The effects of β and γ are also examined, but these yield less striking results, where one notable result is that consumer preference for traditional assets shift cryptocurrency price on by a larger percentage than preferences on cash.

Conclusion

Leveraging the results outlined above, it is clear that cryptocurrency exhibits volatility that has been unseen until recently. In particular, this volatility mains arises from the ever-changing perceptions of consumers in the market, along with an attempt at a sort of Nash equilibrium, where all players are attempting to predict how other players will behave on the aggregate level. Since cryptocurrency is a newer asset class, information is quickly distributed by leading figures in the media, further adding to the complexities and changes in consumer preferences in this market. As this asset grows in age and is more well understood by everyone, volatility will likely decrease over time simply due to decreasing levels of stimuli that mold and change consumer preferences and perceptions on small time scales.

On the other hand, forecasting the future of cryptocurrency markets is quite difficult in this regard due to the majority of trading being speculative rather than calculated risk investments. In particular, individual choice in cryptocurrency investment may be dominated by speculation rather than true consideration of its noteworthy and attractive characteristics. Thus, the hypothesized attributes associated to each parameter within the model may be more nuanced than initially conjectured, where α could reflect more intricate perceptions and feelings towards cryptocurrency assets.

One large issue in the world of cryptocurrency is the lack of sufficient, concise, and logical regulation that is also universal. Thousands of fringe cryptocurrency schemes are created every year only to be subject to "pump and dump" securities fraud schemes that leave new investors in the dust. Thus, the SEC should investigate these markets further and use the results presented in this paper to introduce more legislation that increase the difficulty of creating faux and meaningless schemes that further add to consumer confusion and warped perceptions, and additionally addressing the legality of pump and dump schemes in cryptocurrency markets. Overall, the SEC oversees some regulation at the moment, but should advance its role as a regulatory body in these markets by implementing the policies outlined above.

Future study in this field of research is brimming with opportunities, such as generalizations and extensions of models such as the one presented here. As mentioned previously, cryptocurrency supply and demand is modeled after Bitcoin, which could be changed in future study to glean additional insight into crypto markets as a whole. Additionally, dynamic models are also interesting extensions as well, where time variables may be introduced in order to contrast market correction times after endogenous and exogenous shocks to the markets.

Chapter 1

Introduction

In less than a decade, Bitcoin has appreciated in value from approximately \$100 to over \$60,000. This asset quickly gained traction within consumers and the media, inspiring an entire market for similar goods. Now, a considerable number of economic agents consider the forces of modern cryptocurrencies, in which Bitcoin is the father. With such a volatile but nevertheless growing market for such goods and currencies, many individuals have spent years trading and researching these digital stores of value. Examining this idea of price volatility for cryptocurrencies, consider the following price trend of Bitcoin as presented in Figure 1.1. Most notably, the market experienced a low of approximately \$30,000 in late July of 2021, yet somehow managed to hit a high of approximately \$70,000 a few months later in early November, with significant price fluctuations in between as well. Moreover, the market began to fall again, reaching the mid \$30,000s in early 2022. For one asset, such price volatility is indeed remarkable.

However, questions and debate remain as to how well cryptocurrencies fulfill the traditional functions of money, as well as their place in modern portfolios. As more individuals begin to understand and accept the place of cryptocurrencies in the modern economy, they have begun to infiltrate into various markets as mediums of exchange. Additionally, the future for cryptocurrencies remains unclear, since it is difficult to extrapolate the small amount of data that has been provided thus far, and discussions on future regulation are still in progress, adding to the economic uncertainty.

As is the case with most economic markets, analysis has been performed on the statistical side, with elaborate forecasting models and potential mathematical explanations for trends and cycles within these markets. In particular, several studies and experiments have been conducted since the conception of modern cryptocurrencies, each with their own unique approach and

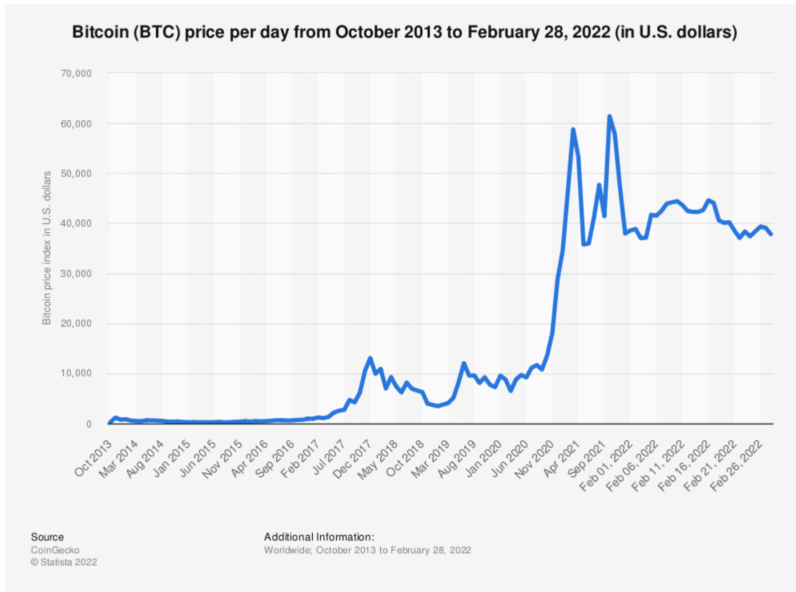


Figure 1.1: Bitcoin Annual Price Trend [1]

conclusions. There have been multiple studies and experiments conducted over the past several years in an attempt to classify and explain consumer behavior within crypto markets. In particular, a study conducted by Xi, O'Brien, and Irannezhad determined that "the significant factors of the choice of investment in cryptocurrency include age, gender, education, occupation, and previous investment experience" [39] using a web-based revealed preference survey and applying a multinomial logit model. Other research has shown that investors' choices in investing in cryptocurrency markets is affected by the choices of others' investments. Further, results have shown that individuals are significantly affected by "herding theory factors, prospect theory, and heuristic theory" [40] when making investment decisions in cryptocurrency markets.

However, the question remains as to what behavioral and traditional modeling can be performed in order to glean additional information regarding consumer choice when choosing distributions of assets within their portfolios. Specifically, what are the motivating factors behind consumer behavior and investment in cryptocurrency markets, including those that generate large price swings? The answer to these questions is not obvious, thus, the aim of the subsequent analysis is predominantly to introduce a model for demand for three asset classes predicated on real world trends and behavior.

In this paper, traditional microeconomic theory is presented as the basis for the model with an emphasis on extending classical utility functions to a logical three good system, compiresed of cryptocurrency, cash, and traditional assets such as stocks, bonds, ETFs, and generally those that provide regular returns. There is a provision of a simple extension of polynomial utility functions to that of the three good economy outlined above. Parameters include total consumer income, prices for each respective good, and behavioral preference parameters for each good. The canonical approach of "comparative statics" is implemented in this analysis, simply meaning that one parameter is varied at a given time and its impact is subsequently analyzed.

Explanations for such observations are also explored, such as the impact of the elasticity of supply for each of these goods as well as the distribution of the three assets within a given portfolio of a consumer. The implications of the choice of utility function are examined as well, since the utility function was forced to yield corresponding demand functions that had income effects as well as price substitution between goods. These requirements were imposed in the choice of utility function in order to most accurately represent real consumer behavior in the markets that are being compared.

Most notably, the results reflect the extreme volatility of cryptocurrency markets in comparison to other well established markets such as those for cash and those in the traditional asset class. This volatility was found to be predominantly generated through one of the behavioral parameters included within the model, denoted by α. In the utility function, this parameter was one of three such values that reflects consumer sentiment within each given market. Each behavioral parameter is designated a value that is predicated on the perceived benefits of each asset. For cryptocurrency, this parameter reflects consumer perceptions regarding its ability to protect against inflationary pressures along with its fulfillment of the functions of money.

More importantly, α serves as a reflection of consumer sentiment for cryptocurrency, and this parameter yielded the largest price swing for the cryptocurrency market, suggesting its pivotal role in generating price swings and volatile price movements. This implies that the perception of cryptocurrency aggregated over all consumers has a larger impact than that of changes in income and the relative prices of the other goods within the market. Unfortunately, the implications of these findings also suggest that the markets are more nuanced than some individuals expect. In traditional behavioral economic theory, individuals are not thought to be completely rational, nor are they assumed to have complete information regarding the goods that they are purchasing and the sentiment of other consumers. Much like a stock, individuals attempt to predict how others are going to behave, with some consumers operating at a deeper level of backward induction than others. In combination with uncertainty regarding inflation and cryptocurrency's imperfect fulfillment of the functions of money, cryptocurrency has become one of the most volatile assets that has been observed to this day.

Going forward, preliminary information and a foundational understanding regarding these assets is convered, including their motivation, modern uses, and regulation. Subsequently, a mathematical model is constructed that reflects this information while also embracing traditional theory. Finally, comparative statics is implemented to analyze price and quantity shifts, along with a general summary and concluding remarks.

Chapter 2

Background

In the modern era, conducting transactions via various forms of currency has become a part of daily life. As currencies have evolved over time, their functions, as defined by economists, have become clear. However, this does not imply that identifying whether or not an asset fulfills these functions is an easy task, and this is the case with modern cryptocurrencies, which have been the subject of a large amount of news and controversy over the past decade. Cryptocurrencies are unique in regard to their transaction verification, storage, and uses in comparison to traditional assets, as well as potential inflation protection due to supply caps. Once thought to be a fringe movement, cryptocurrencies and tokens have amassed considerable market shares, amounting to an industry worth over $1 trillion. However, this history has been quite turbulent, as major currencies have been subject to several major asset bubbles over the past several years.

As government spending continues to increase and inflationary pressures rise, decentralized currency systems look increasingly appealing, especially cryptocurrencies. In particular, many of the top cryptos offer a hard cap on the amount that can be minted by encoding a proportional decrease in rewards as more coins are mined. In terms of the future of these currencies, regulation has been the subject of much discussion. Although some governmental bodies have began to define and attempt to regulate virtual currencies, agreement across the board has not yet been achieved. Going forward, universal guidelines for all regulatory bodies should be established in order to consistently and logically manage virtual services and transactions.

