Analysis of Direct and Indirect Network Effects in Ethereum

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ABSTRACT

Research Purpose
This research set out to investigate different network effects in the Ethereum ecosystem. The aim was to understand what kind of network effects Ethereum might be subject to and what factors cause them.

Research Methodology
The research was conducted through a case study methodology, utilizing both qualitative and quantitative data. The selected sample consisted of Ethereum blockchain and its native cryptocurrency Ether, users transacting on the blockchain, and decentralized projects with their ERC-20 tokens building on the blockchain, as observed from July 2015 until the end of 2021. Quantitative data consisted of different numeric datasets collected as publicly available secondary data from a reputable industry online source. Qualitative data consisted of research, journals and articles from reliable academic and emerging technology covering sources. Data analysis was applied to quantitative data and textual analysis to qualitative data.

Research Results
The case study showed that Ethereum is subject to direct network effects from users transacting on its blockchain and indirect network effects from decentralized projects building on it. Ethereum has reached critical mass, but it has not been subject to continuous winner-takes-all effect. Ethereum has positive feedback loops and decentralized applications act as complementary products reinforcing the network effects. The switching costs are low, but stickiness caused by the requirement of owning Ether creates lock-in for users.

Practical Implications
The research contributed to the industry by showing how ERC-20 tokens and Dapps affect the formation of direct and indirect network effects. A notable contribution was also made by analyzing the role of Ethereum developers in the creation of positive feedback loops.

Research Originality
This research took a holistic approach of applying network effects theory to Ethereum, expanding knowledge of the existing literature. The research also presented new information about network effects formation for example by closing a research gap about positive feedback loops in Ethereum.

Limitations and Further Research
The research successfully identifies factors leading to the creation of network effects, but it does not measure the strength of the phenomenon. This leaves room for further research, especially regarding indirect network effects.

Keywords: network economics, network effects, Ethereum, cryptocurrencies

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CHAPTER 1: INTRODUCTION

Since the inception of Bitcoin in 2009, blockchain has become a prominent technology to build innovative products and experiment with value. A significant milestone for the technology was the introduction of smart contracts by Ethereum, which allowed a wave of new use-cases like decentralized applications (Dapps) to be created. It later helped Ethereum become one of the top cryptocurrencies measured by usage and market capitalization.

The success of decentralized smart contract platforms like Ethereum seems to be heavily influenced by the number of users that transact with tokens issued on its blockchain and the number of Dapps that utilize its smart contract layer. This could be explained by the same network economics principles applying to cryptocurrencies that apply to other networks like mobile phones, internet access, and social media. The concept that defines these interdependencies within networks is called network effects.

1.1 Research Objectives

During the early years of cryptocurrencies, they were thought to behave somewhat randomly. However, in recent years the thinking that they could be subject to network economics has gained a foothold. This research focuses on examining different network effects in the Ethereum ecosystem. The aim is to understand what kind of network effects Ethereum might be subject to and what factors cause them. The research will be conducted as a case study utilizing qualitative and quantitative data.

The research has four objectives. The first objective is to identify essential themes about network effects in cryptocurrencies based on the existing academic literature. The second objective is to collect quantitative and qualitative data, to understand the impact that users and projects have on Ethereum. The third objective is to evaluate whether the actions of users and projects cause network effects in Ethereum. The fourth and final objective is to conclude the research and make recommendations that participants in the Ethereum ecosystem can utilize to ensure that Ethereum can be the most prone to network effects and benefit the most from them.

1.2 Practical Relevance

Network effects in cryptocurrencies are a discussed topic but may not be completely understood. It is often assumed that all cryptocurrencies are subject to network effects, but it is rare to see a comprehensive analysis created from a network economics perspective. Existing research focuses heavily on the direct network effects, and regardless of the topic, places high significance on token price. Smart contract platforms like Ethereum and indirect network effects have remained a less researched topic by academics.

This research provides a comprehensive analysis of whether Ethereum is subject to different network effects and what factors could cause them. The research applies essential themes from the network economics theory to Ethereum. The results can be helpful to various parties in the Ethereum ecosystem that are developing ERC-20 tokens or trying to create better Dapps and business models. The research also makes the value generation and success factors within Ethereum easier to understand and the smart contract platforms more comparable to other network technologies.

1.3 Dissertation Outline

This dissertation consists of six research chapters followed by references. The first and current chapter is the introduction, which describes the research objectives, practical relevance, and the dissertation outline. The second chapter is the literature review, which provides an overview of network effects, introduces relevant research papers about direct- and indirect network effects in cryptocurrencies, and discusses the development of the research questions. The third chapter is the research methodology, which describes how the research was designed and carried out. Emphasis is on the selected sample, data collection, data analysis, and methodological limitations.

The fourth chapter covers the research, which is conducted as a case study. The case study has a section for each five supporting research questions, followed by recommendations and a summary with a concept map. The fifth chapter is the conclusion, which summarizes the results, recommendations, and how the research contributes to the industry. The final part of the dissertation is the references, which provides a detailed listing of all the sources cited throughout the research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Network economics have been researched for multiple decades, starting from the seventies. The early research focused on long-distance telephone networks, and the topics have since then covered a wide range of platforms, systems, and other technologies. Network economics research has an essential role in enabling businesses to make better strategic decisions as well as in providing an understanding of interdependencies between users and products. Academic research about cryptocurrencies and network economics has also increased as cryptocurrencies have gained popularity.

2.2 Network Effects

In a book called Information Rules, Carl Shapiro and Hal Varian (1998) introduce the idea that the new and old economies have one essential difference. Older industrial economies leveraged economies of scale, whereas the new information economies leverage economies of networks. It was distinctive for Industrial economies to have oligopolies with moderately moving market shares, whereas these new information economies tend to have temporary monopolies. These monopolies are subject to change as the currently most prominent technological products often get replaced by superior architecture or technology.
A key factor in these new network economies is network effects, also known as demand-side economies of scale or network externalities.

Shapiro and Varian explain that a product has network effects if its value to a single user depends on the number of other users. These network effects are called direct network effects. Information technologies like e-mail, mobile phones, and internet access have significant direct network effects. Network effects, where the product's value to a single user and vice versa is affected by complementing products or another user group, are called indirect network effects. A simple example of a product with indirect network effects is video cassette recorders and videocassettes. The more video cassettes are available, the more valuable the recorder is to the user, and the other way round. However, not all information technologies and products are subject to network effects.

Network effects can lead to product or technology gaining popularity, which then, in turn, benefits its users or consumers. Nevertheless, it often requires a significant amount of time for the network effects to kick in and the userbase to start growing exponentially. If the product manages to reach critical mass, the growth becomes self-sustaining, and it can tip the market. That is why winner-takes-all behavior is common in products and technologies that show strong network effects.

Two significant concepts in network economies are user expectations and positive feedback. Users expecting a product or technology to become the industry standard usually becomes the standard. This happens primarily because of bandwagoning and positive feedback loops. Growth and adoption of a product or technology based on positive feedback often create an s-shaped pattern with three stages, a slow start, intensive growth, and saturation. If a technology or product becomes a standard, it leads to changes in the competition. Standards decrease customer lock-in and uncertainty, as well as transform from the winner-takes-all to regular market share competition. Governments can also significantly affect emerging technologies' speed of adoption through policies and other measures like financing.

Shapiro and Varian name seven key assets that have a significant role in network markets when products compete to become standards. These assets are control over customer base, intellectual property rights, ability to innovate, manufacturing abilities, first-mover advantage, strong complements, and finally, reputation and brand name. These assets help products position for adoption and protect their interests.

Customer lock-in and switching costs are crucial concepts for a product to benefit from network effects. If the costs of switching between products are notable, the users experience lock-in. Switching costs quantify the level of lock-in to the product or company. Switching costs should be evaluated down to a single user as they can make a big difference in markets with large userbases like networks. Identifying and measuring switching costs can have a significant impact on a product's competitiveness.

2.3 Cryptocurrencies and Direct Network Effects

Academic literature covers direct network effects in cryptocurrencies relating to various specific topics. This section divides the research papers into four categories based on their topic. The categories are token price formation, competition, adoption, and user behavior.

2.3.1 Direct Network Effects and Price Formation

Timothy Peterson (2018) researched if the value of Bitcoin could be explained by modeling it as a network and by applying Metcalfe's law to it. According to Metcalfe's law, the value of a network increases nonlinearly as more people join the network, and the value of the network is equivalent to the square of the number of users. Metcalfe's law has previously been used to value technologies such as telephone and social networks. Peterson researched a period between 2011 and 2017. Bitcoin's price seems to be following Metcalfe's law in the medium to long term, though the peak in price at the end of 2013 could have been a result of market manipulation. Applying Metcalfe's law to cryptocurrencies is a frequently discussed way of estimating Bitcoin's value. As Metcalfe's law addresses direct network effects, it seems suitable for cryptocurrencies like Bitcoin, which are meant for peer-to-peer transactions and payments.

In another paper, Timothy Peterson (2019) wrote that Bitcoin's price also seems to follow Gompertz Sigmoid growth function and has a strong connection to network economics. Peterson used price, time, and number of users in his model and concluded that despite Bitcoin's remarkable rises and crashes, the factor driving Bitcoin's price is the number of users. Gompertz Sigmoid growth function is a less used method to understand and estimate Bitcoin's long-term price action and provides an alternative approach to the more utilized Metcalfe's law. What separates Peterson's Gompertz function model from other research, is that the growth in the number of users over time does not have to be constant. This seems well-fitting for cryptocurrencies, which are proven to have intense market cycles.

