Negative Indirect Network Effects

How can a subsidiary product create a second standard in the Microsoft Windows vs. Apple Mac OS market?

MSc Thesis

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"It is not the strongest of the species that survive, nor the most intelligent, but the one that is most responsive to change."

Charles Darwin, On the Origin of Species

"If you know the enemy and know yourself, you need not fear the result of a hundred battles. If you know yourself but not the enemy, for every victory gained you will also suffer a defeat. If you know neither the enemy nor yourself, you will succumb in every battle."

Sun Tzu, The Art of War

Preface

This thesis was written as the final requirement for graduation from my Master program in Management of Technology. Without a doubt, the underpinning research process shall be associated with a exiting journey. A journey that has brought me several invaluable opportunities and allowed me to interact and collaborate with extraordinarily inspiring people.

Inheriting knowledge by our ancestors, the pioneers risk their life to explore new frontiers. If Homo erectus had not controlled fire or brought its mastery to Europe, our brain would not have evolved enough to make us being Homo Sapiens. If agriculture had not been discovered in ancient Persia, we would not have had civilization. Without invention of writing by Egyptians, the coin by Lydians, the printing press by Johannes Gutenberg, the first practical steam engine by Thomas Newcomen, and many other brilliant discoveries, inventions, and innovations, we would not be standing in the place that we are now. It is really hard, if not impossible, to step in the footsteps of giants and I never claim that I ever did, but reading the history of science and technology inspired me to break my boundaries. Therefore, I came up with this challenging idea to investigate.

This research would not have been possible without the involvement and supervision of my first supervisor Dr. Laurens Rook, for his support, constructive suggestions, critical feedback, and particularly his patience.

I thank Dr. Mamadou Seck, for his great guidance to design and the programming of agent-based simulations. It is an honour for me that such a method probably has been implemented in MOT thesis research, for the first time ever. I also thank Dr. Caroline Nevejan, for her support, feedback, and advice, which made me an Out of Box Thinker. Similarly, I thank Dr. Roland Ortt, for inspiring me from the first day I started at the TPM faculty.

Many thanks to UAF for sponsoring my studies and giving me this wonderful opportunity to get my qualifications and pursue a Master of Science degree.

Last, but certainly not least, I am grateful for the support of my family and friends, specially Mohammad Suprapto, Alireza Rezaee, Dr. Sam Solaimani, Dr. Alireza Parandian, and Hadi Asghari. All those who stood by me during this time and pushed me to become a better person and better professional.

Ahura Qavami Tehrani

The Hague, May 2014

Executive Summary

New technologies create a network of complementary producers and consumers around themselves. Researchers have been investigating the effects of such networks on end-users and called them "Network Externalities". These network externalities are either direct or indirect. There have been no prior researches on negative and indirect consequences of these networks. The aim of this paper is to observe negative effects of the network on the market from both macro and micro level. Therefore, our main research question is: ***"Does expansion of network lead to Negative Indirect Network Effects?"***

The objectives of the present research were to investigate the nature of the network and to acquire more insight into the causes of Negative Indirect Network Effects (NINE) and their impact on network growth, to develop an empirical model for it, and simulate this model in order to have a better understanding of underlying network dynamics.

The focus of the present research was on the laptop operation system network. To start with, we reviewed different aspects of this particular network in order to reform a new conceptual model about consumers' behaviour. Then, we studied three major operating systems (OS) existing in the market today (Windows, Mac OS, and Linux). First, we reconstructed the history of these technologies, their life cycle, network characteristics, network size, and then, we continued with a short history of unwanted complementary products like bugs, viruses, worms, and malware. We surveyed user attitudes for the two main operating systems, Windows vs. Mac OS, and used those insights to make an agent-based simulation derived from our empirical model and mathematical equation. This simulation was applied to different scenarios.

Specifically, we found that a network becomes more attractive for unwanted complementary goods when it expands in size. Also, we discovered that an increase in problems for the dominant design will lead to NINE. Importantly, security measures play an important role in the satisfaction of end-users. When users distrust security measures of the dominant technology, they may decide to switch to a smaller and saver network, and create herd behaviour in NINE, leading other end-users or even new consumers to choose for the secondary technology. However, expansion of the secondary design could also attract unwanted actors in its network and same procedure would emerge for the secondary technology as well.

Our model is able to explain this recursive S-curve mechanism. Therefore, the present research provides additional understanding for industries to implement dynamic strategies in order concern to NINE. That is, security is important and industries have to be conscious about it and maintain safety measures with the intention of preventing NINE to happen. But also, industries must be aware that end-users should be involved in the feedback process.

Content

1. Introduction

When a new technology comes to the market, the manufacturer tries to create a network of complementary products around it. In addition, the growth of the product attracts more suppliers to join the network. More suppliers join the network and produce complementary products, which attracts more end-users to buy the main technology. This effect is called a "Positive Indirect Network Effect". The same could happen for harmful complementary-goods such as: viruses, hackers, and spywares in internet-based technologies. Appearance of such dangerous products in a network and their damage to end-users may destroy the trust of customers in the main technology. If the switching costs are low, not only customers may then choose an alternative technology; new entrants may see this situation and decide to go for the smaller network. This effect is called a "Negative Indirect Network Effect" (NINE). Furthermore, we have to see the impact of psychological factors on these negative externalities of network. Individuals could make such decisions themselves or under influence of other end-users decide to move to the substitute technology and perform "Herd Behaviour". The aim of this research is to observe negative effects and its impact on market, from both side of macro and micro level, and focus on case of network around laptop operation system.

I:

Suppose we have two herds of cattle from the same breed (meaning that their protection system is almost identical). Both herds have one acre of grazing, but one herd has 1000 cattle, the other has only 100 cattle. In case an airborne virus attacks both herds, a pandemic is more probable in the bigger group than in the smaller one, because the cattle in the bigger herd is more in contact with each other than in the smaller herd. So if the owner of these herds wants to add more cattle, to avoid disease, he will choose to add new cattle in smaller group.

II:

Suppose there is a cybercriminal who wants to hack an internet network of a bank. There are two banks he could attack. Bank “A” has 10 times more bank accounts than bank “B”. Presume that proxy walls and cyber security measures of both banks are approximately identical. It then is rational to assume that our thief would probably choose to catch bank “A”. The first attack may cause little concern among bank consumers. But if bank “A” becomes victim of more regular attacks and bank “A” would not provide better security in order to reduce these attacks, account holders may shift to bank “B” which is smaller but safer. Furthermore, not only consumers of bank “A” will shift to bank “B”. They may influence people around themselves and even new entrants to go for the safer bank, while even new entrants will see this situation and prefer to choose the smaller and safer bank.

Both examples described above illustrate the underpinnings of the consequences of a big network as well as of a “Negative Indirect Network Effect”. The negative indirect network effect refers to the phenomenon that a major player and the subsidiary one are almost identical in design and performance. They are compatible, but, like in the example from the nature, a virus may act as a customer. The virus could transmit easily among them. So the only reason that the bigger herd gets more infected cattle is density of its network, in which animals are in more contact to each other.

The same conditions apply to the bank example. The services that both banks give are identical – for example, customers of each bank could use their bank card in any other bank’s ATM. Furthermore, customers of those banks can change from one bank to another easily, fast, and free of charge. Therefore there is no lock-in and switching cost is low.

Both examples illustrate the negative indirect network effect. To properly understand the meaning of these factors and processes, I next review the literature on network externalities.