2.1 The History of Money and Monetary Value

In order to understand the scope and implications that cryptocurrencies have in the modern era, one must understand and be familiar with the established currencies employed by various countries. In particular, one must understand the primitive origins of money and currencies in order to grasp the historical context and importance of such a tool. Long before the use of money, bartering within the human species has been an important concept that can facilitate a fair trade of goods and services. In particular, it is simply not feasible for an individual to produce all goods and services in which he requires, and thus individuals tend to specialize in specific areas of production. Naturally, this generates a desire between individuals for the goods and services offered by their neighbor. Hence, bartering was the most efficient solution in the pre-monetary and unstructured world. However, this system proved to be quite inflexible, since one economic agent may not desire a good or service from another, making an exchange via bartering impossible [2].

In the early B.C era of civilization, the prominent goods that individuals agreed upon when bartering were mainly cattle, ultimately progressing to cowrie shells some thousand years later. In particular, notice that since these were agreed upon bartering standards during this era, both the cattle and cowrie shells served as a medium of exchange, one of the three characteristics that must be satisfied when meeting the definition of money. In particular, economists classify money by having the following three functions: a medium of exchange, a store of value, and a unit of account [8]. From these characteristics, one can see that the cattle were a significant store of value, for only a temporary time. However, during the time of the transaction, the cattle still proved to be a store of value since they had the capacity to produce goods and services to the individual. However, as a unit of account, cattle proved to be sub-optimal as they are indivisible and vary in their abilities and marginal utility to the individual who is obtaining the cattle. On the other hand, cowrie shells served as a medium of exchange between economic agents and also satisfied the unit of account condition, as they tended to be quite homogeneous in composition and look while being quite difficult to counterfeit. However, when examining whether cowrie shells unequivocally met the function of a store of value, such an answer is unclear unlike cattle. Specifically, cowrie shells had vastly different values and cultural significance attached to them, making their wide-spread use and agreed upon value come into question [6]. Therefore, cowrie shells were clearly not the the most efficient when examining currencies and forms of money that have a well defined store of value.

It was not until 1000 B.C that the first metal money and circular coins were made and used in this process, becoming refined over the years until about 500 B.C, in which the metal coins took their form that we are familiar with today. In fact, it was not until the year 806 that the first paper banknotes appeared in China, which is indeed far more recent than its coin predecessor [3]. Coins proved to satisfy the functions of money in a far superior manner in comparison to its cattle and cowrie shell counterparts. Specifically, gold and silver coins served as a medium of exchange between economic agents, and this function is quite straightforward. In addition, these coins were quite efficient as stores of value, as the supply of gold and silver was abundant enough to mint a sufficient amount of coins, while also scarce enough such that all economic agents could not easily obtain considerable amounts of the good, providing a sustainable natural scarcity. In addition, gold was an especially efficacious metal as it was unable to be corroded, and societies and cultures have continually had emotional and physical attractions to it, further perpetuating its generational value [7]. Coins were also efficient units of account, as they were able to be sufficiently standardized, leading to clear countability and fungibility.

However, this begs the question as to what provides the value behind a form of currency. Historically, this value was predicated on precious metals such as gold and silver. In fact, the United States was on the gold standard, a system in which the banknotes in circulation were backed by a fixed amount of gold, and individuals were able to trade their notes at the Federal Reserve for the gold equivalent of their dollars. This was the case until the Nixon Presidency in the 1970's, when he took the United States off the gold standard, thus rendering it a fiat currency. By definition, a fiat currency is a medium of exchange which is not backed by any inherently valuable commodity such as gold or silver, and the paper bank notes now had no intrinsic value to the economic agents in the United States [4]. This concept of fiat currencies is in direct contrast to that of the early forms of money, such as cattle and gold and silver coins, since these goods had intrinsic value and explicit utility to economic agents.

This concept of a fiat currency is precisely the motivation behind modern crytpocurrencies. In particular, these provide a decentralized medium of transaction between economic agents. When the dollar was taken off the gold standard and was officially considered a sovereign fiat currency, the new standard of value that was established was simply the citizens' "full faith and credit" in the government of the United States. With this centralization, an individual may not place full faith in the efficient regulation and management of such currency, thus leaving a decentralized repository of value to be desired [5].

2.2 Crypto Mining, Blockchain, and Wallets

In the cyber realm, there are various concerns and questions that must be addressed in order to convince economic agents as to the validity of crytpocurrencies such as bitcoin. In particular, these concerns are mostly predicated on security issues, such as how an individual knows that a seller is legitimate, or how to verify that a seller is not selling the same coin to two different buyers.

The resolution to these concerns and questions is simultaneously tied with the creation and minting of new cryptocurrencies, and this resolution is a concept known as cryptocurrency mining. Mining is the process of verifying transactions that take place with a given kind of cryptocurrency, and the verification process uses large amounts of computing power in order to solve hash verification processes. These hash codes are unique identifiers to data that are compared to calculated values in order to verify that a transaction is legitimate [8].

This hash verification leads into the concept of the blockchain. To put it simply, the blockchain is an ordered type of database. Specifically, when the hash codes are verified for bitcoin or altcoin transactions, the transactions history is added to the blockchain in the form of blocks. A block is a conglomeration of data and information that has a set storage size, and when filled, the block is chained together to the existing chain of blocks. Hence, the underlying structure of cryptocurrencies like bitcoin is the blockchain. When performing these verifications, the miners are compensated with bitcoin themselves. In particular, mining is the process in which new digital coins are minted and put into circulation [9]. This happens at an extremely slow rate and cannot be exploited, thus ensuring that there is no centralized power that can artificially inflate the price and value of bitcoins or other altcoins. However, by definition this also renders cryptocurrencies to be fiat currencies as well, as there is no commodity that provides a supply of value to the currency.

The mining and in turn the minting rate of cryptocurrencies of course depends on the amount of miners at a given time along with their computation power. However, prominent cryptocurrency schemes such as Bitcoin implement code that creates an artificial scarcity and control for inflation [11]. In particular, Bitcoin does so by setting a cap on the maximum amount that can be minted and hence in circulation, and this cap is set at 21,000,000 in this case. When Bitcoin was initially launched, miners were compensated by a sum of 50 BTC, and this was the case until the first 210,000 blocks were added to the blockchain. At this point, the reward for mining a successive block was reduced by a factor of 1/2, or 25 BTC. As of 2021, the reward for a new block is 6.25 BTC, and this process will continue until the last Bitcoin is mined [10]. In particular, notice that we can see that the cap must be 21,000,000 by the conditions that the initial reward is 50 BTC and is successively halved for every 210,000 blocks mined since:

$$210,000 * \sum_{j=0}^{\infty} 50\left(\frac{1}{2}\right)^{j} = 21,000,000$$

Typical hard currencies, including cash and debit/credit cards, are often held in physical wallets which economic agents typically carry with them at all times. By carrying their valuables within a wallet, they have a high level of security and faith that their information and assets will be safe. In terms of cryptocurrency, there are no tangible holdings that economic agents have when they buy or sell cryptos. However, these assets are stored on digital counterparts to physical wallets, and they are simply known as digital wallets or crypto wallets. These wallets do not store the currencies themselves, but instead store the keys in which allow an economic agent to access their holdings on the blockchain. In particular, these wallets store the passwords that grant the access to the individual, and there are three predominant ways in which individuals are able to store these passwords. Individuals can choose to simply write down these codes on paper (paper wallets), store them offline on internal or external hard drives on their computer (hardware wallets), or entrust the safety of their passwords on online wallets via services offered by crypto trading platforms [28].

These passwords are known as an individual's private key to their wallet, and they must be handled with the same level of security that the individual places on their credit card or similar information. Crypto transactions also function by users having a corresponding public key to their wallet, which is their wallet address. This function is parallel to that of typical bank accounts, as individuals can freely give out their bank account number in order for other economic agents to send or take money from your account with your authorization. Technically, the wallet address and public key are not exactly the same in terms of how computers identify them, since a wallet address is a hashed (more compressed) version of the user's associated public key [29].

2.3 Prominent Cryptocurrencies, Price Trends, and Trading History

It is important to note that although Bitcoin has the largest market share out of the entire market of cryptocurrencies, it is most assuredly not the only contender in the market. In particular, as outlined above, these hash verification processes are intensive in terms of the computation power required, thus forcing miners to adopt expensive pieces of hardware that are geared toward mining Bitcoin as efficiently as possible. There are services and software programs that are offered online that allow users to compute the hash codes within the software rather than on the graphics card, which is a piece of hardware on the computer. However, for Bitcoin in particular, this software based method of computation is not feasible, and hardware is far more efficient. However, another popular cryptocurrency, Litecoin, was purported to have the property such that it was not feasible to mine on the hardware, which is the converse of the property of Bitcoin. As will be made clear, there are other cryptocurrencies that seek to address the problems that Bitcoin in particular faces [12].

Behind Bitcoin in terms of market share is Ethereum, or more specifically the Ether currency. Ethereum is classified as a "practically unbounded state machine" [13]with a corresponding virtual machine. The Ethereum ecosystem uses its own cryptocurrency Ether, denoted by Ξ, which in fact "covers gas costs when executing smart contracts" [13], where gas is a virtual fuel that allows the limitation of resources when computing. The verification process used in the Ethereum ecosystem is a completely different algorithm used than Bitcoin, and this is the Elliptic Curve Digital Signature Algorithm, or ECDSA. Ethereum uses this algorithm to verify that Ether funds can only be spent by their owners [13]. Behind Bitcoin and Ether, there are other coins with considerable market caps, which are listed in figure 2.1 [15].

Bitcoin (BTC)	$856 Billion
Ethereum (ETH)	$357 Billion
Binance Coin (BNB)	$70 Billion
Cardano (ADA)	$69 Billion
Tether (USDT)	$64 Billion
XRP (XRP)	$52 Billion
Dogecoin (DOGE)	$40 Billion
USD Coin (USDC)	$23 Billion
Polkadot (DOT)	$25 Billion
Solana (SOL)	$20 Billion

Table 2.1: Market Capitalization for the Top 10 Cryptocurrencies

Looking at the trends of such currencies, one sees similar time shapes when looking at their net price trend, shown for Bitcoin and Ethereum in Figure 2.1 and 2.2 [16].

Bitcoin has been subject to several asset market bubbles within its short history, and the provision of an explanation can aid in the understanding of where BTC stands today. In early 2013 and leading into the beginning of 2015, there were several small bubbles and rallies, all of which had their associated crashes. The price was first in the tens and eventually shot up to the low hundreds, then later rallying up to the low thousands. The beginning of 2015 presaged a multiyear slump for the currency. In 2017, the fifth price bubble for Bitcoin occurred, where the currency markedly increased from a mere $900 to around $20,000 value within the span of the year. It was at this point that Bitcoin attracted mainstream attention, and individuals began to consider its value and potential challengers within the market for cryptocurrencies.