He Huang (2019) researched how, based on signaling theory, information transmission could affect Ethereum's value creation capability from two angles: sustainability- and scale of value creation. The paper uses transaction data stored on the blockchain as the information transmission. Transactions affect the sustainability- and scale of value creation positively through transaction frequency and the number of users. Also, the number of users seemed to cause network effects, which are crucial for sustaining market capitalization. Huang had an interesting approach by focusing on the transactions to understand value creation while simultaneously acknowledging the existence of network effects.

2.3.2 Direct Network Effects and Competition

By examining competition between different cryptocurrencies, Neil Gandal and Hanna Halaburda (2016) concluded that the network effects in cryptocurrencies are strong, like with any other currencies in general. The more users a currency has, the more useful it is and the more attractive it becomes for new users. However, the cryptocurrency market does not seem to be continuously consistent with the winner-takes-all effect. During different periods in the market, the way different cryptocurrencies appreciate and depreciate against the USD showed discontinuity. At the time of the research, the cryptocurrency market was in many ways not as mature as today. The notion of the market's inconsistency with the winner-takes-all theory is still correct. Though Bitcoin is still six years later the largest cryptocurrency, as its price depreciates against USD and it loses market dominance, sometimes other alternative cryptocurrencies appreciate against USD and increase their market dominance. This is consistent with the winner-takes-all effect as cryptocurrencies compete for market dominance, though it does not seem always to apply.

Catalini and Tucker (2018) explored how blockchain technology can be used to create competitive markets and what kind of possibilities and challenges it includes from an antitrust point of view. They provide two approaches to the subject, optimistic and pessimistic. Blockchain as a technology is revolutionary and can change the way marketplaces are set up since it improves trust and does not rely on third-party verification. Network effects can lead to large digital platforms becoming way more alluring than smaller ones. However, platforms with blockchain-based tokens can incentivize developers and users to leave leading platforms and join the smaller ones. This deteriorates the network effects of large platforms. They also state that blockchain-based platforms have lower switching costs because they are often built using open-source code, strive for interoperability, and tokens can be exchanged easily. Catalini and Tucker make great remarks about how blockchain can revolutionize platform design and affect traditional market dynamics. Regarding switching costs, the paper does not argue why large platforms with tokens couldn't continue incentivizing users and developers. Also, the paper does not differentiate platforms. For example, Ethereum has its native Ether token, but other platforms that have their own ERC-20 tokens can also build on the blockchain.

Stylianou et al. (2021) researched how and whether network effects affected cryptocurrency market competition and concentration. The research focused on the price and number of users in six selected cryptocurrencies. It covers a wider timeline and more data than earlier papers to provide accurate results. According to the analysis, direct network effects in cryptocurrencies do not lead to competitive advantage and concentration, usually expected from network effects. The paper states in more detail that direct network effects are not a valuable tool to predict prices, as cryptocurrencies also experience notable reverse network effects. Also, winner-takes-all does not seem to apply to cryptocurrencies, and network effects do not offer a significant competitive advantage. The paper also states that direct network effects are not frequently visible early in new cryptocurrencies. They conclude that network value could be assessed more accurately using transaction value and token price instead of only token price. Stylianou, Spielberg, et al. make a good remark with the reverse network effects. Cryptocurrencies have also lost a significant number of active users as the market tends to be cyclical. The paper adds to earlier research first made by Gandal and Halaburda as well as later by Peterson. The research also does a great job of comparing the direct network effects of different cryptocurrencies instead of focusing on just Bitcoin.

2.3.3 Direct Network Effects and Adoption

According to William Luther (2016), Bitcoin has had limited success as an alternative currency. This is caused by network effects and switching costs of existing traditional currencies. Bitcoin struggled to gain popularity, despite different service providers possibly finding the traditional currencies being worse than Bitcoin. The research assumes, that currencies are prone to network effects and that the value experienced by a user is linked to other users transacting with the currency. Switching costs arise from using the new unit of account as well as updating systems, records, and machines. Bitcoin and other cryptocurrencies would gain broader recognition only due to government support or monetary uncertainty like hyperinflation. The transition would most likely require a high level of coordination to overcome the network effects of existing currencies. The cost of coordination would increase if early users got exhausted. Luther’s research is heavily focused on cryptocurrencies, and mainly Bitcoin replacing some of the traditional currencies and not necessarily operating as an alternative currency. Operating as an alternative currency would not anyhow necessarily require replacing the traditional ones. Cryptocurrencies and Bitcoin have grown significantly since the publication of the research in 2016. As Luther wrote, monetary turmoil can reduce switching costs, which happened in Venezuela, where the inflation of Bolivar steered people to use cryptocurrencies and Bitcoin.

Cong et al. (2021) introduced a new model for pricing cryptocurrencies and understanding adoption. The model focuses on heterogenous users’ transactional demand as the price-determining factor. The price of tokens is therefore tied to the platform’s productivity and demand for the specific transactions it supports, such as advertising on Basic Attention Token. The model acknowledges network effects as it creates an S-curve. As the productivity of a platform increases, so does the userbase, which accelerates the adoption. Nearing complete adoption, the growth starts tapering. Platforms with tokens experience faster adoption compared to tokenless platforms. Having a token also decreases the volatility of the userbase caused by the assumed positive performance of the token’s value. Cong et al. have a fascinating approach as they acknowledge the importance of productivity as a price influencing factor and emphasize the importance of a platform having a token.

Tatja Karkkainen (2021) examined how network effects and technology impacted exchange-listed Initial Coin Offerings (ICO) in the long term. Based on a set of criteria, if a project raises a high amount of funds at the ICO, it will positively impact its long-term success. Also, if the project is doing the fundraising to an existing proprietary blockchain, it is multiple times better suited for long-term success because of network effects. This is because, in addition to funds, the ICO also helps to obtain more users. Conversely, cointegration into some existing cryptocurrency or platform hurt the long-term success. The paper offers an interesting new way of estimating the future success of ICOs. Typically estimates have not included network effects as one of the evaluating factors. The paper also indicates that network effects can play a role early on in cryptocurrencies, which contradicts the paper written by Stylianou et al.

Koens et al. (2021) wrote about different drivers behind blockchain adoption. They identify different drivers by analyzing six different real-life use cases: cryptocurrency, identity management, supply chain, smart lock, healthcare data, and energy data. Some analyzed scenarios lack technical drivers for implementing blockchain. However, implementation could be explained by multiple nontechnical drivers such as network effects, philosophical beliefs, economic incentives, and the breaking of organizational structures. However, network effects played little or no role in other use cases apart from Bitcoin. The paper was a concrete example of how not all use cases utilizing blockchain are subject to network effects. After all, network effects are not caused by the underlying technology but by how technology is utilized and by what kind of users.

2.3.4 Direct Network Effects and User Behavior

Lee et al. (2020) examined how the structure of decentralized governance and opinions of users affect implemented policies in cryptocurrency projects. They analyze different blockchain forks and what strategic conditions were required. According to the paper, policy proposal forks where the old chain is completely replaced, and the proposal supported by the whole userbase, can happen if network effects are taken into consideration by the proposer. Lee et al. highlight the importance of governance and proposals in decentralized blockchain protocols. The approach taken in the paper is interesting since governance and network effects are not often discussed in the same context.

Sockin and Xiong (2020) created a model to help analyze the risk and fragility of cryptocurrencies. Utility tokens are considered memberships to a platform that enables transactions of specific services or goods between users. Sockin and Xiong analyzed two scenarios, one with information frictions and one with perfect information. According to the model, strong network effects in the platform created by the users and stiffness caused by token speculators can lead to market breaking down without equilibrium. Positive user expectations of the token’s performance increase participation and reduce breakdown, while speculators can worsen it and drive users out. Information frictions reduce the risk of breakdown as users tend to underreact to positive and negative platform-related news at the expense of the platform’s performance. The research separated itself from many others by focusing on utility tokens and the behavioral impact of different market participants. A carrying statement within the research was that users create strong network effects within the platform.

2.4 Cryptocurrencies and Indirect Network Effects

Patrick Waelbroeck (2018) wrote a paper about blockchain technology from an economic perspective. The paper discusses various topics such as token design, mining, security, and Bitcoin. Waelbroeck also touches shortly on direct and indirect network effects. According to the paper, Bitcoin and cryptocurrencies experience direct network effects from mining. An increase in the number of miners makes the network more secure, adding value to everyone. However, adding miners can also come with negative network effects as an increase in miners can decrease incentives for other miners to mine the cryptocurrency. Furthermore, cryptocurrencies are subject to indirect network effects from matching various user groups like consumers and merchants when used for payments or borrowers and lenders when used for loans. The paper goes into more detail about how individual user values Bitcoin more as a payment instrument if merchants accept it. On the other hand, merchants find it valuable and offer it as a payment instrument if buyers are willing to use it for payments. Unlike many other papers covering network effects, Waelbroeck did not discuss cryptocurrency valuation and had alternative approaches like mining and payments.

Trabucchi et al. (2020) researched how blockchain is transforming two-sided platforms. Typical examples of two-sided platforms are Airbnb and Uber, which are centralized entities facilitating transactions between two sides and simultaneously bringing down transaction costs. When a platform is built with blockchain as the underlying technology, it mitigates problems in traditional platforms, creates new opportunities, and the platform provider becomes a service provider. In traditional two-sided platforms, indirect network effects play a significant role in value creation. However, in blockchain-based platforms, also tokens have an impact in creating externalities between the sides. Platforms that are in early development can provide incentives with tokens before the other side even exists. Also, the more the token is used by either side, the more valuable it becomes and starts drawing new service providers to the blockchain. The paper proved how blockchain technology could disrupt traditional business models, and it had an interesting take on how tokens can change the network effects of platforms.