We know that advertisement and mass media play a great role in society and they influence people to change their conception about different issues. The concept of the mass is mainly large aggregate, undifferentiated, mainly negative image, lacking order, and is reflective of mass society (McQuail, 1994). But we assume both technologies has equal weight in the penetration of the society conceptions and they cannot create any kind of mass collective behaviour, and their influence would appear in “Bandwagon Effect”, “Veblen Effect”, and “Snob Effect” which we discuss them later in section 2.3.

1.1. Research Questions

In this thesis, we will investigate the following problems in relation to network externalities and the Negative Indirect Network Effect:

1: Is there any correlation between expansion of a network and the increase of problems in such a network?

2: Will the increase of these problems lead to Negative Indirect Network Effects?

3: What are the possible negative effects of network growth?

4: Under what conditions will end-users become less satisfied with a network and prefer to change the network from the standard one to a subsidiary?

5: Is there a positive correlation between expansion of a network and these conditions?

6: Is there any "Herd Behaviour" in "Negative Indirect Network Effects"?

1.2. Research Objective

- **Acquiring more insight into the cause of negative indirect effect in networks and its possible impact on network growth**
- **Investigating the nature of network growth**
- **Developing model of performance and attempt to measure its impacts**
- **Simulating the model of network in order to get better understanding of network growth**

2. Research on Network Externalities

In this chapter I present the theoretical framework underlying this research. First, an overview is given of various perspectives on network effects taken in literature. Next, we review prior research about indirect network effects. Then we focus on the economic psychology of NINE, and of the switching behaviour of end-users. And lastly, the conceptual model and related hypotheses will be proposed.

2.1. Early Researches into Network Effects

There are three subsections. Subsection 2.1.1 introduces the subject of increasing returns. Next, 2.1.2 makes an investigation of various authors that have previously discussed network externalities. Lastly, 2.1.3 reviews those studies of standard battles.

2.1.1. Increasing Returns

The phenomenon of increasing returns was introduced into economics around the mid-1980s. It can be defined as the more a technology is adopted, the more experience is gained with it, and the more it is improved (Rosenberg, 1982). When two or more technologies compete for a market, one of them may get initial advantage in the adaptation process over the others. Therefore, this technology may improve more than the others, just because it benefits from a "Learning by Using" process, so it may appeal more potential adopters. Then further adoption consequently means further improvement (Arthur, 1989). The Boeing 747, for example, was introduced to the market in 1969. It was the first wide-body commercial airliner ever produced, and it received the nickname of “Jumbo Jet” which commonly referred so far. Juan Trippe, president of Pan Am, necessitated a new wide-body, long distance, airplane for their transcontinental routes across the Atlantic. Trippe went to his old friend Bill Allen, the boss of Boeing, saying he wanted a jet two and a half times the size of the existing Boeing 707 (Branson, 1998). Boeing custom-designed the 747 based on these specifications. Soon after Pan Am’s order and first test flight of the B747, many other airlines adopted this plane, and purchased the first version of it, the Boeing 747-100. This gave incentive to the manufacturer to go on with constant improvements and modifications until now.

Thus, a technology that even by chance gains an early lead in the adaptation process (like successes in the performance of prototypes, satisfaction of early customers, and even political circumstances), might achieve a sufficient adoption and improvement to become dominant in the market (Arthur, 1994).

2.1.2. Network Externalities

An important element of the increasing returns approach is the notion of “Network Externalities” or network effects. Among others, research by Katz and Shapiro on network externalities showed that the utility of a technology can increase with the number of agents consuming that technology (Katz & Shapiro , 1986). The utility that a consumer derives from purchasing a telephone, for example, clearly depends on the number of other agents that have joined the telephone network. There are several possible sources for these positive network externalities.

First, compatibility may play a significant role. Products are compatible, when you can use the same complementary goods on different products. In hardware-software markets, for example, the issue is whether software produced for one brand of hardware may run on another brand of hardware or not. Then, the hardware brands are said to be compatible. If two technologies are compatible, the aggregate number of end-users to the two technologies constitutes the appropriate network. If they are incompatible, such as Telex or quadraphonic audio discs the size of an individual system is the proper network measure for users of that system (Katz & Shapiro, 1985).

Farrell and Saloner also studied network externalities. Their studies showed that there may be a direct "Network Externality" in the sense that one consumer's utility for a technology increases when another consumer has a compatible good, as in the case of telephones or personal computer software. There may be a market-mediated effect, which occurs when a complementary good (such as spare parts, servicing, and software) becomes cheaper and more available as a function of market size. Therefore, it creates more incentives for producers to manufacture their goods cheaper by taking advantage of economies of scale and making their products more compatible. In fact, this standardization pattern is mostly voluntary, rather than due to governmental regulations (Farrell & Saloner, 1985). For example a mobile manufacturer like Nokia which used to have the biggest global market share, preferred to have its own design of charger’s connector. Because of the market domination of Nokia, you could find this Nokia charger almost in all the houses. Of course Nokia defended its patent on its charger connector design, but when the smart phone entered the market, mobile manufacturers needed to use the same port for USB and charging battery (CTIA Press Releases, 2009). Therefore they could not follow the same strategy as before. They gathered at the cellar phone carrier group, Open Mobile Terminal Platform (OMTP) in 2007 and voluntarily endorsed Micro-USB as the standard connector for data and power on mobile devices. In January 2009 it was accepted by almost all cell phone manufacturers. Then later on 22 October 2009 the International Telecommunication

Union (ITU) also announced Micro-USB as the universal charger and data conductor (Parkes, 2009). European official standardization was take place in end of 2010 (New EU Standards, 2010).

In a way, network effects are just economies of scale: the per-buyer surplus available to a coalition of buyers and sellers increases with the size of the coalition. It is more fascinating to know that network effects can lead to "Herd Behaviour".(1) This sequential adoption creates dynamics that are characteristic of network markets: early instability and later lock-in (Farrell & Klemperer, 2006). This will be discussed in next section.

2.1.3. Standard Battle

An important application of network effects is in the area of standards battles. Many products can be perceived of as a collection of two or more components together with an interface between them. The main product only works well in the presence of complementary goods – such as a video game console, which is worthless without video games. All together they make a system, which means that a rational consumer must be sure about availability, price, and quality of the additional components before buying the main product. Once a specific technology with these characteristics is chosen, it is hard and costly to switch to another technology. For instance, when a customer decides to buy a "Play Station 3", s/he has to also buy some games for it. If s/he is not satisfied with the product after all, and willing to switch to the "Xbox 360", s/he not only has to buy a new console, but must also purchase several new games for it (because the Play Station games don't work on the new device).

[1] Herd Behaviour will be discussed in section 2.3. An Economic Psychology of Negative Indirect Network Effects

Increasing returns, compatibility, positive feedback, and network externalities could play an essential role in this [decision-making] process. Manufacturers compete with each other, with the aim of making their technology dominant in the market, and pushing the market to accept their product as the standardized one (Katz & Shapiro, 1994). Companies implement different strategies and methods in order to convince consumers to adopt a certain technology or not. If they achieve this goal, they can win the battle of standardization and consumer adaption (Katz & Shapiro , 1986) (Lee & Mendelson, 2007).

Economists assume that this battle is a “One Shot Opportunity”, and that the dominant design will win most of the market – a phenomenon, which is called “Winner-Takes-All Market” (Frank & Cook, 1988) (Schilling M. A., 2002). They assume that if a technology becomes standard, the other technologies lost the chance and could not rise again. Their reason was high switching cost and customers would exclusively locked-in that technology. Among others, Knittel and Stango assume that when a technology becomes standard, it wins the battle and competitor could not gain any advantage any more, although after a while switching cost and locked-in problems would decrease (Knittel & Stango, 2004).