Figure 2.1: BTC Net Price Trend

Figure 2.2: ETH Net Price Trend

The bullish markets in the summer of 2017 are in turn what caused the formation of the asset bubble, as the rise in prices in the summer attracted the attention of major Wall Street analysts, raising the price even further [19]. After this, however, another significant slump of little growth continued until early 2020, when the coronavirus pandemic took full effect. The shutdown of major economies and the crushing of the stock market during this era attracted many new customers worried about inflation. With the narrative of BTC and its supply cap of 21 million coins in the era of governments printing money to handle the pandemic affairs, the price for BTC hit all time highs of over $60,000. Eventually this bubble crashed in early 2021, but the summer yielded another bull run, elevating the price to $50,000 [18].

It is of widespread agreement within the literature that all cryptocurrency markets are volatile, including the most prominent such as Bitcoin and especially the derivative alt coins. However, as one can see above, both Bitcoin and Ethereum seem to move together, having very similar time shapes and price trends. This is in fact the case with most prominent cryptocurrencies, such as those listed in the table 2.1, as their trends tend to be positively correlated over different time scales. The general asset class of cryptocurrencies have been seen to have increasing connectedness over the past several years, and this connectedness is in fact negatively correlated with consumer sentiment and certainty during a given period [21]. In particular, this means that when consumers have higher levels of uncertainty within the classical markets, prominent cryptocurrencies tend to be less connected overall. Other prominent studies have shown that crypto markets are highly volatile, as mentioned above, but simultaneously positively correlated with one another, at least when examining a basket of cryptocurrencies that have high market caps [20].

Although crypto markets tend to operate a much higher level of volatility in comparison to its traditional market counterparts, it is worth examining whether Bitcoin and other cryptocurrencies offer reliability and safety while traditional markets fall. The answer to this proposal is not entirely obvious, and it is still under contention to this day. In particular, empirical evidence from the Covid-19 bear market was examined, and the following price trends were graphed comparing the price changes in BTC to the S&P 500:

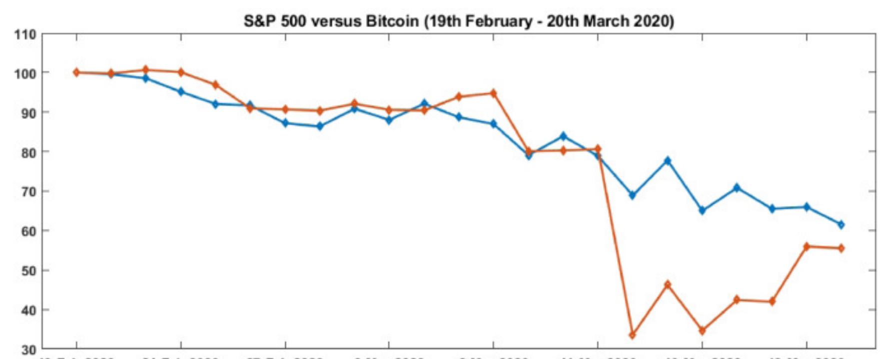


Figure 2.3: S&P 500 graphed against BTC, February and March 2020 (CONLON 2020)

In this graph, the price of BTC is represented by the orange line while the blue line represents the S&P 500 price trend, and both are standardized in this case to start at 100. A statistical analysis of these trends was conducted in order to assess whether Bitcoin was a reliable and safer alternative to the typical markets, and the analysis showed that this was not the case. In particular, Bitcoin moved together with the S&P but with a higher level of volatility, resulting in higher levels of risk for investors [30].

Looking at a longer time horizon, one sees that Bitcoin and other traditional asset classes tend to be quite highly uncorrelated, which is in fact the opposite that one would suppose when examining the figure above. These correlations are summarized in the table below:

Correlation (2/1/2012 to 12/31/2020)	S&P 500	U.S. Bonds	Bitcoin	Gold	U.S. Real Estate	Oil	Emerging Market Currencies
S&P 500	–	-0.25	0.01	0.02	0.73	0.34	0.30
U.S. Bonds	-0.25	–	0.02	0.28	0.04	-0.15	0.10
Bitcoin	0.01	0.02	–	0.00	0.01	0.03	-0.01
Gold	0.02	0.28	0.00	–	0.09	0.08	0.27
U.S Real Estate	0.73	0.04	0.01	0.09	–	0.20	0.29
Oil	0.34	-0.15	0.03	0.08	0.20	–	0.22
Emerging Market Currencies	0.30	0.10	-0.01	0.27	0.29	0.22	–

Table 2.2: Correlations of BTC and traditional asset classes [31] (Data from Morningstar)

Other analyses have been conducted to fortify this conjecture as to the price independence of Bitcoin relative to other traditional asset classes. In particular, analysis has shown that Bitcoin's average one year rolling correlation since the start of 2011 (up until the year 2017) was mostly centered around zero when compared to assets such as equities, bonds, oil, gold, and real estate [32]. Bitcoin's average correlation with the assets mentioned above was also calculated to be -0.03, which strongly suggests the independence of Bitcoin in the markets relative to other assets. This would also suggest that Bitcoin does not respond particularly closely to changes in the prices in other asset classes, suggesting that Bitcoin does not go up in price when traditional assets go down. Overall, it appears to be price independent and untethered to assets such as those listed in Table 2.2.

2.4 The Benefits and Shortcomings of Crypto

The virtues of Bitcoin themselves are two sided coins, since the freedom and capabilities of such a currency simultaneously allow for exploitations and downfalls. However, cryto has never been more prevalent within the mainstream media and has never had such a large collective market capitalization as it does today. In particular, the freedoms associated with Bitcoin are precisely the reason why there are problems such as the ones listed above. However, there is far more capability and advantages to the construction of these cryptocurrencies than there are disadvantages. Since Bitcoin is the predominant coin in the market and functions as a trading pair with most coins, the benefits of Bitcoin will be explored.

As mentioned previously, the decentralization of Bitcoin allows for the absence of high regulation costs and overhead. Additionally, as it is anonymous, this in fact allows for protection against identity theft and fraud in general, assuming that there is no traceable information. Additionally, the exchange of BTC is growing more trustworthy overtime and is being bought and traded at an increasing rate. The public blockchain behind these transactions also allows for added protection against fraud and illegal activity, such as double spending of a Bitcoin. Moreover, through secure cryptograhic encryption and publicly available code, individuals can be confident that their transactions are secure and that this store of value is reliable, since the production of BTC is collective rather than private and the rate at which it is produced have been clearly defined and publicly known. In theory, it is quite straightforward to integrate a Bitcoin server within a platform that deals with user transactions, and adoption can be quite simple [22].

The decentralization of cryptocurrencies also relates back to the idea of the inflation protection provided by many of the most prominent cryptos. In particular, the hard cap set by Bitcoin is generally recognized as a protection against governmental changes or policies. This is particularly appealing to investors, as this asset cannot lose its value from inflationary forces, making it increasingly appealing during times which are characterized by high levels of inflation of national currencies [38].

Another notable problem in the realm of Bitcoin is the fact that the mining process demands a high amount of electricity to function, and other coins seek to fix this issue. In this sense, Bitcoin can be seen as wasteful in a sense, as other currencies seek to fix this high demand on electricity in the mining process. In particular, miners are technically solving Proofs of Work when they are performing hash verifications, which depend on the hashrate. Instead of this wasteful process of mining, other coins such as Permacoin and Primecoin devote the work done to a task the yields more utility overall. On the other hand, a coin known as Spacecoin rather uses Proofs of Stake or Proofs of Space in the mining process rather than the PoWs as seen in Bitcoin. Lastly, Bitcoin's public ledger, the blockchain, fails to provide sufficient anonymity as well, as pseudonyms are the only form of protection in this realm, which has been shown to be an insufficient amount of protection against cyber threats. A new currency known as Zerocash aims to address this anonymity issue and secure the privacy of its holders [12].

These problems presented themselves within the early history of Bitcoin and cryptocurrencies in general. In particular, one of the earliest adoptions of this new technology was on the dark web with cyber criminals on forums such as Silk Road. The illicit use of cryptocurrencies has been seen in marketplaces for assassins, attacks on businesses, sexual exploitation of adults and children, counterfeit goods and services, drug trades, and stolen credit card information [23].

2.5 Cryptocurrency Use in Real Markets and Regulation

Cryptocurrencies have been featured in news media and have been in intense debate over the past several years and months. In particular, an increasing number of companies in the United States and abroad are beginning to accept forms of cryptocurrency, mainly Bitcoin at this point. On the international scale, the idea of these digital forms of currency are becoming increasingly popular, and nations such as Papua New Guinea are proposing their own sovereign cryptocurrencies. These proposals look particularly enticing in nations that have high levels of financial instability of weak value behind their current currency. Papua New Guinea may indeed issue their own cryptocurrency known as the Torokina that would supposedly be backed by their supply of gold, rendering it hard money [17].

The implementation of such a currency structure is no trivial task, and even the United States has had some issues regarding the treatment of virtual currencies. U.S regulatory agencies are not in agreement on the classification of Bitcoin as an asset, as the Commodity Futures Trading Commission classifies Bitcoin as a commodity while the IRS treats it as property [24] [25]. Additionally, federal regulators have increasingly been interested in the realm of cryptocurrencies, and through FinCEN, the Financial Crimes Enforcement Network in the Treasury, they have the jurisdiction to rule over money transmission. However, the established definitions within this bureau do not allow cryptocurrencies such as Bitcoin and their associated online transactions to fit neatly into such descriptions. Any economic agent who partakes in the transmission of valuable goods that are substitutes for currency will be viewed as a money transmitter, in which FinCEN has regulatory authority. However, FinCEN is more concerned with how the transmission of currency occurs, including how and why the transmission was conducted, as well as what economic agents were involved. Virtual currencies do not, however, fit neatly into FinCEN's definition of currency, since Bitcoin and other altcoins are not legal tender in any country [26]. FinCEN has ruled in some cases over companies that function as an exchanger of virtual currencies, concluding that they must register as a money transmitter within their definitions.