Benedetti and Nikbakht (2021) examined how getting cross-listed on exchanges affects different metrics on cryptocurrencies. They find out that after the first cross-listing, there is notable growth in on-chain activity, network growth, trading volume, and price. Tokens seem to be subject to significant returns within two weeks around the listing. Tokens enabling peer-to-peer networks and platforms tended to generate higher returns, which is aligned with other theories on how network effects cause increases in valuations. Especially tokens issued on Ethereum as ERC-20 tokens have higher than normal on-chain transactions and token volume around the cross-listing. Benedetti's and Nikbakht's paper aligns with other papers that present how cryptocurrencies can be valued based on network effects and offers a concrete example of how that can happen through cross-listings. The paper often refers to network externalities but does not discuss the difference between the types. It can be assumed that Benedetti and Nikbakht focus on direct network effects and how having more users lead to increased value. Anyhow, Cross-listing is a fine example of indirect network effects. The exchange listing connects the cryptocurrency users with another group of users who can now access the cryptocurrency and start interacting with the original user group. It can also enable new complementary products and services, such as on and off-ramps to other currencies or access to interest products.

2.5 Development of the Research Questions

Observations from the literature showed that cryptocurrencies and network effects have been a topic for research in recent years. Existing research covers strictly defined topics about network effects in connection to themes like ICOs, exchange listings, competition, and risk. There is also a notable emphasis on using different methods and models like Metcalfe's law or Gompertz Sigmoid growth function to explain the price formation in cryptocurrencies. In general, the existing literature focuses heavily on Bitcoin and direct network effects. Some research also makes direct assumptions of network effects without further questioning.

The research questions this paper is looking to answer were created based on the reviewed literature. The main research question is what kind of network effects is Ethereum subject to from users transacting on its blockchain and decentralized projects building on it? There are also five supporting research questions that assist in answering the main research question.

1. Is Ethereum subject to direct network effects, and has it reached critical mass?
2. Is Ethereum subject to indirect network effects, and how decentralized projects might cause them?
3. Has Ethereum been subject to the winner-takes-all effect?
4. Does Ethereum have positive feedback loops?
5. Does Ethereum have customer lock-in, and what switching costs exist?

The formulation of the research questions considers the network effects themes discussed by Shapiro and Varian, as well as tries to build on top of the existing literature and fill research gaps. Some of the research questions have more coverage in the literature, such as direct network effects, whereas other themes like switching costs and indirect network effects have only limited coverage. Particularly feedback loops in cryptocurrencies can be considered a research gap. Diverging from part of the literature, the research questions of this paper do not focus on estimating the future price or seeking justification for historical price action based on network effects.

Table 1 summarizes the most essential research papers included in the literature review. The table has three columns; the research topic, authors, and themes that will be discussed in the case study based on the paper.

Table 1: Literature summary

Topic	Authors and year	Themes that will be discussed in the research
Cryptocurrencies and competition	Gandal and Halaburda (2016)	Has Ethereum been subject to winner-takes-all effect, and has it been continuous?
Cryptocurrencies as alternative currencies	Luther (2016)	Is Ethereum subject to switching costs arising from software and hardware?
Blockchain as a marketplace disruptor	Catalini and Tucker (2018)	Is there a risk caused by low switching costs that Ethereum developers leave and join smaller blockchain platforms that have their own token?
Platform productivity as adoption accelerator	Cong, Li and Wang (2021)	Have the Ethereum ecosystem's productivity created direct network effects?
Competition in the cryptocurrency market	Stylianou, Spiegelberg, Herlihy, and Carter (2021)	Can it be assumed that Ethereum has been subject to reverse network effects?
ICOs and long-term success	Karkkainen (2021)	Can projects conducting ICOs on Ethereum increase the direct network effects?
Economic analysis of cryptocurrencies	Waelbroeck (2018)	What decentralized use-cases does Ethereum have that could create indirect network effects from matching different user groups?
Cryptocurrencies and exchange cross-listings	Benedetti and Nikbakht (2021)	
Transformation of two-sided platforms	Trabucchi, Moretto, Buganza, and MacCormack (2020)	Did Ethereum incentivize early users before Dapps added the other side of users that could lead to indirect network effects?

2.6 Summary

The existing literature provides valuable knowledge and insight that can be used to investigate network effects further. Network effects and cryptocurrencies have been researched from various angles, often approached from direct network effects and price standpoint. Most of the existing literature are strictly defined quantitative papers, which leaves room for a qualitative case study with a holistic approach.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This research was conducted as a qualitative case study examining network effects in Ethereum. The aim was to narrow research gaps and provide new ways of looking at Ethereum's value drivers and success factors. The case study utilizes quantitative and qualitative data to look for answers to the main- and supporting research questions. This chapter provides an overview of how the research was designed and why the selected methodology serves the research well.

3.2 Sample Selection

The selected sample consists of four items. Ethereum blockchain and its native token Ether, users transacting on the blockchain, decentralized projects with their ERC-20 tokens building on the blockchain, and lastly, the period for observation.

The first item is Ethereum, which was selected as the sample blockchain because of its importance to the cryptocurrency ecosystem. Ethereum is highly dominant in the smart contract and Dapp usage. Owning the native cryptocurrency Ether is required to transact with ERC-20 tokens or use Dapps as it is used to pay for the transaction fees. There is also a vast amount of quantitative data available about Ethereum that can be used in the case study.

The second item is users, who have wallets on the Ethereum blockchain holding Ether and ERC-20 tokens. The users include different groups such as individual token holders, miners, and developers. Users were included in the sample, as they are the most essential part of the network effects theory.

The third item is decentralized projects that utilize Ethereum's blockchain to run Dapps like peer-to-peer lending and borrowing. Out of all projects and products offered for Ethereum, only decentralized projects were included in the sample to represent the ecosystem in its most decentralized form. Also, most of the centralized services offered for Ethereum already have a decentralized alternative available as a Dapp. Many of the projects have their own ERC-20 token built on Ethereum. There is also reliable data available about decentralized projects that can be extracted from the blockchain.

The fourth and last item is the observed period. The period starts in July 2015 at the creation of Ethereum's genesis block and lasts till the end of the year 2021. No periods were left out, though some datasets, such as the price of Ether in USD, have been volatile over the years and might have even been subject to manipulation at times. The chosen period provides a reliable overview of Ethereum's lifecycle so far.

3.3 Data Collection Methodology

Both quantitative and qualitative data were needed to support the case study and assist in answering the research questions. The collected data was used in forming arguments and finding connections.

The quantitative data was collected as publicly available secondary data from reputable online source Etherscan. Etherscan is the most used block explorer for Ethereum. The quantitative data consists of different numeric datasets from the blockchain, like daily active Ethereum addresses or daily verified smart contracts. The datasets provide one value of the measured variable per day, starting from the inception of the blockchain. The data is valid and trustworthy because it has been extracted directly from the blockchain. The data can be easily confirmed, as the Ethereum blockchain is public and accessible using blockchain scanning websites or tools. The quantitative data was collected in .csv format from the Etherscan website.

The qualitative data is collected from trustworthy academic online sources such as London School of Economics Business Review and Harvard Business Review, as well as from respected online sources covering emerging technologies like Wired. The qualitative data consists of research, journals, and articles that add insight to the case study. Subjects of the data cover network effects in different contexts, and they are used as references. The data were collected from recently published sources when possible.

3.4 Data Analysis Methodology

A qualitative case study as the research method was flexible and allowed utilizing techniques typical for both qualitative and quantitative research. A case study was also well fit for interpreting and applying concepts related to network effects, which have a notable social aspect. Quantitative research would not have been as suitable because some concepts within network effects would have been difficult to express numerically within the scope of this research.

Data analysis was applied to quantitative data, which was represented as line charts. Data analysis was a great way to provide perspective as the datasets span over multiple years, and some of the data grew exponentially or had high volatility. Datasets in .csv format were converted to line charts using SPSS software. Observations made from the data analysis were discussed and analyzed as part of the case study.

Textual analysis was applied to qualitative data, and it was presented in narrative form. The textual analysis had an essential role in bridging relevant network effects related information and concepts to Ethereum. Qualitative data did not require further processing.

Findings from data analysis and textual analysis were also presented as a concept map. The concept map was used to visualize relevant themes and essential connections. It was selected to be part of the research because it is an effective way to present findings based on qualitative data. The concept map was created using XMIND software.

Utilizing both quantitative and qualitative methods allowed a thorough analysis and helped to avoid biases. This, in addition to the case study being reproducible, makes the analysis and results valid. The case study is reliable, as the methodology can also be applied to other competing smart contract platforms that have enough data available. There were no ethical concerns as the case study does not include collecting or analyzing personal data.

3.5 Methodological Limitations

The chosen research design was functional, and there were no significant limitations. However, few remarks were made about sample selection and applying network effects to Ethereum.

The sample selection came with some trade-offs. By focusing only on decentralized projects, some possibly significant network effects inducing centralized service providers had to be left out. For example, many centralized companies like cryptocurrency exchanges could cause notable indirect network effects. Also, with the decentralized projects, some simplifications had to be made. It would be impossible to include all use-cases of the Ethereum ecosystem and fit them into the research scope.

Network economics and network effects theory is best applied to traditional networks and technologies. Applying them to Ethereum is not always a perfect fit and therefore requires making some assumptions. The adoption and success of Ethereum is also a highly complex subject, which is affected by many factors, not only network effects.

As mitigating actions, the sample and dataset selection needed much attention. Also, biases needed to be avoided when analyzing and applying network effects theory to Ethereum.