2.2. Indirect Network Effects

In network-based studies, network externalities are usually divided into two categories, direct and indirect network effects. The classical sort of network externalities is referred to as direct network effects: if more people apply a technology, this increases the utility of the technology itself. That is, when a technology becomes popular, more companies would like to invest in supplies and complementary goods. The more complementary goods come with a technology, the more people are prepared to use that technology (Clements, 2004). For indirect network effects, however, Clements made two claims: 1) for indirect network effects, unlike direct network effects, increases in the size of network do not increase the likelihood of standardization, but 2) indirect network effects are associated with excessive standardization. The latter standpoint is not undisputed. Church and Gandal show that there is no excessive standardization, but like direct effects there are either multiple networks or insufficient standardizations (Church & Gandal, 2012).

Indirect network effects arise through improved opportunities to trade with the other side of a market. Being in the bigger market means higher demand and the possibility that the price of complementary goods may increase with limited supply. Therefore, end-users typically should not like the popular technology. But when demand is high, more suppliers will be attracted to that market, and consequently more complementary goods will be produced for that specific market. In that case, buyers indirectly gain from the re-equilibrating entry by sellers, and vice versa, because the result would be cheaper, better, and more availability of complementary goods. If so, there is an indirect network effect (Farrell & Klemperer, 2006).

The positive effects of indirect network externalities were recognized only a decade ago when researchers realised for the new network-based technologies like CD, DVD, and HDTV that there is a two-way contingency between the demand for the main product and supply of complementary products, which is that most of these products and their complementary goods are provided in independent firms. Therefore, performance and availability have an enormous influence on the market acceptance. So they realized that there is a strategic interdependence relation between their actions to create a demand for new products (Gupta, Jain, & Sawhney, 1999). Positive indirect network effects are present when the utility of the product increases due to greater availability of compatible complementary products (Basu, Mazumdar, & Raj, 2003). The value of a product in these categories increases as the installed base or availability of complementary products increases (Cottrell & Ken, 1998).

In many cases, positive effects of network externalities were found. Clements and Ohashi for instance studied the game market between 1994 and 2002, and found a positive interrelationship between game console adoption and availability and quality of the games (Clements & Ohashi, 2004). Church and his colleagues showed the benefits of the indirect network effects for complementary goods' market adaptation, as well as different benefits (like variety, product quality and reduction of price) for the end-users (Church, Gandal, & Krause, 2008).

More recently, Stremersch et al established that there could be a possible negative indirect network effects due to low availability, high price, and poor quality of complementary goods. They for instance argued that higher past software availability could lead to more intense competition among complementary goods providers, as a result of which fewer providers would be attracted to join the market, and produce new software (a so-called "Competition Effect"). Second, the authors pointed to the possibility that high costs of producing new complementary goods may discourage providers to involve in the new risky market (Stremersch, Tellis, Franses, & Binken, 2007).

2.3. An Economic Psychology of Negative Indirect Network Effects

In the early 1950's, Leibenstein concluded that consumers' collective behaviour could lead to changes in preference for a subsidiary technology instead of a standard one. This phenomenon was called the “Bandwagon Effect” (Leibenstein, 1950). This bandwagon effect could occur in different ways. One of the most classic bandwagon effects is to adopt a given product or technology in order to be “one of the boys” or to be fashionable or stylish. Apple consumers for instance, come to mind as a contemporary illustration of this sort of “Herd Behaviour” in consumption. When consumers want to be seen as a member of special society class, this is called the “Veblen Effect” (Dolfsma, 2000). And finally there is another network externality called “Snob Effect”. This effect is exactly opposite of the “Bandwagon Effect” and it happens when demand for a consumers’ good decreases because of the fact that others are also consuming the same product. This effect represents the desire of some of consumers to be exclusive and different from herd (Leibenstein, 1950). For a review, see Rook (2006).

These three effects were investigated and stressed as a sort of network externalities on the micro level, but everybody looked at these effects from the macro level, just before standardization battle, and general expectation was “Winner-Take-All” (Schilling M. A., 2002). Rook concluded that, economists mostly concentrate upon macro level processes while keeping psychological measures like individual performance and motivation constant, and those assumptions have yielded weak results (Rook, 2006). It makes sense that herd behaviour also influences NINE.

2.4. Switching Behaviour

In several markets for network-based technologies, such as the operation system and smart phone market, we witness some decrease in the standard product’s market, because the dominant network lost a few percent of its market to a subsidiary technology. Basic evidence shows that expansion of a network also attract negative complementary products like viruses, bugs, spam, criminal abuse of network, and spy.

Simultaneously when consumer knowledge increases, switching cost will decrease. Therefore in the absence of lock-in these undesired actors make that technology becomes vulnerable and end-users may decide to shift to the subsidiary technology. Hence, it seems network growth could have possible negative effects.

To illustrate, Microsoft windows operating system could be a good example. Microsoft won the battle of standardization by mass production and creating a big network of alliance around its operating system. This company benefits from indirect network effect on suppliers and buyers, by attracting software programmers as well as end-users to help this network to grow faster and become dominant in the operating system market. On the other hand, more and more it also attracted unpleasant programmers and consumers. Suppose you are a hacker and you want to hack a normal consumer to use or sell their confidential information, like their bank account and so forth. The logical choice would be to work on a dominant operating system because it has more consumers. Therefore Windows operating system attract more hackers and virus programmers as well.

After decades of using computers the general knowledge of consumers increased. Moreover interfaces and applications of both Windows and Apple OS, become more similar to each other. That means it becomes easier for Windows users to shift to Apple OS, or in other words: “Less Lock-In and Switching Cost”. When a subsidiary technology becomes more innovative, with less problems, it thus becomes more attractive.

It seems these phenomena have not been considered seriously. For that reason this research aims to observe these negative indirect network effects and investigate the possible consequence of these effects, test the magnitude of these effects, and see if they have a significant influence on consumer's decision–making process.

To summarize, we assume that new consumers may mostly be attracted to a dominant technology as result of Bandwagon Effect, but that some of them would prefer a subsidiary technology in niche market according to Snob, and Veblen Effects. But the more unwanted attacks on the dominant technology (due to weak security measure and vulnerability of this technology to new attacks, as well as lack of lock-in and switching cost for end-users), the more likely the consumers may decide to change to the compatible secondary technology.

2.5. Conceptual Model

After reviewing the literature on network externalities, we came up with a conceptual model, which is representative of all effects (See Fig. 1). Arrow 1 in the model states that an increase in the hardware sale of dominant technology will lead to network externalities, as a result of which network density of the dominant design will increase. With an increase of network density, new consumers in the environment of the specific technology may become interested to utilize the same technology, leading to some sort of feedback effect called the "Bandwagon Effect". This response is acknowledged in the model as Arrow 2. Some of the new users may want to be exclusive, and for that reason choose the subsidiary technology, a response called the "Snob Effect". Arrow 3 represents this effect. When the network becomes denser, it will motivate software developers to produce complementary goods for that technology. The more software is produced for that technology, the more users will adopt some hardware, a response called the “Positive Indirect Network Effect”. But not all the software developed will be useful: some will appear in the network as some sort of attack to the network of consumers, especially in a dense network. This will increase the possibility of attacks from unwanted actors. Arrow 4 in the model is representative of this effect.

When the chance of attacks in the network increases, the satisfaction of the end-users will be negatively influenced. When there is a compatible technology with a low switching cost, those unsatisfied consumers may switch to this secondary technology. They may also psychologically influence some of the new entrants to choose the substitute technology instead of the dominant one, a response called the “Negative Indirect Network Effect”. This notion is identified as Arrow 5 in our model. Finally, Arrow 6 represents all possible shifts from the dominant technology to the alternative one.