Apart from debate as to whether Bitcoin fulfills the functions of money and general currencies, there has also been governmental debate as to whether Bitcoin constitutes a security. In particular, a security, as outlined in section 2(a)(1) in the Securities Act, is defined as:

> ... any note, stock, treasury stock, security future, security-based swap, bond, debenture, evidence of indebtedness, certificate of interest or participation in any profit-sharing agreement, collateral-trust certificate, preorganization certificate or subscription, transferable share, investment contract, voting-trust certificate, certificate of deposit for a security, fractional undivided interest in oil, gas, or other mineral rights, any put, call, straddle, option, or privilege on any security, certificate of deposit, or group or index of securities (including any interest therein or based on the value thereof), or any put, call, straddle, option, or privilege entered into on a national securities exchange relating to foreign currency, or, in general, any interest or instrument commonly known as a "security", or any certificate of interest or participation in, temporary or interim certificate for, receipt for, guarantee of, or warrant or right to subscribe to or purchase, any of the foregoing. (15 U.S. Code § 77b) [27]

Bitcoins are not technically classified as securities themselves, but in some cases, they are involved in investment contracts, thus rendering them an asset that falls within the authority of the securities act. Overall, one can conclude that cryptocurrencies fall within a legal gray area, as their definitions and uses are not consistent among economic agents and companies, making it nearly impossible to apply a consistent standard to this form of currency.

One other such issue regarding cryptocurrencies is the regulation of tokens, and the classification of some tokens as securities while others remain unregulated. By definition, a cryptocurrency or virtual coin is a proposed medium of exchange that operates on its own native blockchain, where transactions are recorded. On the other hand, tokens are more broad in their uses as they are representations of assets that are payable with coins, and the infrastructure for these tokens are typically built upon the existing blockchain for the underlying coin in which the token is associated with. In short, virtual currencies and coins function as direct mediums of exchange in a transaction, while tokens represent tradable assets [36]. This is a key distinction to be made since regulators will have to classify different types of digital assets and currencies when proposing regulatory policy. This has already proven to be an issue within the United States, as there are two major tokens that are traded on exchanges - utility tokens and security token. As the names of these tokens suggest, a utility token offers some utilitarian function on a platform, while a security token is a representation of equity or share in a company [34]. This is crucial within the discussion of tokens, as some have made attempts to over exaggerate their utility in which they offer in an attempt to evade regulation by the Securities and Exchange Commission, since utility tokens do not fall under the purview of the

SEC [37].

While the United States and other countries struggle to produce logical and consistent guidelines related to the regulation of virtual currencies and smart contracts, some countries have taken more definitive actions recently in order to start regulating such assets. Earlier this year, South Korea's Ministry of Economy and Finance added a legal amendment regarding the taxation of cryptocurrencies, stating that users will be taxed 20% on profits that exceed 2.5 million South Korean won, which is equivalent to approximately $2100 USD [33]. One other such example of a newer attempt of cryptocurrency regulation can be found in Japan, in which the Payment Services Act has served as the primary regulatory body over all cryptocurrency exchange businesses [35]. The Payment Services Act defines cryptocurrency broadly as the property value that can be used a payment for a good or service that is also mutually exchangeable among unspecified individual in which the transfer occurs through an electronic data processing system. In fact, cryptocurrency exchanges must be granted permission via local Finance Bureaus under the Payment Services Act. Additionally, these businesses must also establish verified security systems in order to protect customer's assets, and must manage these assets separately from their own [35].

2.6 Behavior in Cryptocurrency Markets

There have been multiple studies and experiments conducted over the past several years in an attempt to classify and explain consumer behavior within crypto markets. In particular, a study conducted by Xi, O'Brien, and Irannezhad determined that "the significant factors of the choice of investment in cryptocurrency include age, gender, education, occupation, and previous investment experience" [39] using a web-based revealed preference survey and applying a multinomial logit model. Other research has shown that investors' choices in investing in cryptocurrency markets is affected by the choices of others' investments. Further, results have shown that individuals are significantly affected by "herding theory factors, prospect theory, and heuristic theory" [40] when making investment decisions in cryptocurrency markets.

Overall, when examining Bitcoin in particular, notable features that shall be reflected in the model include its inflationary protection via its hard cap of 21,000,000 BTC supply, along with its appeal as a currency itself. Additionally, this new form of fiat currency offers consumers a general and unique decentralized medium of exchange that leverages online security and cryptography. A final key takeaway is in regard to its price volatility and movement alongside other traditional assets, and the current lack of regulation within these markets. These very characteristics of this infantile market offer new questions and avenues of investigation that will be explored in the proceeding section.

Chapter 3

The Model

In classic microeconomic theory, two dimensional plots are often analyzed after a shift in supply or demand has occurred given a change in a parameter within the given model. Such a change in a parameter yields a different supply curve or demand curve, which in turn shifts the market equilibrium point within the model. This analysis is quite useful when analyzing the effects of these different parameters, and the modeling approach is referred to as ”comparative statics” within the field of microeconomics.

In traditional theory, an introductory look into comparative statics will first start with supply and demand with linear functions, where simplifying assumptions are made regarding individual preferences within the model. When attempting to create a more ”true to life” model, analysis begins with the introduction of a utility function, where the variables within this functions are the goods that are being studied. Classical utility functions are those such as Cobb-Douglas utility, quasi-linear utility, as well as other simple polynomial forms. Once a utility function has been specified, one can solve for the demand for both goods given the budget constraint for an arbitrary consumer. When attempting to extend the traditional utility functions into the case where there are three goods within the model, the functions yield utility maximizing (Marshallian) demand functions for the goods that encounter the same ”problems” as in the two good case, such as no substitution between goods, no income effect, or simply unsolvable systems. Ultimately, a symmetric polynomial form over three goods yields demand functions that satisfy the desired properties, and these may be aggregated to determine market demand, ultimately being compared to a market supply curve as well.

3.1 Model Outline

When examining consumer choice in real markets, a typical economic agent may separate their assets into the following three classes:

- Cash
- Cryptocurrency
- Stocks/Bonds

The determination regarding the amount of each asset to hold in a given portfolio by a consumer weighs the positive and negative characteristics of each asset. In particular, it is natural to hypothesize that individuals understand that their cash holding offer no inflation protection, but fulfill the functions of money exactly (by definition). Economic agents who wish to have cryptocurrency holdings would likely understand its unique inflation protection characteristic, but may not fully grasp how well it fulfills the three functions of money. In terms of the traditional asset class, stocks and bonds are prototypical assets that fall within this category, and a majority of Americans understand and own them. Therefore, when constructing a model, a standard approach would begin with a general utility function with the following parameters:

- x: Crypto
- y: Cash
- z: Stocks, bonds, and all other traditional financial assets that produce regular returns such as interest payments and dividends

Recalling conventional micro-economic theory, a rational consumer wishes to maximize their utility over a given budget constraint across their goods. In particular, this corresponds to choosing the bundle of goods (X, Y), which in our case will be (X, Y, Z), such that the budget constraint is tangent to the indifference curve at this bundle. This occurs when the marginal rate of substitution is equal to the price ratio between the two goods. The marginal rate of substitution is the slope of the indifference curve, where the price ratio is the slope of the budget constraint.

3.2 Utility Functions

3.2.1 Cobb-Douglas

Of the simpler utility functions, one would first try a formulation similar to that of a Cobb-Douglas utility function. This is a utility function of the form:

$$U(x, y) = x^{\alpha} y^{\beta}$$

where α and β are typically preference parameters such that $\alpha, \beta \in [0, 1]$ and $\alpha + \beta = 1$. The natural extension would be a function of the form $U(x, y, z) = x^{\alpha} y^{\beta} c^{\gamma}$ in the case mentioned above, but recall first that a Cobb-Douglas utility function yields Marshallian demand functions of the form (where M is income):

$$x^* = \frac{\alpha M}{p_x}, y^* = \frac{\beta M}{p_y}$$

Multiplying by the prices of these demand functions, we get the expenditure on x and y to be $p_x x = \alpha M$ and $p_y y = \beta M$. This is not feasible when looking at real consumer behavior in the markets for stocks, bonds, and cryptocurrencies, for example, since there is no substitution between goods when any of the prices change.

3.2.2 Quasi-Linear Forms

Another functional form that one may wish to select would be the quasi-linear form. In the case of the three asset classes listed above for the model, the extension of the two good quasi-linear form would be as follows:

$$U(x, y, z) = ax^{\alpha} + by^{\beta} + cz$$

Now, note that the budget constraint would also be quite similar to the two good case, as it would be $M = p_x x + p_y y + p_z z$. The Marshallian demand functions for this given utility function are solutions to the following optimization problem:

$$\max_{\text{s.t } xp_x + yp_y + zp_z \leq M} U(x, y, z) = \max_{\text{s.t } xp_x + yp_y + zp_z \leq M} (ax^{\alpha} + by^{\beta} + cz)$$

Lagrange Multiplier Approach for Three Goods

One canonical approach to solving this optimization problem is to use Lagrangians. Let us define the following function, with Lagrange multiplier λ:

$$\boldsymbol{\mathcal{L}}[x, y, z, \lambda] = U(x, y, z) - \lambda(p_x x + p_y y + p_z z - M)$$

This is the typical formulation taken, and recall that the first order conditions for this function are such that its first order partial derivatives are equal to 0. Thus, we have the following three equalities:

$$\frac{\partial \boldsymbol{\mathcal{L}}}{\partial x} = MU_x - \lambda p_x = 0 \rightarrow MU_x = \lambda p_x$$
$$\frac{\partial \boldsymbol{\mathcal{L}}}{\partial y} = MU_y - \lambda p_y = 0 \rightarrow MU_y = \lambda p_y$$
$$\frac{\partial \boldsymbol{\mathcal{L}}}{\partial z} = MU_z - \lambda p_z = 0 \rightarrow MU_z = \lambda p_z$$

While also note that $\frac{\partial \boldsymbol{\mathcal{L}}}{\partial \lambda} = M - p_x x - p_y y - p_z z = 0$, but this simply returns the budget constraint. Notice that by taking the ratios of each of these equations, one can obtain the following equality:

$$\frac{MU_j}{MU_k} = \frac{p_j}{p_k}$$

where $j, k \in \{x, y, z\}$. These yield that that marginal rate of substitution for any two of the goods among x, y, and z to be equal to their price ratio. Although this was the expected result and natural extension from the case of two goods, Lagrangians help in the formalization of the utility maximization problem. Using this, let the analysis return to the utility function of the specified form above. First, the marginal utilities:

$$U(x, y, z) = ax^\alpha + by^\beta + cz \rightarrow MU_x = \alpha a x^{\alpha-1}, MU_y = \beta b y^{\beta-1}, MU_z = c$$