3.6 Summary

A case study proved to be a suitable method for answering the research questions. The case study utilized quantitative and qualitative data, of which the quantitative data were presented as line charts and qualitative data in narrative form. Essential themes and connections were also presented as a concept map.

CHAPTER 4: CASE STUDY

4.1 Introduction

Since the inception of Ethereum in 2015, its ecosystem has grown significantly. Ethereum's cryptocurrency Ether has become one of the largest cryptocurrencies by market capitalization. The blockchain hosts a broad selection of Dapps and has been used to issue a wide variety of different tokens. It can be said that Ethereum has become the go-to platform for decentralized protocols and an all-purpose ecosystem within the cryptocurrency space.

This case study will help assess whether being subject to network effects has been one of the reasons behind Ethereum's success. The case study has five sections covering each supporting research question, followed by recommendations and a summary.

4.2 Direct Network Effects and Critical Mass

For network effects to start impacting a network, the userbase needs to reach critical mass. Before critical mass is reached, the cost for a user to join a platform is higher than the value gained from joining. For that reason, platforms need strategies to incentivize and reward early users (Nicholas Johnson, 2018). In Ethereum, early users had the possibility to mine Ether and earn rewards, which could have acted as an incentive to join the platform before the real growth started.

Figure 1 shows the number of unique addresses created on the Ethereum blockchain. The number of unique addresses remained almost flat until the beginning of 2017. Later at the end of 2017, the number of accounts started growing more rapidly. The timing also matches with the closing of the cycle top in Ethereum's price at the end of 2017, visible in Figure 4. The chart indicates that closing to the end of 2017, Ethereum reached critical mass in the number of unique addresses. The number of unique addresses has started to create a typical s-shaped adoption pattern, being still in the growth phase and not having reached the saturation phase.

In addition to userbase growth, also network usage is an essential factor indicating network effects (Anu Hariharan, 2016). Figure 2, daily active addresses, and figure 3, daily Ethereum transactions show almost constant growth, despite a decline from the beginning of 2018 to the beginning of 2020. This indicates that as the number of unique Ethereum addresses has continued to increase, also the usage has followed.

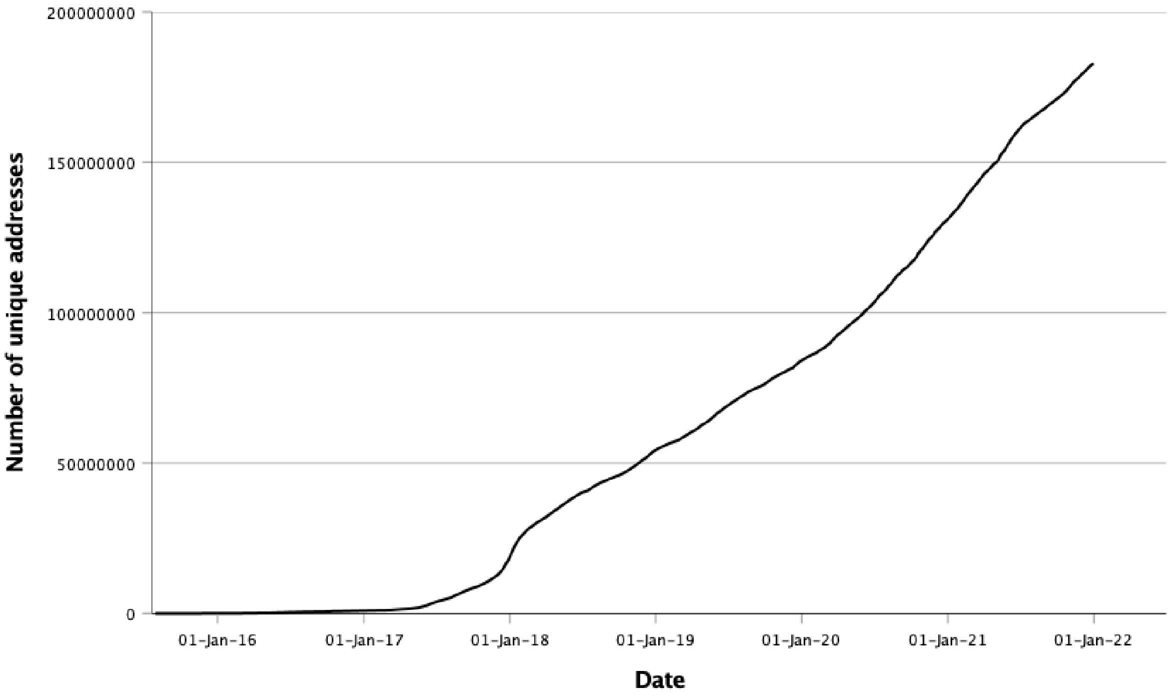
When applying network economics theory, two factors separate Ether and tokens built on Ethereum blockchain from many other technologies and networks. Ether and other tokens have value as determining factors, and they are also meant to be used as either means of exchange or have some other kind of utility. Technologies that are often used as examples of network effects, such as landline telephones or internet access, do not have the same distinguishing features and are more tied to physical hardware. According to network economics theory, the network effects increase the price of entire networks. In cryptocurrencies, this means an increase in the token's price.

When analyzing direct network effects, a distinction should be made between network effects and virality. As more users join a network, viral growth accelerates only the adoption speed, whereas network effects also add value. Based on figure 4, Ether price in USD, it can be seen that the value of the Ether has experienced significant growth, but it has also been cyclical. The chart shows that Ether's price has not grown in a perfectly linear or exponential manner. Despite the high volatility, the network has become more valuable to its users. Despite cryptocurrencies having experienced hype and virality, this could be considered one indicator of Ethereum being subject to direct network effects.

As noted by Cong et al. (2021), an increase in a platform's productivity promotes network effects through growth in userbase and adoption. The rise in productivity increases token demand because they are used to facilitate use-case-specific transactions. In the Ethereum ecosystem, everyone using Dapps need Ether to pay for the transactions. As Ethereum has the most Dapps utilizing its smart contract layer, it can be assumed that the combined growth in the Dapp productivity has drawn new users to the Ethereum ecosystem adding to the network effects. The same thinking can be applied to ICOs. Projects conducting ICOs to build on top of Ethereum add to the overall productivity once the project is ready and can entice new users. The new users who come through ICOs need Ether to use the Dapps, increasing Ether demand.

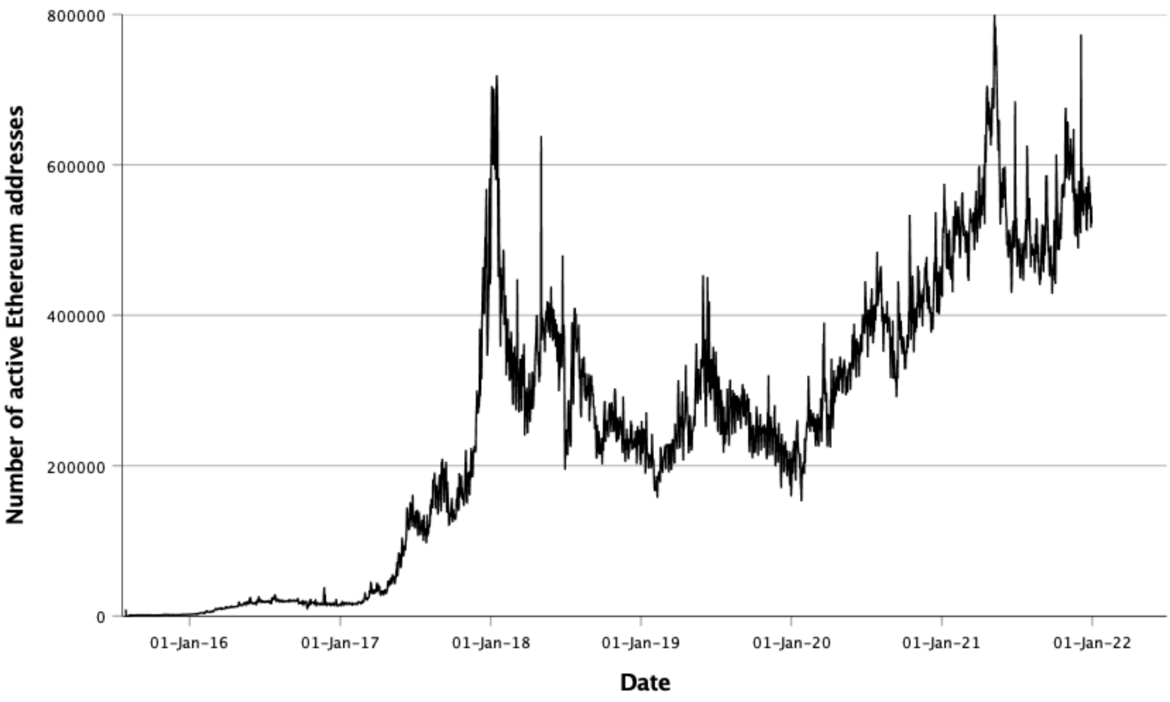
As network effects add value to a single user, reverse network effects create opposite effects. Reverse network effects can occur because of various reasons as the network scales. For example, as more users join, the interaction quality can become lower because of spam, or the network favors the early users more than the later users. Reverse network effects can lead to users exiting the network in masses (Choudary, 2014). Stylianou et al. (2021) noted that also cryptocurrencies are subject to reverse network effects. In Ethereum, reverse network effects can be identified by looking at Figures 2, 3, and 4. The growth in daily active addresses, daily transactions, and Ether price have not been perfectly continuous. As the previous cryptocurrency cycle ended at the beginning of 2018, not only was there a decline in Ether's price, but there was also a drop in active users and overall network usage in the form of daily transactions. This could indicate that in the big picture, Ethereum can be at times subject to reverse network effects, and therefore the direct network effects would not be entirely continuous.