Importantly, the same relations are theoretically assumed for the substitute technology, where the same effects could occur in time. To avoid any complication in the model we assume our market is a duopoly. Therefore all the switching would be back and forward between these two designs. But in reality they could shift to any other compatible designs available in the market.

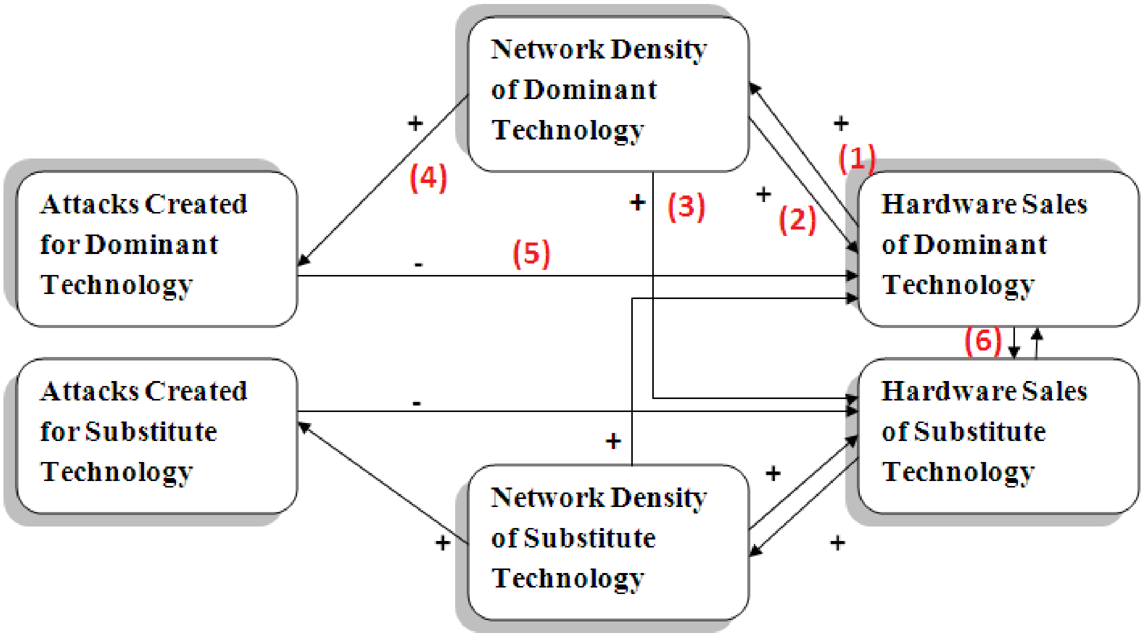

Figure 1 – Empirical Model

2.6. Hypothesis

The empirical model leads to the following set of testable hypotheses:

Hypothesis 1: ***An increase of undesired complementary goods in the network will raise dissatisfaction of the dominant design's consumers such that hardware sale of the dominant design will decrease.***

Hypothesis 2: ***Highly dense networks attract more undesired complementary goods that dissatisfy consumers, leading fewer consumers to adapt the dominant design in the future.***

Hypothesis 3: ***If consumers feel less safe and satisfied with the dominant design because of the existence of undesired complementary goods, they may choose substitute design instead, leading to an increase in hardware sale of the substitute technology will increase.***

Hypothesis 4: ***An increase in hardware sales for a substitute design, because of switching of end-users due to unwanted actors in the dominant design's network will lead to a denser network that will attract more undesired actors and make this substitute technology vulnerable too.***

Hypothesis 5: ***The relation described under Hypothesis 4 is recursive in nature, leading some consumers to switch back to their old technology.***

3. Case-Survey Microsoft Windows vs. Mac OS in laptops

In this chapter, the details of the designing and conducting the case-survey study will be elaborated upon. Section 3.1 presents the case study on three major operating systems (OS), reviews the history of operation systems, and analyses their technological life cycles. Then we focus on network characteristics and network size. Lastly we review the history of computer viruses, worms, and malwares.

In section 3.2 we use the insights from our literature review and case study to design a survey in order to gather empirical data supporting this research.

3.1. The Case study (Microsoft Windows, Mac OS, and Linux)

Most network-based technologies are in the standardization process and involve in their pre-diffusion or stabilization phase of their life cycle. Their Operation System is old enough to cross these stages and at this time is in post-standardization phase. You may ask why laptop OS not hole operation system? The answer to this question is; large amount of personal computers are bought by organization for their employees and they almost forced to have them, so there is no end-user decision making process. But purchasing laptop is almost personal choice. Therefore, it is possible to investigate whether negative indirect network effect is actually happens or not. In order to do that we have to investigate when and how this technology reached to this point, and what is the existing network.

Laptops are use the same OS as PC's, so although target group is different, from technology producer's view point they are the same and they almost benefit from same network characteristics. For that reason, first phase of this research should be case study about background and characteristics of all three dominant operating systems' network.

3.1.1. History of Operation Systems

The term "personal computer operating system" (PC OS) has been known since the very first generation of personal computers was introduced in the market during 1973 – 1981 (Tanenbaum, 2001) (Polsson, 2009a). During that period, there were two dominant command line interface operating systems: CP/M (Control Program for Microcomputer) and MS-DOS (Microsoft Disk Operating System). However, the diffusion of PC OS did not start until the introduction of the graphical user interface (GUI) OS, with Macintosh System 1.0 by Apple and Microsoft Windows 1.0 during 1984-1987 (Campbell-Kelly, 2001) (Linzmayer, 2004). Both made the PC easier to use and in turn led to the increased adoption of PC in the market.

Apple:

The story of Apple and Mac OS began when Steve Wozniak and Steve Jobs founded Apple Computer Company in 1976. They envisioned to manufacture and to sell microcomputers that everyone can use. From 1976 to 1980, Apple Computer started producing the Apple I, Apple II, and Apple III (Polsson, 2009b) (Sanford, 2009). The development of the Macintosh operating system started in 1979 when Apple Computer launched the "Lisa" project, a code name for a high-end microcomputer. Although Lisa failed in the market, the development of "Lisa" also triggered the development of Macintosh (Hormby, 2005). The first Macintosh prototype was revealed by Steve Jobs to Bill Gates in 1981 (Tuck, 2001). The released of Macintosh Operating System 1.0 with built-in GUI environment was a breakthrough technology at that time (Polsson, 2009b) (Sanford, 2009) (Tuck, 2001).

Following the successful introduction of Macintosh System 1.0, Apple Computer continued to release System 2.0 (1985) up to System 7.5 (1996). The next generation operating system released in 1997 was called Mac OS 8.0. With declining market shares in the PC market, Apple Computer started the Mac OS X project 1998 based on the UNIX kernel. Since 2000, Apple Computer has released 6 versions of Mac OS X.

Microsoft:

In its earliest years (1975-1980), Microsoft was known as pioneer in software development language. Bill Gates and Paul Allen started their partnership and eventually founded Microsoft in 1976 with BASIC programming language as their first product (The History of Microsoft , 2009) (Polsson, 2009c). Microsoft then entered the operating system business when Bill Gates and Paul Allen got a contract from IBM to supply the operating system for the IBM PC. The first version of Microsoft's operating system, MS-DOS 1.0 was released with as default operating system for the IBM PC in 1981 (The History of Microsoft , 2009) (Polsson, 2009a) (Polsson, 2009c).

As it became a prominent software vendor, Microsoft was requested by Steve Jobs to develop applications for Macintosh. Inspired by the graphical user interface feature of Apple's Macintosh prototype, Microsoft began to develop Windows 1.0 on top of MS-DOS in September 1981. The first version of Microsoft Windows, Windows 1.0 — initially called Interface Manager to MS-DOS— was released in November 1985 (The History of Microsoft , 2009) (Polsson, 2009c).