Using the result proved above, one can solve for x and y as follows:

$$\frac{MU_x}{MU_z} = \frac{p_x}{p_z} \rightarrow \frac{\alpha a x^{\alpha-1}}{c} = \frac{p_x}{p_z} \rightarrow x^* = \left[\frac{cp_x}{\alpha a p_z}\right]^{1/(\alpha-1)}$$
$$\frac{MU_y}{MU_z} = \frac{p_y}{p_z} \rightarrow \frac{\beta b y^{\beta-1}}{c} = \frac{p_y}{p_z} \rightarrow y^* = \left[\frac{cp_y}{\beta b p_z}\right]^{1/(\beta-1)}$$

Substituting back into the budget constraint, the following Marshallian demand function for z can be found:

$$p_x x + p_y y + p_z z = M \rightarrow p_x \left[\frac{cp_x}{\alpha a p_z}\right]^{\frac{1}{\alpha-1}} + p_y \left[\frac{cp_y}{\beta b p_z}\right]^{\frac{1}{\beta-1}} + p_z z = M$$

$$z^* = \frac{M}{p_z} - \left(p_x \left[\frac{cp_x}{\alpha a p_z}\right]^{\frac{1}{\alpha-1}}\right)/p_z - \left(p_y \left[\frac{cp_y}{\beta b p_z}\right]^{\frac{1}{\beta-1}}\right)/p_z$$

Now, relating the marginal rates of substitution to the price ratio for goods x and y yields the following:

$$\frac{MU_y}{MU_x} = \frac{p_y}{p_x} \rightarrow \frac{\beta b y^{\beta-1}}{\alpha a x^{\alpha-1}} = \frac{p_y}{p_x} \rightarrow y = \left[\frac{\alpha a x^{\alpha-1} p_y}{\beta b p_x}\right]^{\frac{1}{\beta-1}}$$

When attempting to solve for x^*, one would have to solve y in terms of x, where x is linear in order to factor it out of the budget constraint. Hence, such a method of solving for Marhsallian demand functions is impossible in this case, unless further assumptions or simplifications can be imposed that allow for y to be linear in x, such as $\alpha = \beta$. Thus, the most general utility function that has solvable Marshallian demands is of the form $U(x, y, z) = ax^\lambda + bx^\lambda + cz$. In such a case, we would have the simplification:

$$y = \left[\frac{ax^{\lambda-1}p_y}{bp_x}\right]^{\frac{1}{\lambda-1}} \rightarrow y = x\left[\frac{ap_y}{bp_x}\right]^{\frac{1}{\lambda-1}}$$

Substituting into the budget constraint and solving for the utility maximizining value of x:

$$p_x x + xp_y\left(\frac{ap_y}{bp_x}\right)^{\frac{1}{\lambda-1}} + M - \left(p_x\left[\frac{cp_x}{\alpha ap_z}\right]^{\frac{1}{\lambda-1}}\right) - \left(p_y\left[\frac{cp_y}{\beta bp_z}\right]^{\frac{1}{\lambda-1}}\right) = M$$

$$x^* = \left[\left(p_x\left[\frac{cp_x}{\alpha ap_z}\right]^{\frac{1}{\lambda-1}}\right) + \left(p_y\left[\frac{cp_y}{\beta bp_z}\right]^{\frac{1}{\lambda-1}}\right)\right]\Bigg/\left[p_x + p_y\left(\frac{ap_y}{bp_x}\right)^{\frac{1}{\lambda-1}}\right]$$

Similarly, since utility is defined arbitrarily with similar formulations for x and y, without loss of generality, we have the Marshallian demand for y:

$$yp_x\left(\frac{bp_x}{ap_y}\right)^{\lambda-1} + p_y y + M - \left(p_x\left[\frac{cp_x}{\alpha ap_z}\right]^{\frac{1}{\lambda-1}}\right) - \left(p_y\left[\frac{cp_y}{\beta bp_z}\right]^{\frac{1}{\lambda-1}}\right) = M$$

$$y^* = \left[\left(p_x\left[\frac{cp_x}{\alpha ap_z}\right]^{\frac{1}{\lambda-1}}\right) + \left(p_y\left[\frac{cp_y}{\beta bp_z}\right]^{\frac{1}{\lambda-1}}\right)\right]\Bigg/\left[p_x\left(\frac{bp_x}{ap_y}\right)^{\lambda-1} + p_y\right]$$

Notice that these demand functions are algebraically messy and distractingly complex, making the original utility function a subprime candidate. Additionally, by this three good case extension of traditional quasi-linear utility functions, we have that the linear term, z, is the only term with demand dependent on income, meaning that consumers will spend a fixed portion of their income on x and y, then pour the rest of the income into z, which is unrealistic when analyzing traditional portfolios. Thus, let us consider a different formulation for utility.

3.2.3 Symmetric Polynomial Forms

This new formulation could be symmetric about all three variables, such as utility:

$$U(x, y, z) = \alpha x^\lambda + \beta y^\lambda + \gamma z^\lambda$$

With $\lambda \in [0,1]$ in order to capture an individual's decreasing marginal utility. Let $\lambda = \frac{1}{2}$ for the moment. This yields the following marginal utilities for the three goods:

$$MU_x = \frac{\alpha}{2\sqrt{x}}, MU_y = \frac{\beta}{2\sqrt{y}}, MU_z = \frac{\gamma}{2\sqrt{z}}$$

Equating marginal rates of substitution with price ratios:

$$\frac{MU_x}{MU_y} = \frac{p_x}{p_y} \rightarrow \frac{\alpha\sqrt{y}}{\beta\sqrt{x}} = \frac{p_x}{p_y} \rightarrow y = \frac{\beta^2 p_x^2 x}{\alpha^2 p_y^2}$$

Using the symmetries of the utility function, when performing the same procedure with the variables x and z, we can see:

$$z = \frac{\gamma^2 p_x^2 x}{\alpha^2 p_z^2}$$

Substituting into the budget constraint and isolating x yields the following utility maximizing demand (Marshallian demand) for x:

$$x\left[p_x + \frac{\beta^2 p_x^2}{\alpha^2 p_y} + \frac{\gamma^2 p_x^2}{\alpha^2 p_z}\right] = M$$

$$x^* = \frac{M}{p_x\left[1 + \frac{p_x}{\alpha^2}\left(\frac{\beta^2}{p_y} + \frac{\gamma^2}{p_z}\right)\right]}$$

Both y^* and z^* can be found using the symmetries within the utility function quite easily as follows:

$$y^* = \frac{M}{p_y\left[1 + \frac{p_y}{\beta^2}\left(\frac{\alpha^2}{p_x} + \frac{\gamma^2}{p_z}\right)\right]}$$

$$z^* = \frac{M}{p_z\left[1 + \frac{p_z}{\gamma^2}\left(\frac{\alpha^2}{p_x} + \frac{\beta^2}{p_y}\right)\right]}$$

Thus, such a utility function more realistically captures the income effect on all three variables, and still has demand functions dependent on the relative prices of each good. Additionally, these functions can be fitted to real world data from consumer portfolios by altering the preference parameters α, β, and γ. Thus, let us choose this formulation for utility going forward in the model.

3.3 Substitution and calculations of parameter values

With the above formulations of Marshallian demand functions, or utility maximizing demand functions for the three goods x, y, and z, values may be substituted into the equations in order to observe demand as a function solely dependent on parameter values α, β, and γ, or the consumer preference parameters. In this case, let $M = 100000$, $p_x = 1000$, $p_y = 1$ (cash is the numeraire), and $p_z = 100$. With this, the demand equations become:

$$x^* = \frac{100}{\left[1 + \frac{1000}{\alpha^2}\left(\beta^2 + \frac{\gamma^2}{100}\right)\right]}$$

$$y^* = \frac{100000}{\left[1 + \frac{1}{\beta^2}\left(\frac{\alpha^2}{1000} + \frac{\gamma^2}{100}\right)\right]}$$

$$z^* = \frac{1000}{\left[1 + \frac{100}{\gamma^2}\left(\frac{\alpha^2}{1000} + \beta^2\right)\right]}$$

In terms of the demand parameters, one can set expenditure ratios for each good in order to calculate these corresponding parameters, such as having 10% of income in cash holdings, 10% in cryptocurrency assets, and 80% in traditional financial assets. The following MatLab code performs a calculation for such parameters, α, β, and γ as documented in Appendix A.

With the rendering of asset ratios outlined above, the program yields parameter values of sola $= \alpha = -\sqrt{5}/2$, solb $= \beta = -\sqrt{2}/40$, and solc $= \gamma = 1$. Changing this distribution of assets to percentx $= 0.05$, percenty $= 0.10$, and percentz $= 0.85$, the system solves to sola $= \alpha = -\sqrt{170}/17$, solb $= \beta = -\sqrt{15}/30$, and solc $= \gamma = 1$. Notice that the solutions to α and β are reported to be negative, but are more logically interpreted to be positive, since preference is assumed to satisfy monotonicity, where they always prefer more of the asset rather than less. Additionally, keeping α and $\beta > 0$ does not change the calculated Marshallian demand functions, as these terms are squared in the equations above.

3.4 Graphing Marshallian Demand

Using these parameter values, one can begin to plot these Marshallian demand functions in terms of each good's respective price, keeping in mind that the parameters in use only apply to a specific distribution of assets within an economic agent's portfolio. First, cryptocurrency, or x:

$$x^* = \frac{100000}{p_x\left[1 + \frac{p_x}{1.1^2}\left(\frac{0.04^2}{1} + \frac{1^2}{100}\right)\right]}$$

$$x^* \approx \frac{100000}{p_x + 0.00959(p_x)^2}$$

One may then observe the following graph for this demand curve, following traditional economic convention with quantity demanded on the horizontal axis and the corresponding price on the vertical axis. Note that Figure 3.1 below is a representation of simulated market demand and supply, with formulations that differ quite substantially from that of the individual demand curve outlined above. Note that the market demand for a particular good, in this case X, or cryptocurrency, is the horizontal summation of all individual demand curves across individuals within the market. Operating under the assumption that all individual demand curves are identical to one another, one can perform such an aggregation simply by scaling the right hand side of the equation above by the number of consumers within the market. One common metric that has been reported in terms of cryptocurrency is that around 16% of Americans have had some form of experience with investment in cryptocurrency, which corresponds to approximately 50 million Americans who have been personally involved in the cryptocurrency market [41]. Thus, the aggregate demand curve uses the figure of 50 million as the appropriate scalar for the number of individual consumers within the market, which is shown the aggregate demand curve in Figure 3.1.