Figure 1: Number of unique Ethereum addresses



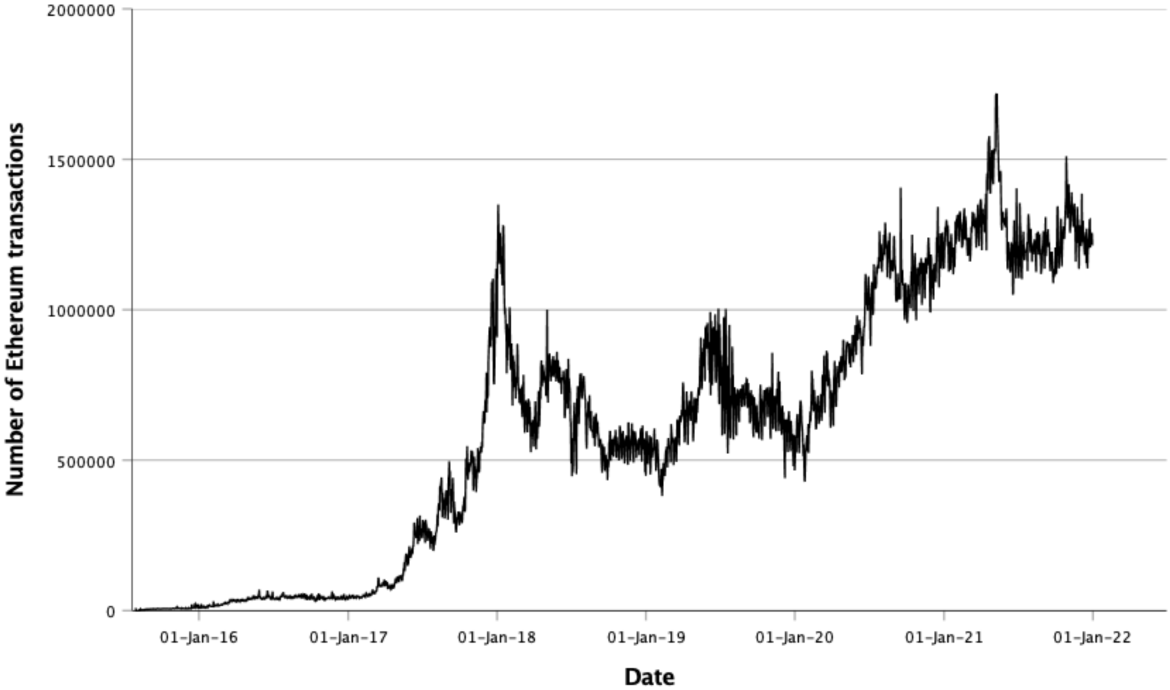
Source: Etherscan (2022, a)

Figure 2: Number of daily active Ethereum addresses



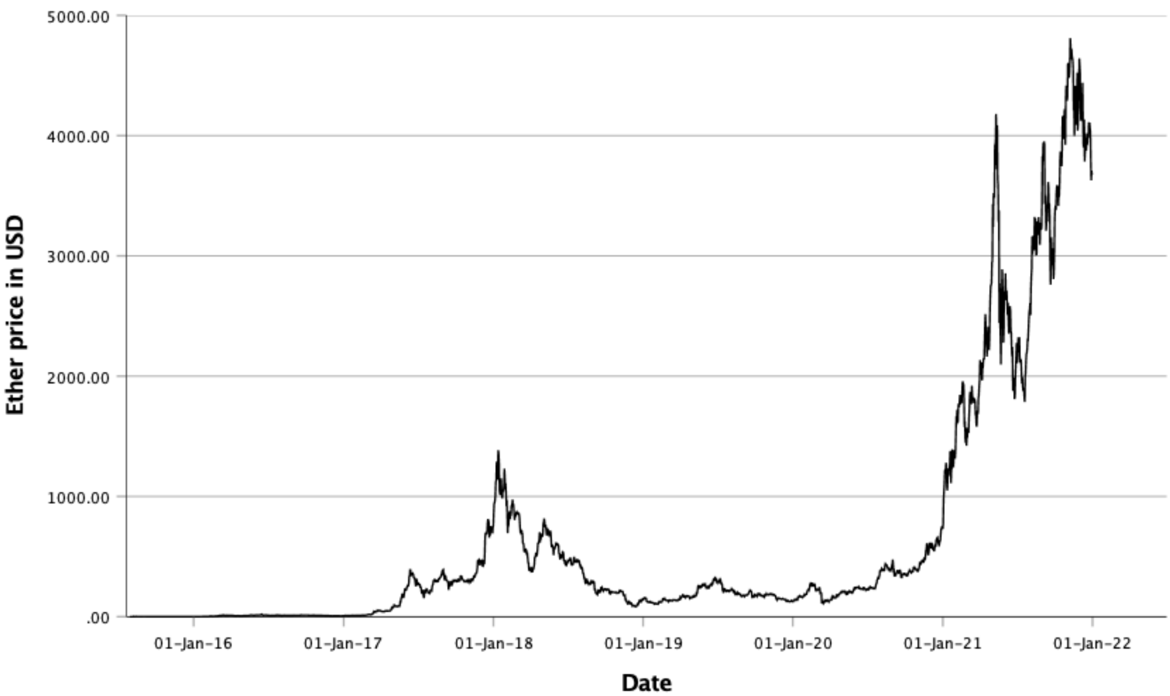
Source: Etherscan (2022, b)

Figure 3: Number of daily Ethereum transactions



Source: Etherscan (2022, c)

Figure 4: Ether price in USD



Source: Etherscan (2022, d)

4.3 Indirect Network Effects

Nicholas Johnson (2018) discusses how network effects apply to platform businesses. According to him, indirect network effects are more applicable to platforms than direct ones, as the platforms have two separate groups of users. These user groups are producers and consumers. The value that the producers experience from the network strictly depends on the number of consumers and the other way round. Johnson uses Uber to give a practical example. Uber operates a platform and has two different groups of users, riders and drivers. The riders can be considered consumers and the drivers as producers. The more drivers join the network, the better functioning and valuable the platform is for the riders, and the other way round. Also, contrariwise if the number of riders would increase, it would not add more value to other riders.

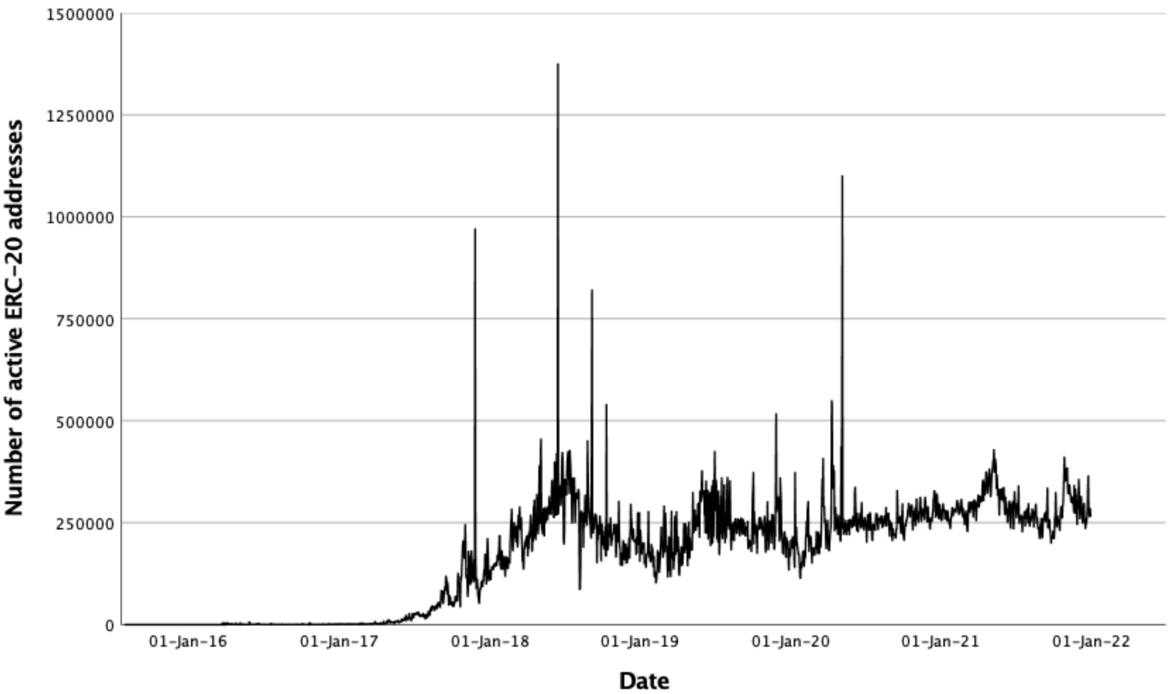
Johnson's analogy of platforms and network effects can be applied to the Ethereum ecosystem. The platform itself connects multiple user groups through Dapps. For example, lenders and borrowers through DeFi applications like Aave, non-fungible token (NFT) creators and collectors through NFT marketplaces like Opensea and start-ups and investors through crowdfunding launchpads like DAO Maker. In these scenarios, lenders are producers and borrowers are consumers, as well as NFT creators are producers and collectors are consumers. Likewise, start-ups are producers, and investors are consumers. Like in the Uber example, an increase in the number of start-ups in a crowdfunding launchpad does not add more value to other start-ups, but it adds value to investors and vice versa. These producers on Ethereum can also be divided into multiple segments based on their use case. For example, derivatives protocols like DyDx can be considered financial producers as they offer perpetual futures, and protocols offering protection for risks like Nexus Mutual can be considered insurance producers as they offer cover for unexpected incidents like smart contract bugs.