Within 5 years after its first release, Microsoft released two version of Windows operating system, Windows 2.0 (1987) and Windows 3.0 (1990). Microsoft Windows 3.0 was a very successful operating system that reached mass scale adoption with 2.75 million copies sold in

1990 and gained 75% market share in 1991 (Polsson, 2009c). At the end of 1994, Windows 3.0 and Windows 3.11 for workgroup (released in 1992) had reached 50-60 million of installed base users in the market (Polsson, 2009c).

The years of 1993 – 1998 marked Microsoft's innovation activities in building the next generation Windows with built-in GUI components such as Windows NT (released since 1993), Windows 95 (released on August 24, 1995), and Windows 98 (released on June 25, 1998) (The History of Microsoft , 2009) (Polsson, 2009c). Microsoft continued its domination in the PC OS market by introducing Windows XP in September 2001 which can be considered as the most successful PC operating system in the history. Up until now, Microsoft has released Windows Vista (released in January 2007), Windows 7.0 (released in July 2009) and Windows 8.0 (released in August 2012).

Linux:

The history of Linux started in September 1991 when Linus Torvald introduced the Linux kernel for the Intel-based PC as a porting version of Tanenbaum's MINIX operating system that was released since 1987 for education purpose (Staff, 2006) (Tanenbaum, 2001). Since its first release to the public, software programmers under GNU project started integrating GNU's collection programs into Linux kernel (Stallman, 2007). In February 1992, the first Linux distribution, called MCC Interim Linux was released to the public. Within the same year two other Linux distributions called SLS and SUSE Linux were also released. In March 1994, the official Linux kernel version 1.0 was released (Staff, 2006).

The period from 1992 to 1998 was an adaption phase for Linux with numerous technical developments and market acceptance. The technical development of Linux was ranged from the development of kernel, GUI desktop (X-Window, KDE, and GNOME) and supporting end user application such as WordPerfect and OpenOffice. On the market side, several “distribution” packages were developed by a number of companies such as SuSE, Redhat, and Caldera (Staff, 2006)..

The year 1999 can be defined as the start of market adaptation for Linux. In 1999, a paid distribution of Linux, Red Hat Linux gained an acceptance from Dell Computer that pre-installed the operating system in its servers and workstations. Also in 1999 Red Hat and a year later Caldera had their IPO (West & Dedrick, 2001) (Staff, 2006). From the beginning 2000s, big companies like Amazon and Google adopted Linux as their IT system infrastructures. Since 2005, leading IT companies such as IBM, Novell, Intel, and Oracle also entered Linux business segment.

3.1.2. Analysis of Technology Life Cycle

By applying the hallmarks criteria of technology lifecycle on the historical data of Mac OS, Microsoft Windows and Linux, the hallmarks of the PC OS battle based on the definitions by Ortt et.al are shown in figure 2 (Ortt, Shah, & Zegveld, 2007).

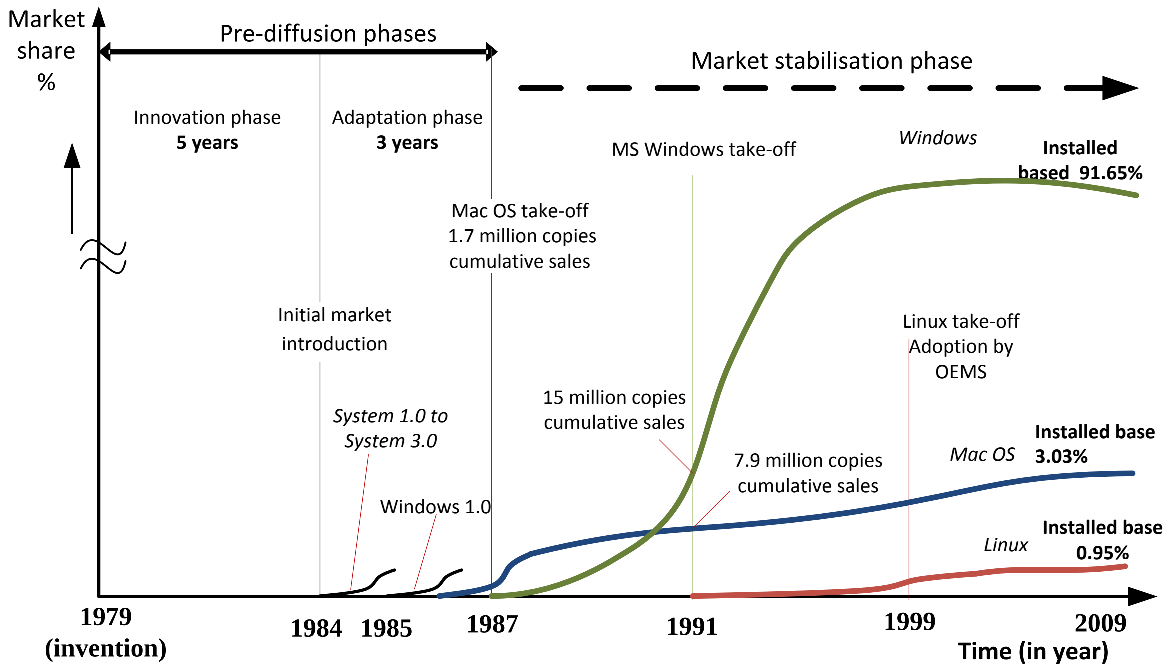

Figure 2 – The technology lifecycle of PC operating systems based on Ortt et.al definition

Figure 3 shows the timeline of Suarez's phases (Suarez, 2004). In this PC OS case, innovation phase (I) can be further divided into a R&D build-up phase (I-a) and a technical feasibility phase (I-b). The market adaptation phase (II) is in line with the market creation phase (II) and the market stabilization phase (III) consists of decisive battle phase (III-a) and post dominance phase (III-b).

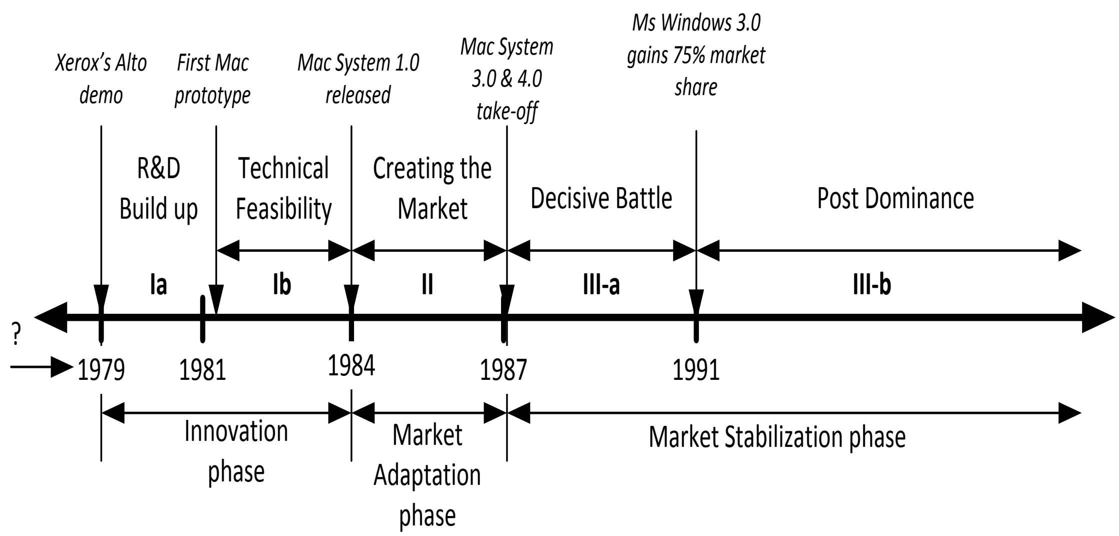

Figure 3 – The technology lifecycle of PC operating systems based on Suarez's definition

The start of R&D build up (I-a) might already have started since mid-1970s when a team of Xerox's engineers in PARC developed the Alto computer with graphical user interface system. However, Alto's novel GUI system was never targeted for the microcomputer. The development idea of a GUI-based operating system for microcomputer was then capitalized by Apple's Lisa developer after seeing a Alto computer demonstration at Xerox's PARC in 1979 (Campbell-Kelly, 2001) (Linzmayer, 2004). We set the start of R&D build up at the end of 1979 since the basic idea of a GUI-based PC OS was initiated by Apple (although the working principle of graphical user interface originated from Xerox).