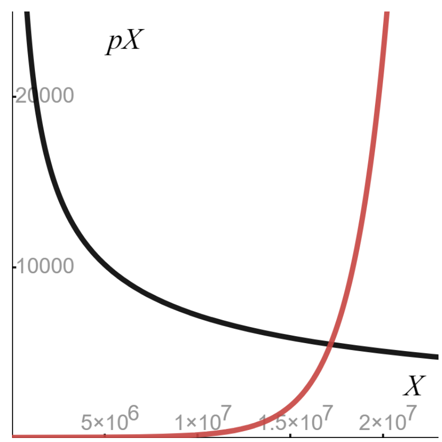


Figure 3.1: Market Demand for cryptocurrency as a function of its price, with an intersection with market supply

In terms of the supply side of the model, one should first note that modelling cryptocurrency as a whole is simply not feasible, as the supply structure for each prominent cryptocurrency is so vastly different. Most notably, Bitcoin has entirely fixed supply while Ether is controlled only by an annual minting cap. Thus, in order to capture the most investors in cryptocurrency markets, the model assumes a supply structure that mirrors that of Bitcoin. Now, recall that the reward mechanism for mining is such that the reward is halved every four years. Thus, when examining the total number of Bitcoin in circulation since its creation, one would notice the general logarithmic growth of the asset, which is consistent with the reward mechanism described above. Thus, an inverse relationship is assumed within the model, where price increases exponentially with increases in cryptocurrency, albeit very slowly at first in an attempt to match real-world trends. Thus, a functional form for supply is given to be $p_X = e^{0.0000005X}$. Such a function mimics the behavior of BTC quite closely, as its price did not start to move exponentially until after at least 10 or 11 million BTC were in circulation, which is exhibited by the function as well. Additionally, in terms of the domain of interest in the graphs, it appears to approach a vertical asymptote of $X \approx 21$ million, which is indeed the supply cap for Bitcoin. Thus, with all assumptions and formulations outlined, parameters are now able to changed in order to observe shifts in this demand curve and its resulting equilibrium with the fixed supply curve.

It is also useful to observe the market demand functions and corresponding graphs for the other two goods within the model. Below are the explicit demand functions for cash and traditional assets:

$$y^* = \frac{100000}{p_y\left[1 + \frac{p_y}{0.04^2}\left(\frac{1.1^2}{1000} + \frac{1^2}{100}\right)\right]} \longrightarrow y^* = \frac{100000}{p_y + 7.00625(p_y)^2}$$

$$z^* = \frac{100000}{p_z\left[1 + \frac{p_z}{1^2}\left(\frac{1.1^2}{1000} + 0.04^2\right)\right]} \longrightarrow z^* = \frac{100000}{p_z + 0.00281(p_z)^2}$$

Using these Marshallian demand functions, one can plot each good as a function of its price as demonstrated above for cryptocurrency:

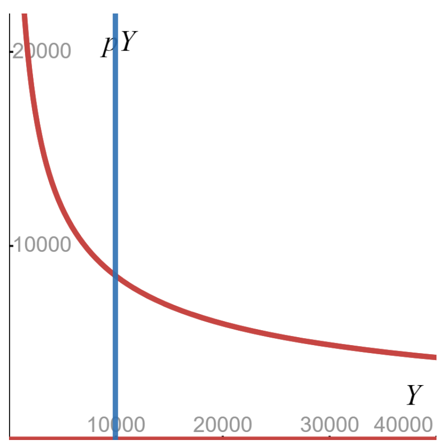


Figure 3.2: Market Demand for cash as a function of its price, with an intersection with market supply

Arbitrary supply functions have been used in order to approximate a logical equilibrium point for these two goods. For the cash supply, following traditional economic modeling, a vertical money supply has been assumed where

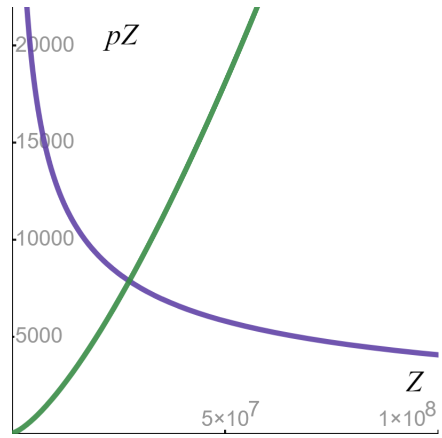


Figure 3.3: Market Demand for stocks, bonds, and all other traditional assets as a function of their price, with an intersection with market supply

$Y = 10000$, where Y (cash) is modeled on the horizontal axis and its price on the vertical axis. This semi-arbitrary value was selected in order to assume an equilibrium at a neutral or approximately unitary elasticity of demand. Additionally, a supply curve given by the equation $p_z = 0.0000003Z^{1.4}$ has been assumed for the goods that fall under the traditional asset class. With this provision of supply and demand curves for the three goods within the model, analysis may now be performed in accordance with the methodology used in comparative statics.

Chapter 4

Analysis

As discussed at length above, the demand functions that were implemented were ultimately selected due to their ability to satisfy a number of desired properties, such as the income effect and substitution between the goods. With these properties, a guided analysis regarding these income effects, price effects, and preference parameters is necessary in order to gather further insight into the model and consumer behavior within these markets. With explicit equations and graphs as outlined previously, changes in income may be observed as well as price effects, such as demand shifts in stocks and bonds can simultaneously change the demand for cryptocurrency and vice versa.

Additionally, the key parameter within the model is α, or the preference parameter for cryptocurrency bundles, where this parameter may be decomposed into its respective parts that make the asset appealing to consumers. Of course, increases in this parameter are hypothesized to increase demand for cryptocurrency while decreasing demand for the two other goods, assuming a fixed income. Conversely, a decrease in this parameter is hypothesized to decrease demand for cryptocurrency while demand for the other two goods increases. This substitution effect is captured by both the prices and relative preferences among the three goods.

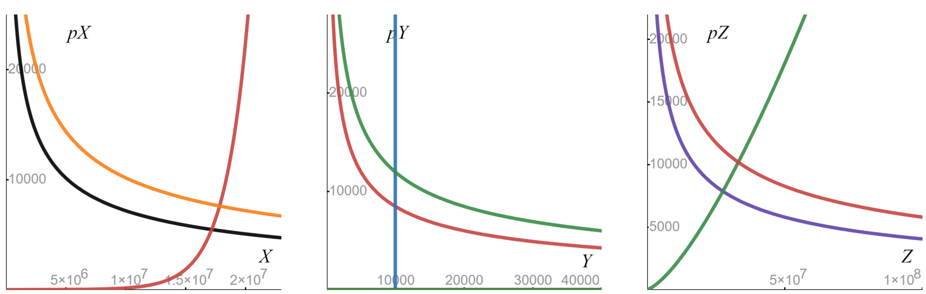
4.1 Income effects

The first and potentially simplest analysis that may be performed when the initial model has been created is to first examine how changes in consumer income levels effect the corresponding markets of all three assets. In particular, these shift are explicitly demonstrated in Table 4.1. Consider the following market equilibria before and after a doubling of consumer income in the markets for the three goods, as demonstrated in Figure 4.1. Analyzing these numbers, one

$(Q_X^1, p_X^{eq1}) = (17.2 \text{ million}, 5450)$	$(Q_X^2, p_X^{eq2}) = (17.9 \text{ million}, 7590)$
$(Q_Y^1, p_Y^{eq1}) = (10000, 8450)$	$(Q_Y^2, p_Y^{eq2}) = (10000, 11950)$
$(Q_Z^1, p_Z^{eq1}) = (27.6 \text{ million}, 7850)$	$(Q_Z^2, p_Z^{eq2}) = (33.2 \text{ million}, 10170)$

Table 4.1: Equilibrium Price and Quantity for each good before and after income shifts

sees that they yield the expected results that are predicted from theory. In particular, notice that the market for cash, Y, has completely inelastic supply, which is a generally safe assumption for short term market analysis. Therefore, an increase in income stimulates an increase in demand, and has a correspondingly large price swing despite the quantity remaining fixed. Additionally, the supply curve for cryptocurrency, X, is also exponentially inelastic towards the 21 million supply point. Similarly to cash, there is a small shift in quantity demanded but a fairly large swing in prices. Lastly, with a nearly linear supply function for traditional assets, corresponding to underlying linear productivity growth within the economy, it is apparent that this market has the largest shift in quantity demanded with a comparatively similar shift in asset price in the other two markets.



(a) New Simulated Demand in Orange

(b) New Simulated Demand in Green

(c) New Simulated Demand in Red

Figure 4.1: Effects on demand when income doubles

The notable qualities of the graphs as outlined above only tell part of the story, and more analysis may be performed in order to fully understand and quantify the results that are seen. In particular, observe the following percentage changes in quantity and demand for the three goods: As to be expected, since cash has a completely inelastic supply while cryptocurrency has an exponential but not completely inelastic supply, these goods produce large price swings with small changes in quantity demanded while traditional assets appear to be more stable. Cryptocurrency and cash have comparable changes in percent changes

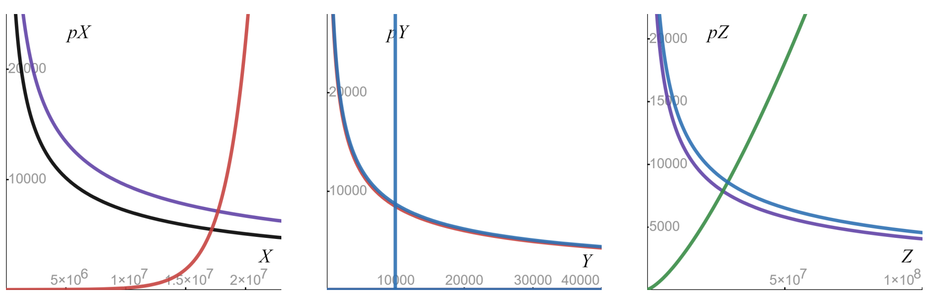
	ΔQ	Δp
X	3.8%	39.1%
Y	0%	41.4%
Z	20.3%	29.6%

Table 4.2: Percent changes in quantities and price when income doubles

in their prices from a change in consumer income, and this is a logical result that stems from the elasticities involved within the demand curve and supply curves for each good.