Attention should also be paid to complementary networks when discussing networks and network effects. Complementary networks are networks where an increase in one product's usage by a specific set of users helps increase the value of a separate complementary product, which consequently increases the value of the original product. For example, Microsoft Windows operating system and Microsoft Office application suite are complementary networks. The operating systems are subject to network effects on their own, but the Microsoft Office as a complementary product helps to reinforce them (Anu Hariharan, 2016). The same analogy can be applied to Ethereum as many projects building on Ethereum can be considered complementary products to Ethereum. The projects are created and used by a set of users, but they also add new use cases to the network and add value to Ethereum users. Therefore, these complementary projects can create indirect network effects in Ethereum.

Figure 5, the number of daily active ERC-20 addresses, and figure 6, the daily ERC-20 token transfers, show that activity around ERC-20 tokens has been growing. Though the number of daily active ERC-20 addresses peaked in the middle of 2018 and has remained relatively stable ever since, the number of daily ERC-20 transactions has kept growing after the peak. This could support the idea that as the Ethereum network grows around Ether, there is also growth in smaller separate ERC-20 token clusters. The ERC-20 token clusters add complementary products to Ethereum and come with their own user network while requiring Ether to transact with the ERC-20 tokens. It can be concluded that both add value to each other.

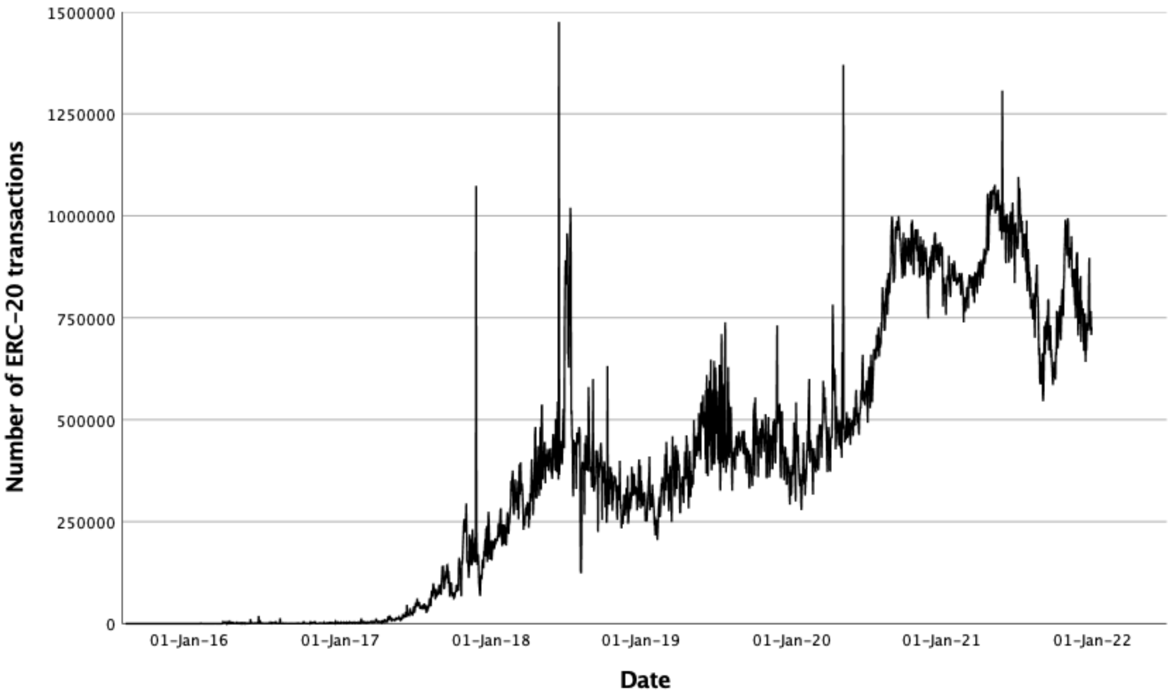
If indirect network effects are created by matching user groups through Dapps, it should be discussed how Ethereum incentivized early users before Dapps were available. In Figures 5 and 6 the period is visible before the second half of 2017 when the number of daily active ERC-20 addresses and ERC-20 token transfers was still modest. In the early days, Ethereum could be mainly used for transaction and payment purposes. As noted in section 4.2, mining Ether could have served as an incentive to start using Ethereum before Dapps were available. Mining Ether in the hopes of token appreciation might have enticed users to commit to the ecosystem before the technology's true potential could be utilized through Dapps. This would be aligned with the research Trabucchi et al. (2020) conducted, where new platforms could incentivize users with tokens before the other side of users exists.

Figure 5: Number of daily active ERC-20 addresses



Source: Etherscan (2022, e)

Figure 6: Daily ERC-20 token transfers



Source: Etherscan (2022, f)

4.4 Winner-Takes-All Effect

A market is likely to be subject to the winner-takes-all effect when the users want to interact with as many other users as possible, and the networks or platforms within that market have strong network effects. Many network markets have a single large dominant platform like DVDs and fax, whereas other markets allow rival platforms to exist like credit cards or instant messaging services. When entering these networked markets, failing to realize whether the market is prone to the winner-takes-all effect can be a costly mistake (Thomas Eisenmann, 2007).

To date, Bitcoin has always had the largest market capitalization of all cryptocurrencies. However, Bitcoin's market capitalization has started declining over the years, as other competing cryptocurrencies have entered the market, and competition has become more intense. Ether has held second place most of the time, being the largest of all other alternative cryptocurrencies (Coinmarketcap, 2022). Bitcoin remaining as the market leader would indicate a first-mover advantage and winner-takes-all effect. However, other individual cryptocurrencies like Ethereum being able to gain and maintain a significant share of the markets could, on the other hand, indicate that the market allows rival cryptocurrencies to exist.

Figure 7 shows Ethereum's share of total cryptocurrency market capitalization in percentages and how it has developed since its inception. In 2017 when the cryptocurrency market topped Ethereum's market share rose to its highest point and represented over 30% of all cryptocurrencies. Following the top, the market share plummeted and eventually started recovering at the beginning of 2020. If the market share would be constantly growing, it would indicate winner-takes-all effect. As visible from Figure 7, Ethereum's market share has been relatively stable in recent years, and it has not at least to date overtaken the 2017 peak. Therefore, it can be stated that if Ethereum would be subject to the winner-takes-all effect, the effect would not be continuous, as Gandal and Halaburda (2016) noted about the winner-takes-all effect in the cryptocurrency market. Should be noted that since 2017, the cryptocurrency market has grown significantly, and Ethereum's competition has increased many folds. The total cryptocurrency market capitalization increased from approximately 820 billion at its peak in January 2018 to almost 3 trillion at its most recent peak in November 2021. Despite the growth in competition and the whole cryptocurrency space, Ethereum has been able to maintain a roughly similar market share.

Figure 7: Share of total cryptocurrency market capitalization

Source: Coinmarketcap (2022)

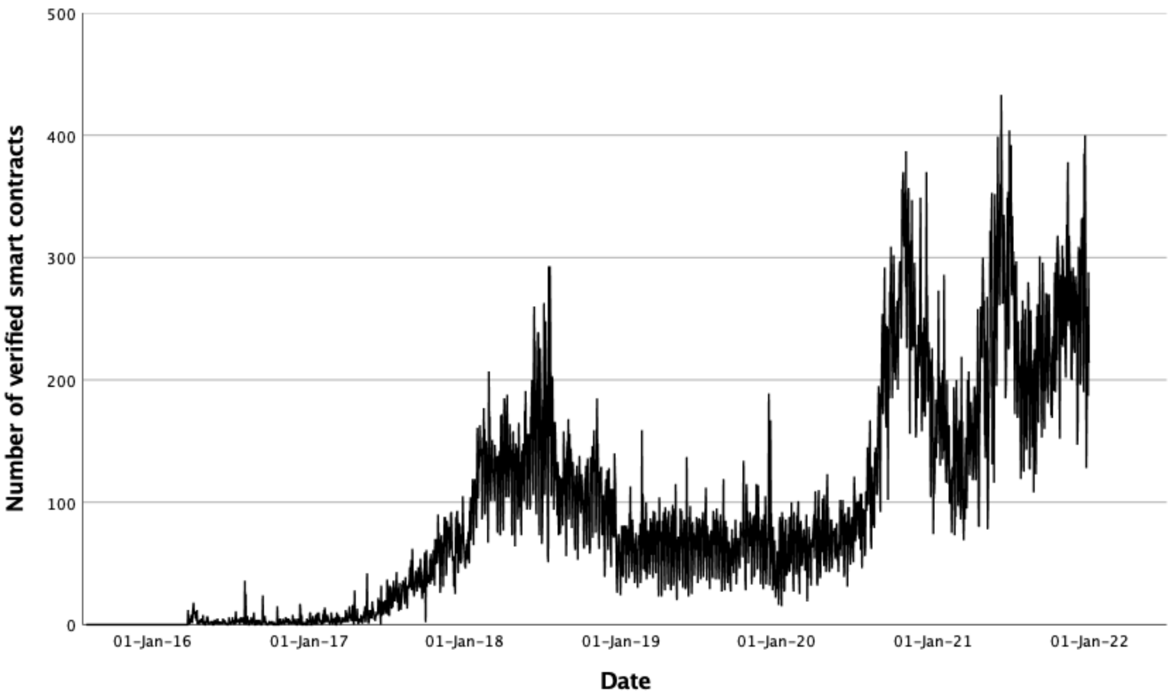
4.5 Positive Feedback Loops

When a platform has talented developers that create high-quality applications, more users will be drawn to the platform. As the platform's user base grows, more people are learning to develop applications on the platform as the overall market is growing. This leads to a broader selection of first-class applications and draws the attention of talented expert developers who can no longer ignore the opportunity that the platform provides. This connection between users and developers creates a positive feedback loop and accelerates the platform's success (Johnson, 2018).