The technical feasibility phase (I-b) of GUI-based operating systems for PC can be set in 1981, when Steve Jobs demonstrated the first Macintosh prototype with GUI-based operating system to Bill Gates. Despite the fact that the basic idea of GUI for Macintosh was inspired by the graphical display of the Alto computer developed by Xerox's PARC team in the 1970s, Apple Computer was indeed the first company that incorporated the idea into a prototype for PC. Apple's GUI-based Macintosh project then triggered other prominent software vendors to develop GUI-based operating systems such as Microsoft for Windows 1.0, VisiCorp for VisiOn, Digital Research for GEM (Graphical Environment Manager), IBM for TopView, and QuaterDeck for DESQ within the period of 1982 to 1984 for IBM PC-compatible (Campbell-Kelly, 2001).

The start of the market creation phase (II) can be marked by the introduction of the first Macintosh with System 1.0 on Jan 22, 1984. In the following years, other GUI-based operating systems were also released into the market such VisiOn (January 1984), DESQ (May 1984), GEM (September 1984), TopView (August 1984), and Microsoft (November 1985). Although these products attracted strong media focus with user-friendly user interfaces as the unique selling point, Macintosh System 1.0 never attracted complementary suppliers due to its proprietary system (Campbell-Kelly, 2001). Other GUI-based operating systems for IBM PC-compatible computers such as VisiOn, GEM, DESQ, TopView, and Windows 1.0 also failed to gain significant market adoption. The technical complexity of GUI-based operating systems was significantly increased as compared to text-based operating systems. This caused the delayed of development and increased the costs. Other reasons came from the limitation power of Intel 8088/86 microprocessors (Cottrell & Ken, 1998) (Campbell-Kelly, 2001).

The decisive battle phase (III-a) can be set at the end of 1987 marked by the start of large scale diffusion of the Macintosh System 3.0 and 4.0 that booked 0.6 million units of sales during the year (Linzmayer, 2004). In the next years, Macintosh sales grew consistently and followed by Microsoft Windows 2.0 (released by the end of 1987). The period of 1987 to 1991 can be set as Suarez (2004) phase of decisive battle between Mac OS and Microsoft Windows. First Mac OS dominated the market from 1987 to 1990 with cumulative sales of 5.1 million units while Microsoft Windows booked only 1.3 million units.

The start of post dominance phase (III-b) was marked by the emergence of a clear dominant design (Suarez, 2004) set at the end of 1991 when Microsoft gained a significant installed base over Mac OS and triggered the wide scale adoption by IBM and other PC makers (OEMs). By the end of 1991, with the release of Windows 3.0 Microsoft took a significant lead by securing 15 million units of cumulative sales, almost twice as much as Mac OS cumulative sales of 7.2 million units. Since 1991, Microsoft dominates the GUI-based PC OS until now (Campbell-Kelly, 2001) (Linzmayer, 2004) (Polsson, 2009b) (Polsson, 2009c).

The duration of the pre-diffusion phase for GUI-based PC OS is 8 years, which consists of 5 years of innovation phase and 3 years of market adaptation phase as shown in figure 1. In comparison, the average duration of the pre-diffusion phase within Telecom, Media and Internet industries is 15.3 years, and consists of 8.9 years for the innovation phase and 6.4 years for the market adaptation phase (Ortt, Tabatabaie, Alva, Balini, & Setiawan, 2009).

3.1.3. Network Characteristics

Network around these technologies were changed during their life cycle. For instance, during the post dominance phase, the Linux entered the battle with quite a diverse network of actors. Table 1 summarizes the number and diversity of actors for the three competing networks.

Type of actors	Apple	Microsoft	Linux
Standard supporters	Apple, Motorola and IBM, and Intel.	Microsoft, Intel, and AMD.	GNU/Linux (Free Software Foundation), Linux Foundation, Red Hat, Novell, Canonical, open source developers.
OEMs	Apple; worldwide market share of Macintosh from 1991-2005 declined from 8.1% to 2.1% (PC Sales, 2006) (Linzmayer, 2004)	Dell, HP, Acer, Toshiba, Lenovo/IBM, NEC, Fujitsu, Sony, Samsung, Gateway; worldwide market share of Windows PCs are consistently above 90% (PC Sales, 2006) (Polsson, 2009c)	HP, Dell, Fujitsu, etc with limited pre-install Linux-based PCs; worldwide market share of Linux PCs 3.1% in 2001 and 5.6% in 2005 (Iansiti & Richards, 2006)
ISVs	Approximately 12,000 software applications (Gilbert, 1995) (Jackson, 1999); approximately 4,500 ISVs support Mac OS platform in 2003 (Iansiti & Richards, 2006)	Approximately 70,000 software applications (Gilbert, 1995) (Jackson, 1999); about 9,500 ISVs and development service companies (Iansiti & Levien, 2004)	More than 6,000 open source applications (FSF, 2009); approximately 1.8% (1999) to 5.9% (2002) of ISVs support Linux platform (Iansiti & Richards, 2006)
IHVs	Graphic Cards: ATI/AMD, Intel, NVidia; Processors: Intel Printer: HP, Canon, Xerox	Graphic Cards: ATI/AMD, Intel, NVidia; Printer: HP, Canon, Xerox, etc;	Graphic Cards: SiS, S3, ATI/AMD, Intel, NVidia; Printer: HP, Canon, Xerox, etc;
Sales channels	408 retail stores as of May 2013 in fourteen countries (Apple Retail Store, 2013)	More than 23,000 resellers (Iansiti & Levien, 2004)	Limited through OEMs, Linux distributors such as Red Hat, Novell, Canonical, etc, & online stores.

Table 1 – Networks of Apple, Microsoft & Linux during Post Dominance Phase (1991-2009)

Data from Table 1 indicate that the networks around PC OS have become more diverse, dense, and more competitive. Microsoft stayed on top with the largest and most diverse network of actors. Apple still maintained its proprietary position with its own hardware and sales channels. Linux despite its large and diverse network is still lacking in pushing its platform into mainstream market. The recent structure of PC OS network is shown in Figure .