4.2 Price effects

Now, one may wish to observe a shift in demand from an increase in another asset, for example the traditional asset class, z. For example, consider a price increase in z from $p_z = 100 \to p_z = 200$. This change in demand is shown in Figure 4.2a below. The result is qualitatively quite similar to the demand shift shown in Figure 4.1a above, but it appears as though the doubling of the relative price of traditional assets, z, stimulates a smaller increase in demand for cryptocurrency, x, than the doubling of consumer income M. Now examine



(a) New Simulated Demand in Purple

(b) New Simulated Demand in Blue

(c) New Simulated Demand in Blue

Figure 4.2: Effects on demand when p_z doubles on X, and the effects of p_X doubling on markets for Y and Z

the following market equilibria resulting from these price shifts in each market, keeping in mind that the initial equilibria points for X, Y, and Z, denoted by (Q^1_X, p^{eq1}_X), (Q^1_Y, p^{eq1}_Y), and (Q^1_Z, p^{eq1}_Z) respectively, remain the same in the subsequent analysis:

One quite interesting result from this modeling portion is the fact that an increase in prices of other assets in a given portfolio does not induce as

$(Q_X^2, p_X^{eq2}) = (17.7 \text{ million}, 7100)$
$(Q_Y^2, p_Y^{eq2}) = (10000, 8690)$
$(Q_Z^2, p_Z^{eq2}) = (29.4 \text{ million}, 8560)$

Table 4.3: Equilibrium Price and Quantity for each good before and after price shifts

large of an increase in demand as an increase in income of the same magnitude. When examining the market for cash, a doubling in the amount of income corresponds to a demand swing that swings prices up in the thousands. On the other hand, when the price of cryptocurrency doubles, it stimulates an increase in the demand for cash at a level that is an order of magnitude smaller than the shift resulting from income changes, or in particular, an increase in price of a couple hundred. One potential explanation for this phenomena is the fact that cryptocurrency prices outscale the prices of cash and assets found in traditional asset classes by a large amount, recalling the pricing scheme derived in a previous chapter. Also, examining the demand functions for Y and Z, the price of cryptocurrency only appears in a fraction within the denominator. The implications of this structure are seen in Figure 4.2, since an increase in this denominator from 1000 to 2000 has smaller demand swings compared to when the numerator, consumer income, increases from $\$100,000$ to $\$200,000$.

Moving on from the qualitative and theoretical analysis as presented above after seeing the graphs, it is now important to consider the percent changes in quantity demanded and price for each of the goods within the model as presented in the previous section: Once again, as is the case with changes

	ΔQ	Δp
X	3.1%	30.2%
Y	0%	2.8%
Z	6.4%	9.1%

Table 4.4: Percent changes in quantities and price when prices double

in consumer income, cryptocurrency markets exhibit high price volatility, this time overshadowing the small price swings within the markets for cash and traditional assets. Additionally, another trend to note is that assets that fall within the "traditional" basket once again exhibit comparable percent changes in quantity demanded and price, which again is a logical result that follows from the more elastic supply form that has been taken. Once again, cryptocurrency exhibits some of the largest price swings with small percent changes in quantity demanded.

4.3 Consumer Preferences

Modern economists and modern economic theory has shifted to focus on the *perception* of different goods and services, and how individuals do not always have access to all information or ability to make logical and rational decisions. This then leads into the discussion of consumer preferences on a good, which is indeed influenced by their perception of that extent to which the good satisfies various noteworthy and important characteristics. Shifts in these preference parameters are of particular interest since these can vary very quickly and substantially among consumers, and the effects of these preference parameters on other goods within the economy is unknown and worth studying in the subsequent subsections.

4.3.1 Cryptocurrency Preference (Shifts in Alpha)

Using the same formulation above, demand shifts may be demonstrated, such as a shift in demand following a change in preference parameters for cryptocurrency, X. Recall that the parameters of the goods determine the distribution of asset ratios, and these parameters are determined by individual preferences. The coefficient on the cryptocurrency term within the utility function is denoted by α. This term may be decomposed as follows: $\alpha = Ip + Fm$, where Ip is the *perceived* inflationary protection preference parameter and Fm is the *perceived* fulfillment of the functions of money. Thus, if the perception of at least one of these characteristics increases for the general public, α will then increase, stimulating a shift in demand that is demonstrated in Figure 4.3, where α is twice as large:

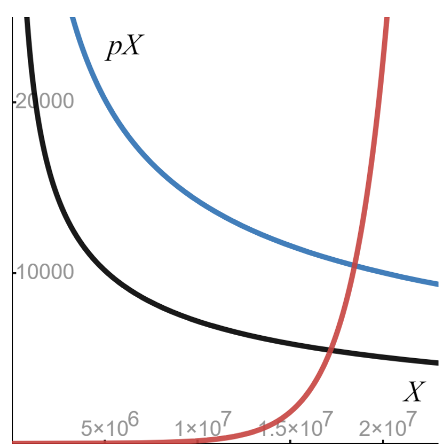
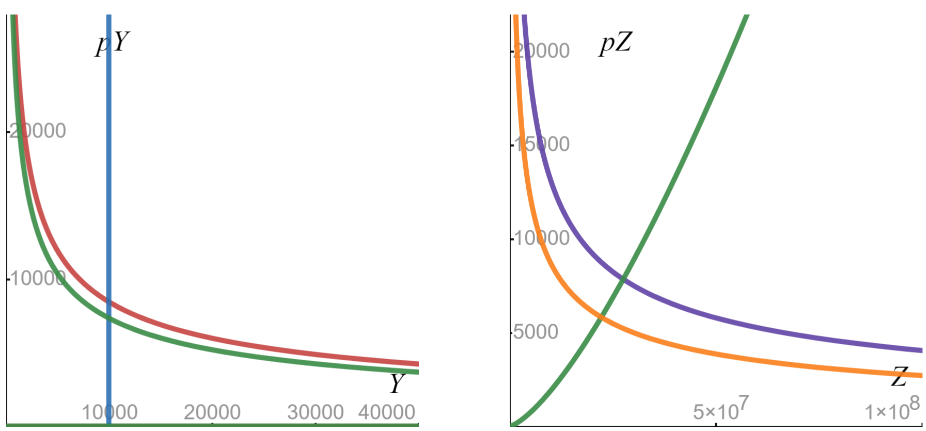


Figure 4.3: The black curve is identical to the one above, while the blue curve is the result of a demand shift from α being twice as large

As is to be expected, such a change in preference parameters yields greater demand for cryptocurrency at at every given price. In particular, there seems to be larger increases in demand where the price elasticity of demand, $e_{(pX)}$, is locally unitary, or more specifically where elasticity is changing from less elastic to more elastic.

As seen in Figure 4.3, the market equilibrium price and quantity is given by approximately $Q_X^1 = 1.7208 * 10^7$ and $p_X^{eq1} = 5453.42$. However, when all individuals within the market have an α that is twice as large as that shown by the black curve in Figure 3.1, the demand for cryptocurrency X shifts out and to the right as represented by the blue curve in Figure 4.3. Here, the resulting new market equilibrium quantity and price are given by $Q_X^2 = 1.8501 * 10^7$ and $p_X^{eq2} = 10412.23$. Notice that since the supply of cryptocurrency is largely inelastic, there is a large price swing from a relatively small increase in demand. In particular, demand only increased 15 million to 16 million units, which is best characterized as an incremental increase in demand. However, such an increase has a considerable effect on the price of a cryptocurrency, nearly doubling its equilibrium price. If all consumers within the market learn of the inflation protection offered by cryptocurrency and understand its fulfillment for each function of money, then α could increase in such a manner, generating a large price swing as demonstrated in the model, assuming the same asset ratio and price distribution as outlined above.

Now, when examining the change in market equilibrium between Figure 4.3 and Figure 4.2a, one qualitatively and quantitatively notes that the shift in demand from doubling α is greater than that of doubling p_z. Such an increase can be observed within the following two graphs for demand for Y and Z:



(a) New Stimulated Demand in Green

(b) New Stimulated Demand in Orange

Figure 4.4: Effects on demand when α doubles on Y and Z

It is also important to consider the effect that an increase in α has on the other goods within the model economy, in particular, to what extent does α stimulate a decrease in demand for cash and traditional assets. Recall that for cash, the initial equilibrium point is given to be $(Q_Y^1, p_Y^{eq1}) = (10000, 8447.70)$. The new stimulated demand in green as seen in Figure 4.4a produces a new equilibrium point given by $(Q_Y^2, p_Y^{eq2}) = (10000, 7342.18)$. Conversely, recall that for traditional assets, the initial equilibrium point is given to be $(Q_Z^1, p_Z^{eq1}) = (2.762 * 10^7, 7850.14)$. The new stimulated demand in orange as seen in Figure 4.4b produces a new equilibrium point given by $(Q_Z^2, p_Z^{eq2}) = (2.231 * 10^7, 5821.26)$. Notice that such a shift in preferences for consumers such that they find cryptocurrency more appealing leads to a larger downward shift in demand for traditional assets than it does for cash. Looking at the demand functions for these assets, one potential explanation for such a phenomena is the multiplier within the denominator for Y given by p_y/β^2 and p_z/γ^2 for Z. Since the parameter value β is far smaller than γ, the multiplier for Y scales down any movement within the term $\alpha^2/p_x + \gamma^2/p_z$ quite considerably, and any such doubling of α or p_x has less of an impact than it otherwise would for the term $\alpha^2/p_x + \beta^2/p_y$ for Z, due to Z having a smaller multiplier due to larger parameter value γ.

Theory aside now, consider the following table of quantity and price shifts within the three good system when α increases, or consumer preference for alpha doubles: The trend continues within this experiment, as cryptocurrency

	ΔQ	Δp
X	7.5%	90.9%
Y	0%	-13.1%
Z	-19.2%	-25.8%

Table 4.5: Percent changes in quantities and price when α doubles

again appears to be the most volatile of the three assets, nearly doubling in price when consumer preference for this good doubles. Additionally, note that traditional assets are forecasted to take a harder hit to their equilibrium prices within the market in comparison to the market for liquid cash. However, most notably, α generates a large price swing that outweighs changes in consumer income and the prices of the other goods in a given consumer's portfolio.

4.3.2 Cash Preference (Shifts in Beta) and Traditional Asset Preference (Shifts in Gamma)

Now, observe other such differences, such as doubling the other preference parameters: β and γ:

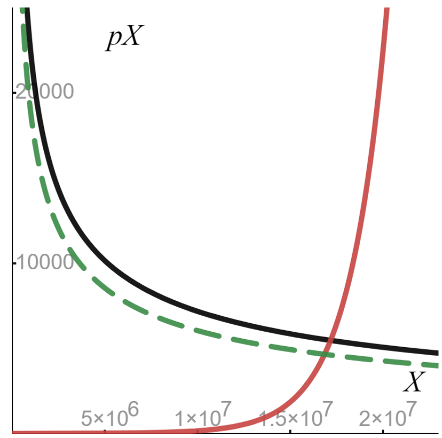


Figure 4.5: The dashed green curve is the new demand for cryptocurrency when preferences for cash, β, double (Demand of coures decreases!).