Ethereum serves as a platform for different projects utilizing its blockchain, like those that issue ERC-20 tokens. Ethereum has also created a smart contract programming language called Solidity. Solidity was the first smart contract coding language and has remained the most utilized. As Ethereum gained popularity and attracted more users to its ecosystem, more developers started learning Solidity and building Dapps. Ethereum became the underlying platform for the first mass utilized DeFi applications like Aave and Compound, as well as decentralized exchanges like UniSwap. Users have had strong expectations of Ethereum becoming a significant player in the market thanks to its innovative design, which was achieved with the support of developers.

Figure 8 shows the number of smart contracts that have been verified daily using Etherscan's smart contract verification tool. Smart contracts are verified to promote transparency and build trust towards developed smart contracts. From figure 8, it can be seen that during 2017 the number of verified smart contracts started to increase. Despite high volatility, the number of verified smart contracts has remained on an ascending trend. This indicates that Ethereum has an active developer base that keeps developing an increasing number of smart contracts for the Dapps. Based on the growing number of unique and daily active Ethereum addresses together with the active and growing development of smart contracts on the blockchain, it can be assumed that Ethereum has positive feedback loops.

Figure 8: Ethereum daily verified smart contracts



Source: Etherscan (2022, g)

4.6 Switching Costs and Customer Lock-in

Together with switching costs, network effects can create customer lock-in and eventually lead to competitive advantage. Switching costs mean the cost of switching to use other suppliers' products, whereas the customer lock-in means the inability or unwillingness to switch to use other suppliers' products. In digital networks, the switching costs are not necessarily the cause of network effects because digital networks have fewer information asymmetries than physical ones. With digital networks, it is also possible that a network keeps growing while switching costs remain low (Prud'homme, 2019).

In the cryptocurrency market, switching costs are low. New competitors can easily enter the non-regulated market, and users can switch between coins relatively easily. Owning cryptocurrencies and using Dapps does not require significant hardware or software investments, so it does not create switching costs, act as a barrier to entry, or lock-in existing customers. Nowadays, cryptocurrencies also have multiple different on-ramps for buying, and many do not require technical knowledge. However, using Dapps does require a level of technical understanding about how wallets and the web3 ecosystem operates. This is most likely a barrier to entry for some new users. Once a user is accustomed to interacting with the Dapps in Ethereum, this most likely does not add to switching costs and customer lock-in, as Dapps in other smart contract platforms are being used similarly.

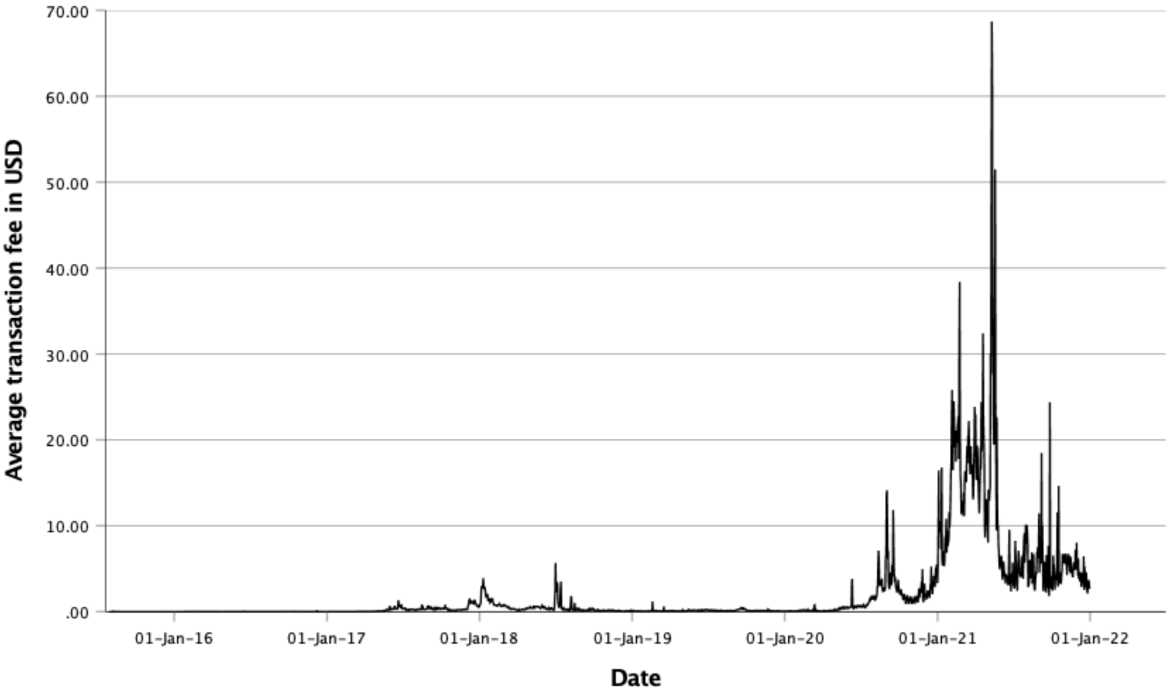
In digital platforms where switching costs are low, network effects can be a source of competitive advantage if the platform is sticky. Being scalable does not guarantee competitive advantage and long-term success if customers can easily leave and join another platform. There have been arguments that platforms can increase stickiness if users buy data using the platform. When data is stored in one central place in the platform, it would lead to customer lock-in and network effects. However, this does not apply in all scenarios or continue forever because competitors with new innovative business models can enter the market, or the data in question might no longer add value (Tucker, 2018). In Ethereum, as users hold Ether, they own a part of the network and store data on the blockchain. Using the mentioned logic, owning Ether could add to Ethereum's stickiness and strengthen the customer lock-in, despite the low switching costs.

The low switching costs of blockchain platforms not only apply to users but also to developers. Platforms need to incentivize developers to stay in the platform and not switch to building competing platforms. Catalini and Tucker (2018) pointed out that large platforms have the risk of developers switching to smaller platforms that incentivize them with their tokens. Ethereum ecosystem is subject to the same risk. However, Ethereum can be considered to have a somewhat secure position, being the largest platform and having the Ether and other ERC-20 tokens for incentivization purposes. As the ecosystem is comprehensive, there are significant opportunities for developers within. Instead of moving outside Ethereum, developers can move to another project within the ecosystem as new projects are constantly created. This helps in holding on to the talented developers as they can continue using their existing skills and find even more rewarding positions within the ecosystem. Therefore, if projects on Ethereum have low switching costs between them, that could create lock-in within the ecosystem for developers.

As noted by Carl Shapiro and Hal Varian (1998), governments can impact on the adoption speed of technologies through policies. In 2018 a director at the United States Securities and Exchange Commission (SEC) gave a speech, where amongst other topics, he suggested that Ether in its current form might not be considered security (Hinman, 2018). The cryptocurrency industry took it as a clarification of Ether's non-security status. Though cryptocurrencies are decentralized and accessible globally, the speech must have impacted the competition amongst cryptocurrencies. Projects deciding to build on Ethereum instead of competing blockchains based on the non-security status would add more use-cases to Ethereum and add more value to users. Also, for users of Ether, the non-security status might have provided more comfort to keep using the Ethereum ecosystem, as the competing blockchains could experience hardships if later declared as securities by the SEC. This could have helped to create customer lock-in in the Ethereum ecosystem.

From figure 9, it can be seen that transaction fees have varied significantly to date. The fees have ranged from just a few cents to almost 70 dollars. The fees should be considered when discussing customer lock-in. Despite the notable increase in transaction fees around market peaks in 2018 and 2021, Ethereum users have continued to use and remained committed to the network. As the number of active and unique addresses continued growing, the intermittent high transaction fees also did not become a barrier to entry for new users. The cryptocurrency market already has competing platforms with cheaper transaction fees, but Ethereum has managed to hold on to its users. This could be considered an indication of customer lock-in.

Figure 9: Average Ethereum transaction fee



Source: Etherscan (2022, h)

4.7 Recommendations

Based on the case study, recommendations can be given on how Ethereum can be most prone to direct and indirect network effects and benefit the most from them. Though should be noted that as Ethereum is a decentralized protocol, there is no central authority that can single-handedly execute the recommendations. Significant decisions are made through decentralized governance and more minor changes through collective actions made by the community.

Ethereum should ensure remaining in the growth phase on the s-curve. They can achieve this by improving continuity of network effects by promoting growth in network usage and productivity. This would simultaneously reduce the periods of reverse network effects. During market turmoil, users would have more Dapps adding value to them and keeping them committed to the ecosystem. Ethereum should also remain open to new innovative use-cases like the recent NFT boom. This continuous trend in innovativeness will protect Ethereum's market share against rivals.

Ethereum should prioritize having incentives and being inviting for new users. An active and committed community is vital in a market with low switching costs. Though users have continued to use the network despite occasionally high transaction fees, this can likely become a barrier to entry for some new users with less capital. Ethereum can influence this by switching from proof of work consensus mechanism to proof of stake consensus mechanism, which has been in the works for some time.