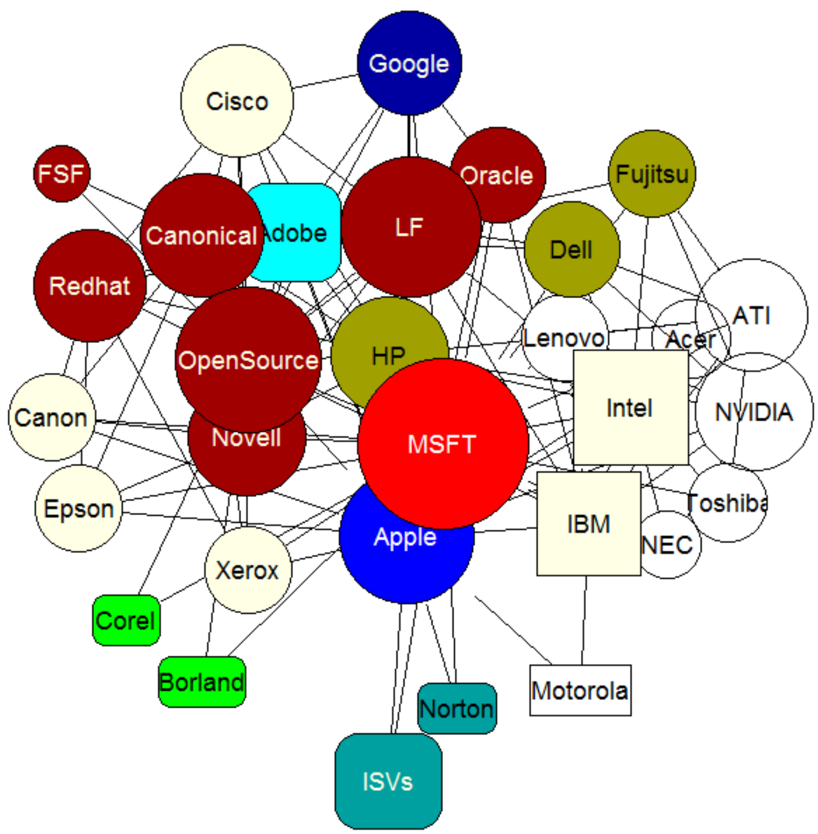

Figure 4 – Apple, Microsoft, and Linux Network during Post Dominance Phase (1991-2009)

Based on the above analysis, the overall characteristics of networks of Apple, Microsoft, and Linux can be summarized in Table 2.

Characteristics of Business Network	Innovation I		Adaptation II		Stabilization III
	R&D build up I-a	Technical Feasibility I-b	Market creation II-a	Decisive Battle II-b	Post Dominance III
Size					
Microsoft	Not existed	Very small	Small, slow growing	Medium, fast growing	Very large, stable
Apple	Small	Small, growing	Small, fast growing	Medium, slow growing	Large, stable
Linux	Not existed	Not existed	Not existed	Not existed	Medium, growing
Diversity					
Microsoft	Not existed	Very low, internal R&D actors	Low, growing; actors: OEMs and limited ISVs	Medium, fast growing; actors: OEMs, ISVs	High, growing then stable;
Apple	Low, limited R&D actors	Low, but growing; ISVs for Mac software	Low, fast growing; ISVs for Mac Software	Medium, growing; ISVs for Mac Software	Medium, stable; ISVs; sales partners
Linux	Not existed	Not existed	Not existed	Not existed	Medium, growing; lack of market actors
Density					
Microsoft	Not existed	Low	Growing	Medium	High

Apple	Low	Growing	Growing	Medium	Medium
Linux	Not existed	Not existed	Not existed	Not existed	Medium
Type of structure					
Microsoft	Not existed	Hub and spoke;	Hub and spoke;	Hub and spoke;	Core periphery;
Apple	Hub and spoke;	Hub and spoke;	Hub and spoke;	Hub and spoke;	Core periphery;
Linux	Not existed	Not existed	Not existed	Not existed	amorphous
Structural holes					
Microsoft	Not existed	Many	Many	Many	Few
Apple	Many	Many	Many	Many	Few
Linux	Not existed	Not existed	Not existed	Not existed	Many

Table 2 – Summary of Apple, Microsoft and Linux Networks during Technology Lifecycle

Next, we will explain each characteristic of the competing networks with respect to competing platforms of operating systems for PC.

3.1.4. Network Size

Network size is determined by the amount of actors in the network. Due to the lack of supporting data on the exact number of actors over time, we estimated the number of actors in the network based on the relation between the main actor and its partners such as suppliers, OEMs, ISVs, distributors and retailers for each platform.

Apple:

Apple's network started small in size, and mainly consisted of Apple, Motorola, and Xerox PARC during the R&D build-up phase (Hormby, 2005) (Linzmayer, 2004) (Reimer, 2005a) (Tuck, 2001). In technical feasibility phase, Apple's network was increased as Microsoft started to develop application for Macintosh (Polsson, 2009b) (Reimer, 2005b). Adobe also formed Apple's network as it licensed the postscript technology as part of Apple Laser Writer in January 1984 (Adobe: 25 Years of Magic., 2007). After introducing Macintosh, Apple's network slowly grew to medium network as several ISVs such as Aldus, Adobe, and Ashton-Tate made their application available for Macintosh (Adobe: 25 Years of Magic., 2007) (Bellis, 2009) (Linzmayer, 2004) (Reimer, 2005a) (Tuck, 2001). The Apple's network consistently grew from small to medium and finally to large network in the next phases particularly on the number of ISVs with over 12,000 applications (Gilbert & Katz, 2001) (Jackson, 1999).

Microsoft:

The size of Microsoft's network around Windows operating system was initially small during the technical feasibility phase. During the market creation phase from 1984 to 1987, Windows 1.0 only attracted limited OEMs with no supporting applications from ISVs. From the historical data, we found only a limited amount of ISVs (such as Aldus) made software for Windows platform even after the release of Windows 2.0 in 1987. After the release of Windows 3.0 in 1990, Microsoft's network grew significantly to medium size mainly consisting of all major OEMs and ISVs such as Ami, Borland, Corel, WordPerfect, etc. In the post dominance phase, with the support from OEMs, ISVs, hardware vendors, and resellers, the Microsoft network grew to a very large network as described in Table 1.

Linux:

As Linux introduced in the late 1991, Linux's network was relatively medium in size, and mainly consisted of "free software programmers" (Stallman, 2007). In the following years as internet diffused rapidly, Linux's network grew increasingly. Since 2005 more than 3,700 individual developers from over 270 different companies have been involved in Linux kernel development (Kroah-Hartman, Corbet, & McPherson, 2008). Up to present Linux is supported by more than 6,000 open source projects (FSF, 2009).

3.1.5. History of computers' viruses, worms, and malwares

Theoretically, computer viruses attracted scientists' attention since the middle of the 20th century. Only three years after the public announcement of the world's first electronic general-purpose computer "ENIAC" in 1946 (Kennedy Jr, 1946), John von Neumann wrote an article about self-reproducing automata in 1949 (von Neumann, 1966). Although Neumann's work explained the logical steps and mathematical structure of self-replicating machine even before the discovery of the structure of the DNA molecule, it contributed to logical understanding of any kind of self-reproducing characteristics. Frederick Cohen used the same theory to conceive and formulize a computer virus for the first time in November 1983 (Cohen, 1987).

However, the first experimental self-replicating program, the Creeper virus, was written in 1971 by Bob Thomas at BBN Technologies (Chen & Robert, 2004) (Chen & Xie, 2007). This experimental virus was used to contaminate DPD-10 computers which manufactured by DEC and running on the TENEX operating system (Computer Security Basics, 1991).

The first large-scale computer virus outbreak in history was recognized in 1981, when the fifteen years old student Richard Skrenta created a program called “Elk Cloner” as a practical joke. This virus spread by infecting the Apple DOS 3.3 operating system using a technique now known as a "boot sector" virus. This virus copied itself into the boot sector of a floppy disk and then spread into all future disks. However the first virus, which infected Microsoft's operating system was called "Brain" and written by two Pakistani brothers in 1986. It was also a boot sector virus. Both viruses did not cause any serious damage (Leyden, 2012).