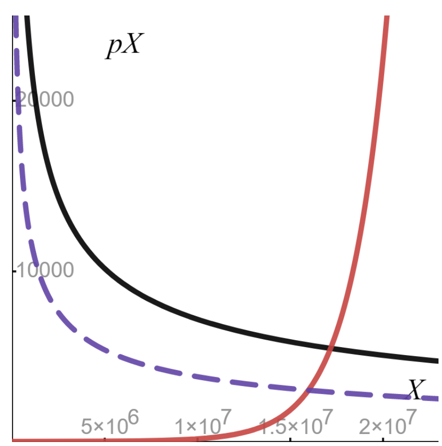


Figure 4.6: The dashed purple curve is the new demand for cryptocurrency given an increase in preference for γ, in particular an increase of a factor of 2.

Figure 4.4 and Figure 4.5 again demonstrate logical and expected behavior when such preferences change within the market. In either case, when cash or traditional assets become more desirable, demand for cryptocurrency decreases since income, M, is divided amongst these three assets. One considerable result from these trials was that the demand for cryptocurrency decreased significantly more when γ was doubled in comparison to when β was doubled. The key characteristic assumed regarding the cash asset is that individuals invest some share of their income into this asset as it perfectly fulfills the function of money. On the other hand, the key characteristic assumed regarding the traditional asset class is that individuals are drawn to its ability to provide regular returns over time such as interest payments and dividends. Hence, the model captures a type of risk-aversion by consumers of sorts. In particular, the stimulated decrease in demand from an increased preference in cash is overridden by the stimulated decrease from an increase in preference for stocks, bonds, and other traditional assets. Thus, demand in cryptocurrency markets is influenced more substantially by changes in preference for stocks and bonds than it is for preferences for cash. Thus, if small, regular, and consistent returns become more favorable, and/or when individuals exhibit more risk-averse behavior within the markets, the affect on cryptocurrency demand is quite noticeable in comparison to an increase perception of inflation protection.

Again, insight is gained by analyzing the percent changes in the quantities demanded and prices of cryptocurrency when consumer preference for the other two goods within the model increase, yielding: One will note that shifts

	ΔQ	Δp
X_β	-1.9%	-15%
X_γ	-1.5%	-45%

Table 4.6: Percent changes in quantities and price in X when β and γ increase

in γ create larger price swings for cryptocurrency markets than do shifts in β. Once again, explanations for this phenomena fall back upon the functional form that was specified for the demand functions. From this modeling section, one will notice that traditional assets respond *more* to changes in preference parameters in comparison to cash or liquid assets.

4.4 Summary

Through each trial and experiment as outlined in the subsections above, cryptocurrency has been shown to be the most volatile of the three assets throughout changes in income, prices of other goods, and preference parameters for consumers. Additionally, traditional assets have been fairly predictable in their movements, as they have comparable swings in price and demand given a change within the model. One notable result from these effects is the fact that changes in the prices of other goods within the model produce the smallest percent changes in demand and price for the other goods. In particular, this implies that both income and consumer preferences have a greater effect on price and demand swings within the markets for the three goods. Additionally, the preference parameter α had quite an extreme impact on the price for cryptocurrency, nearly doubling its price. However, the inelasticity of supply for cryptocurrency allowed for this large price swing to occur over a small change in quantity demanded, specifically a 7.5% increase in demand induces a 90.9% uptick in prices for the good.

Chapter 5

Conclusion

Cryptocurrency as a concept and its place in the real economy is a source of confusion for many individuals in the modern era. The goal of the former analysis was to illuminate the elementary concepts associated with these assets, using them to formulate a simple economic model in order to provide insight into the volatility that is commonly observed within them. Through this research, one notable takeaway was the connection that is formed via the mining, or minting, process for cryptocurrencies, along with the implications this has for mining incentives, supply caps, and inflation protection. In particular, miners are incentivized to use their computers to perform hash verification processes that ultimately award them with units of the given cryptocurrency. This is the scheme that is implemented in many prominent cryptos at this time. This simultaneously provides security and proof of transactions while also providing value for the work that has been completed.

As is the case with Bitcoin, miners are compensated with half of the previous payment when an additional 210,000 blocks have been mined, starting from 50 BTC per block. This scheme implies that the maximum supply within this market is precisely 21,000,000 BTC. For consumers, this system provides security against inflation, since no third party or inside regulatory body can move the supply of BTC at any given time. This enticing factor is hypothesized to have a large impact on the behavioral parameter for cryptocurrency within the model that was constructed. Moreover, the supply for the crypto market was modeled after Bitcoin's logarithmic growth and its exponential implications for the price as this asymptote is approached.

The model itself is a simplification to a three good economy, where consumers allocate all of their income between cryptocurrency, cash, and traditional assets that provide regular returns. To choose an appropriate utility function that provided demand functions representative of real consumer behavior, several canonical forms were weighed against one another. Most notably, three good Cobb-Douglas and Quasi-Linear forms had shortcomings that could not be overlooked, namely a lack of income effects and price effects, respectively. Ultimately, the following symmetric polynomial was chosen as utility function:

$$U(x, y, z) = \alpha x^{\lambda} + \beta y^{\lambda} + \gamma z^{\lambda}$$

Through this formulation, symmetric demand functions were derived in terms of consumer income, prices of all goods, and all behavioral parameters. Thus, findings were categorized into income effects, price effects, and consumer preference effects. A canonical approach to comparative statics was taken, with one given parameter being varied at one time, with all changes defined by a doubling of said parameter. With this construction, it was found that the relative prices of each good had the least effect on the change in price and quantity demanded for the other goods within the economy. Income logically had a larger percent shift in price in all of the markets, since a doubling of consumer income is a far larger endogenous shift than the doubling in price of another good. Consumer preference encapsulated by preference parameter α for cryptocurrency induced the largest price swing in crypto, nearly doubling its price with a comparatively small increase in demand.

Such price volatility arises due to imperfect and changing perceptions held by consumers within the market along with their attempt to predict how other consumers will behave on the aggregate level. Especially since cryptocurrency is a newer asset class, investors of all ages are quite inexperienced, relying on the information that is available on the large scale, listening to major news organizations and celebrity figures who have invested in these markets. Consumer preferences and perceptions of these markets are intensely complex and continuously changing on small time scales, leading to major price swings and unseen volatility. Especially since regulation in these markets is quite sparse, new cryptocurrency schemes are created and implemented quickly and flippantly, with some even resulting from memes such as Dogecoin and Shiba Inu. Moreover, some of these cryptos are created and grow quickly over short time scales only to be subject to "pump and dump" schemes, where their mere creation was solely predicated on quick profits an inconsideration for other investors.

Thus, the future of cryptocurrency is likely to have an increasing amount of regulation based on findings derived from research as presented above. Policy prescriptions from the findings in this paper would first be to impose restrictions on the creation of meaningless or faux cryptocurrencies, further adding to consumer confusion and unnecessary pump and dump schemes. More importantly, regulators could consider to investigate "pump and dump" schemes in these markets, precisely as they do in other real markets. Consumer perceptions of cryptocurrencies are heavily influenced by others, especially those who seek to promote the crytpos in which they have shares in, thus artificially inflating the price as seen in traditional securities fraud schemes. These more traditional examples of fraud are closely mirrored in these newer markets, and regulators must eventually attempt to control these illegal profit generating systems. Looking forward, these markets should be regulated further while consumers also understand them better, leading to smaller price fluctuations and lower volatility levels. Overall, as outlined in the background, the SEC provides some oversight into cryptocurrency holdings and trades, but its policies and regulation are still quite vague and unclear at this time. Going forward, this regulatory body should investigate these markets further and assume the role of a transparent regulator who seeks to minimize illegal behavior such as securities fraud schemes. Additionally, it should seek to educate consumers on the volatility and potential consequences of investment in these markets, both good and bad.

The future study in this area is laden with interesting avenues of research and areas where more insight is required. One logical extension of the work presented above is to expand upon the cryptocurrency in order to yield more general results. The supply and aggregation of consumer demand was predicated on the markets of Bitcoin, since this is the natural choice due to its mainstream influence and largest market share by far compared to other cryptos. However, any generalization to all crypto markets could yield more insightful results that may or may not differ from those presented above. Moreover, incorporating more dynamic models within the model could potentially yield different or more insightful results. Employing time as a variable, and having varying rates of consumer adaptation to these shifts in parameters could further guide policy decisions within the markets for cryptocurrency since it would illuminate how and when consumers switch their behaviors. Overall, the field is young and rich in research opportunities, and the analysis presented in this paper provides an additional bit of insight into consumer choice and price behavior within cryptocurrency markets.

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Appendix A

Code snippets

The variables a, b, and c denote the preference parameters α, β, and γ, respectively:

```
syms a b c
percentx = 0.1
percenty = 0.1
percentz = 0.8
eq1 = 100000 / (1 + ((1000 / a^2) * (b^2 + (c^2 / 100)))) == percentx * 100000;
eq2 = 100000 / (1 + ((1 / b^2) * ((a^2 / 1000) + (c^2 / 100)))) == percenty * 100000;
eq3 = 100000 / (1 + ((100 / c^2) * ((a^2 / 1000) + b^2))) == percentz * 100000;
[sola, solb, solc] = solve(eq1, eq2, eq3)
```

Appendix B

Exact calculations

Income effects:

$(Q_X^1, p_X^{eq1}) = (1.7208{*}10^7, 5453.42)$ and $(Q_X^2, p_X^{eq2}) = (1.7869{*}10^7, 7588.43)$

$(Q_Y^1, p_Y^{eq1}) = (10000, 8447.70)$ and $(Q_Y^2, p_Y^{eq2}) = (10000, 11946.88)$

$(Q_Z^1, p_Z^{eq1}) = (2.762{*}10^7, 7850.14)$ and $(Q_Z^2, p_Z^{eq2}) = (3.3236{*}10^7, 10171.25)$

Price effects:

$$(Q_X^2, p_X^{eq2}) = (1.7735 * 10^7, 7098.24)$$

$$(Q_Y^2, p_Y^{eq2}) = (10000, 8685.32)$$

$$(Q_Z^2, p_Z^{eq2}) = (2.939 * 10^7, 8560.23)$$