Another essential aspect is holding on to developers so that they do not leave to competing platforms but instead switch positions within the ecosystem. Developers keep the positive feedback loops intact, and the creation of Dapps draws in new users. A broad developer base promotes the creation of complementary products that add to the platform's productivity. Developers should be incentivized with tokens and by providing reliable tools.

4.8 Summary

Unique addresses on Ethereum reached critical mass at the beginning of 2017 and have remained in the growth phase ever since. In addition to the growing user base, the usage of the network has continued to increase. Through the usage of Dapps, productivity has also continued growing, adding to the direct network effects as it creates more token demand and growth in the userbase. The value of Ether and the value of the entire Ethereum network has grown significantly, making it more valuable to its users signaling direct network effects. Therefore, the growth in the number of users and speed of adoption cannot be justified only by virality. As the first smart contract platform, Ethereum has benefited from a first-mover advantage on its segment and seems to be subject to direct network effects. However, the direct network effects are not completely continuous, as seen from the daily active Ethereum addresses, daily Ethereum transactions, and Ether price, indicating periodical reverse network effects.

Ethereum serves as a platform connecting different user groups through a wide range of Dapps. Dapps also act as complementary products to Ethereum as they add value to each other. Mining was likely a significant incentive for early users to get into Ethereum before the critical mass was reached, and Dapps provided the other side of users. The usage of ERC-20 tokens has continued to increase despite the number of daily active ERC-20 addresses being stable. The impact that Dapps have on the ecosystem meets the criteria of creating indirect network effects in Ethereum.

The cryptocurrency market may not be prone to the winner-takes-all effect in the same way as seen in other network markets. Bitcoin has always had the largest market capitalization, but Ethereum and other cryptocurrencies have managed to grow and maintain significant market shares. Therefore, it can be said that the winner-takes-all effect does not seem to be continuous and allows rivaling cryptocurrencies to exist. Ethereum has not expressed winner-takes-all behavior so far during the period of examination.

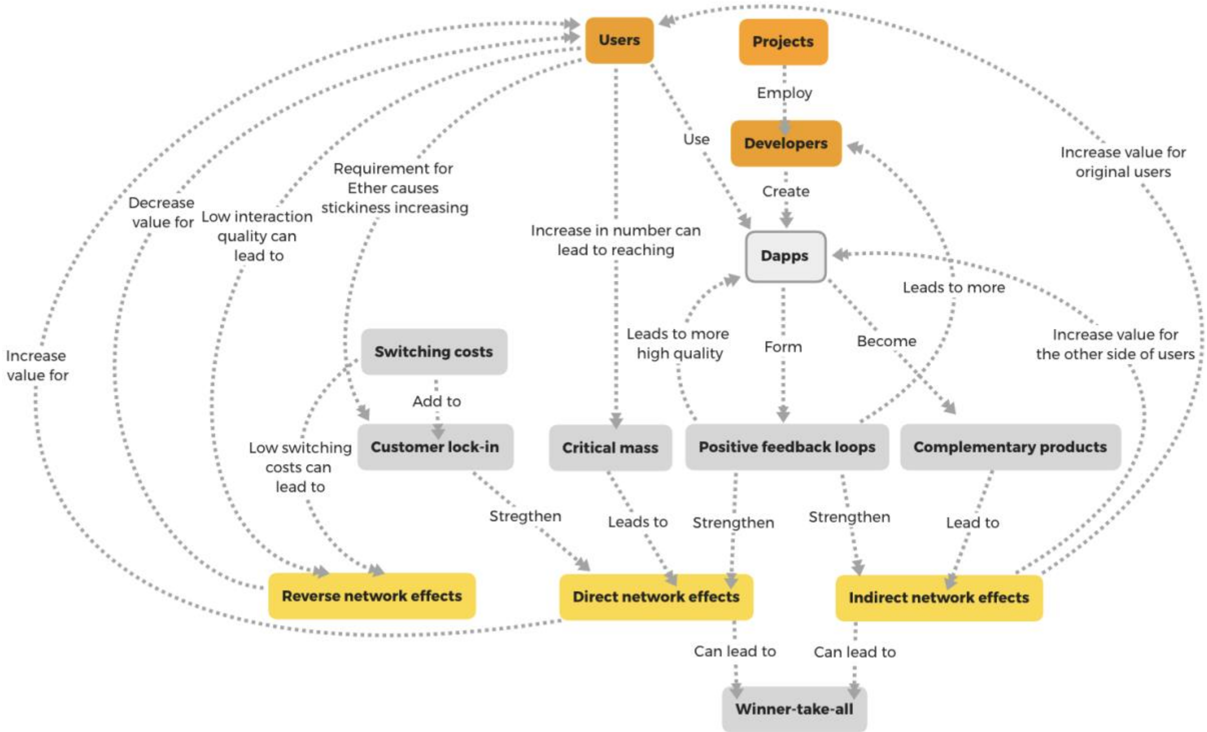
Ethereum's Solidity smart contract programming language has become the industry leader, and the ecosystem has a talented developer base. Through the introduction of new use cases on top of Ethereum like Defi applications and NFT marketplaces, new users have been drawn to the ecosystem. Also, the number of developer activities has kept growing in the form of smart contracts submitted for verification. Therefore, it can be concluded that Ethereum's productive and innovative developers create positive feedback loops in the ecosystem.

Ethereum has low switching costs for users like all cryptocurrencies in general. This stems from new protocols being able to easily enter the non-regulated open-source-based market and users being able to switch between cryptocurrencies freely. The requirement of owning Ether to interact with the Dapps increases the stickiness of Ethereum and strengthens the user lock-in. The possibility to incentivize developers with tokens and the broad selection of career opportunities within the ecosystem create lock-in for developers. Ethereum has benefited from its assumed non-security status in the United States, which has increased lock-in for both regular users and developers. The continued and growing use of the network despite the intermittently high transaction fees confirms the existence of customer lock-in.

To conclude and answer the main research question, Ethereum is subject to direct network effects from users transacting on its blockchain and indirect network effects from decentralized projects building on it. The direct network effects are not continuous, which can be explained by the cyclic and emerging nature of Ethereum. Indirect network effects are justifiable based on feedback loops and the complementary nature of Dapps.

Figure 10 shows a concept map visualizing essential themes in the case study and highlighting connections between them.

Figure 10: Concept map of network effects formation in Ethereum



CHAPTER 5: CONCLUSION

5.1 Main Research Issues

No significant issues were faced when conducting the research. However, one challenge was applying the network effects theory to Ethereum. Though the theory is relatively straightforward, cryptocurrencies do differ from traditional technologies like landline telephones, which is one of the networks the theory was initially applied to. The challenge was mitigated by becoming familiar with earlier research and publications applying the theory to other modern information technologies like online marketplaces. The challenge was overcome by making justifiable conclusions and assumptions based on the publications.

5.2 Summary of Results and Recommendations

Based on the case study Ethereum's number of unique accounts reached critical mass at the beginning of 2017 and has remained in the growth phase ever since. The usage and productivity of the network have also continued growing. Ethereum has benefited from its first-mover advantage and is subject to direct network effects. The direct network effects are not completely continuous, indicating the existence of periodical reverse network effects. Ethereum's growth cannot be explained with only virality, as the network has also become more valuable to its users, confirming the existence of direct network effects. Ethereum serves as a platform connecting user groups through Dapps. Dapps act as complementary products to Ethereum, adding value to each other. The impact that Dapps have on the ecosystem creates indirect network effects in Ethereum.

Ethereum has talented developers and great developer tools such as its Solidity smart contract programming language. The active and innovative developer base creates positive feedback loops in the ecosystem. Ethereum has low switching costs for users, caused by competing platforms having easy access to the market and users being able to switch between cryptocurrencies freely. However, the requirement of users owning Ether to interact with the Dapps increases Ethereum's stickiness and strengthens customer lock-in. The possibility to incentivize developers with tokens and the broad career opportunities within the ecosystem create lock-in for developers. The growing usage of the network despite intermittently high transaction fees confirm the existence of customer lock-in.

For Ethereum to remain in the growth phase of the s-curve, it should improve the continuity of network effects by promoting growth in network usage and productivity. This reduces the periods of reverse network effects. Furthermore, Ethereum should continue being inviting for new users as having a large and committed community is critical for building network effects in a market with low switching costs. To continue attracting and being a worthy option for new users, Ethereum should switch to a proof of stake consensus mechanism, which allows lower transaction costs. It is also recommended that Ethereum tries to hold on to developers within the ecosystem by providing token incentives. The developers have an essential role in the formation of positive feedback loops and the development of complementary products. As Ethereum is a decentralized protocol, the recommendations can only be executed through decentralized governance voting and other collective actions by the community.

5.3 Knowledge Contribution to the Industry

The case study made knowledge contributions in several ways. To date, holistic academic research about applying the network effects theory to Ethereum or other decentralized smart contract platforms did not exist. The research successfully added on top of existing literature, filled research gaps noted in the literature review, and provided a theoretical approach to network effects formation in Ethereum.

The case study contributed by analyzing how ERC-20 tokens and Dapps affect the direct and indirect network effects formation within Ethereum. A notable contribution was also made by examining the role of developers in the creation and enhancement of network effects. Developers create complementary products and are an essential part of positive feedback loop formation. The complementary nature of Dapps and positive feedback loops on Ethereum were not covered in the existing literature.

5.4 Recommendations for Further Research

The case study opens up promising possibilities for further research. These topics include measuring how switching costs between Dapps in Ethereum affect the overall switching costs of the whole ecosystem for both users and developers, as well as measuring the strength of indirect network effects within Ethereum. The case study can also be extended in the future, as the period for observation could end up representing the very start of an innovation diffusion curve, leading to more rapid growth in adoption later on.

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