According to Dr. Nic Peeling and Dr. Julian Satchell’s report in 2001 for Qinetiq, a British multinational defence technology company, there were about 60,000 viruses known for Windows OS, and hundreds of them caused widespread damages. Only 40 viruses were detected for Mac OS at the same time, and only two or three of them were harmful (Peeling & Satchell, 2001).

In 2008 BBC reported that computer viruses hit one million, and that the vast majority of them are aimed at PCs running Windows OS (Computer viruses, 2008). There are millions of viruses, but only small portion of them are circulating wildly, and many of them are not harmful. Still most of them are for Windows OS and make Windows consumers vulnerable (Number of Viruses, 2013) (Threats Detected, 2013). Therefore, end-users are psychologically affected by the fact that Windows is not safe, whereas actually Mac OS was safe and almost virus-free operating system for a long time (Welch, 2007).

In 2006, two new worms known as “Leap” and “Ingtana” were targeting the Apple OS X operating system for the first time after a decade of soft. It raised conscious thinking about future safety measures of Mac OSin anti-virus companies (Roberts, 2006).

In 2012, the first ever Mac OS X malware was detected by the Russian anti-virus company "Doctor Web". This notorious Trojan known widely among Windows OS and originally designed to attack Windows users, showed that Mac OS is no longer immune against Trojans (Huffpost Tech, 2012).

Mikko Hypponen, chief researcher officer for F-secure, stated that there is common belief that Mac OS is safe and there is no virus and spy for this operating system. This statement is not valid anymore. On the other hand Windows 7 is as safe as the new version of Mac OS, and there are no more advantages for Mac in the security area. However, the reason why Macs have not been attacked is they are few in number, compared to PCs. Consequently, online criminals prefer to attack OS with a much larger number of people, because there is more money involved there. By increasing of Apple laptop sale, they will also become a more attractive target for the online criminal (Hypponen, 2011). Alan Woodward also stated that it will be a pattern change in Mac security. Increases in the Mac OS consumers' quantity, will thus make it more attractive for online criminals and it will be more vulnerable (Woodward, 2012).

In the past two years, Windows lost 1.67 percent of his global OS market. In the same period Mac OSgain 1.27 percent of the global market share. It shows that more Windows consumers shift to the Apple OS. However, this statistics included all sort of desktop computers from PC to laptop (PC OS Share Trend, 2013). Even before this period, statistics show that the Apple Global PC market share by unit sold raised 7 percent during 11 years up to 2011, and it reached 10.7 percent of global market share by unit sold (Computer Sales Statistics, 2012). All other statistics show the same trend in OS global market share, indicating that Apple computer sales growth is faster than PC sale (The Guardian, 2011).

3.2. Survey (Windows vs. Apple OS)

According to our literature review, and case study, NINE could occur in the laptop operating system's market. There were no data supporting this particular research, therefore we decided to launch a survey at the TU Delft campus (See Appendix 1).

3.2.1. Method

Participants:

In total 86 participants from Delft University of Technology (including 79 students and 9 staff members) from 22 different nationalities took part in a pencil-and-paper survey (68 men and 17 women; M = 24.13 years old, SD = 5.543).

Procedure:

This questionnaire was designed to assess two different scenarios. First, we asked participants to assume wanting to buy a new laptop and go to a media shop to choose between two technologies available – one Microsoft-based, the other Apple-based. We requested them to indicate their preference for either of these two technologies, or even a possible alternative third technology (such as Linux). Then we asked them about their current technology, to find out possible switches in their anticipated preferences. After that, we asked about different aspects of and their degree of satisfaction with their current technology: learning process, costs and maintenance, the status of one's social network, brand, performance of hardware and software in general as well as the level of offered security measures, and their final opinion regarding for their current technology. In the second scenario, we asked almost the same questions, but in the case of a switch to the other technology. All items were measured on a 9-point scale (ranging from “Not at all” to “Extremely”), as well as items assessing age, gender, education, and nationality.

3.2.2. Measures

System security: The factor labelled “system security” was measured with two items, satisfaction with security performance, and availability and performance of security software. Specifically, the first item inquired: “To what degree are you satisfied with security performance (referring to spyware and viruses)? The second read: “To what degree are you satisfied with availability and performance of security software (anti-spy and anti-virus)?” Analysis showed that these two items had a high inter-item consistency reliability (Cronbach’s alpha = 0.81).

Network Pressure: The factor labelled “Network Pressure” was measured with two items, influence of friends or existing users’ advice, and shift in social network from one technology to another. Specifically, the first item inquired: “To what degree did friends’ or existing users’ advice influence your choice?” The second read: “To what degree did you change your technology because of a shift in your social network (that is, your friends also changed / or are in the process of changing their technology)?” Analysis showed that these two items had a high inter-item consistency reliability (Cronbach’s alpha = 0.69).

Current Hardware Choice: A single item measured the actual choice of a participant for either a Windows-based or Apple-based laptop.

Intention to Switch: The factor labelled “Intention to Switch” was derived from two items specifically asking: “How like is it that you will choose an Apple-based (or Microsoft-based) laptop instead?” By look at answers, we recognized, however, that only Windows users intended to switch, whereas none of the Apple users indicated to switch to the other technology. That's why further analyses were based on the single item "How like is it that you will choose an Apple-based laptop instead?"

3.2.3. Results

We applied the PROCESS procedure created and recommended by Dr. Andrew F. Hayes, Ohio State University, to test our hypotheses. We created a model in which system security was the interdependent variable, switching behaviour the dependent variable, and network pressure served as a mediator. For the entire model, 1000 bias corrected bootstrap samples were run with a 95% confidence interval (Hayes, 2013). This overall model was significant, $\Delta R2 = .12$, $F(1, 84) = 10.93$, $p < .002$. Analysis revealed main effects of system security on network pressure, $\beta = -.48$, $z = -2.69$, $p < .01$, and of network pressure on switching behaviour, $\beta = .27$, $z = 1.83$, $p < .07$ (See fig.5). Analysis showed an indirect path of system security via intention to switch, CI = [-0.3081, -0.0037].

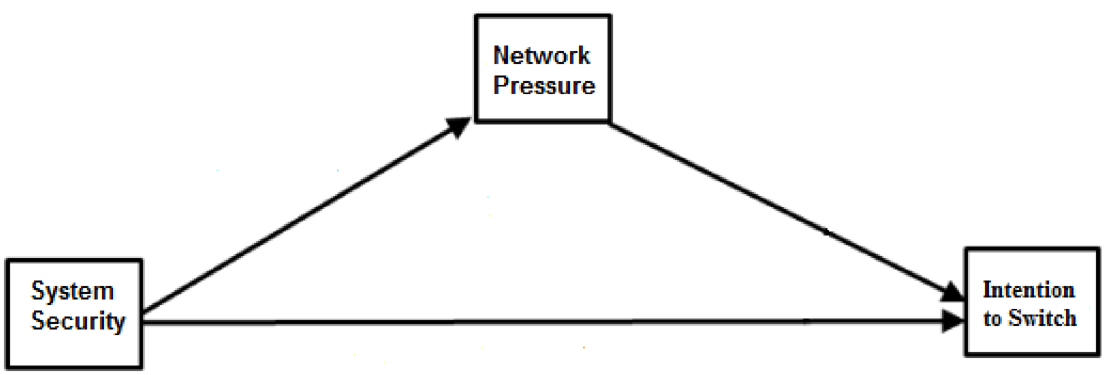

Figure 5 – Primer model of switching behaviour

Then we added current hardware choice as a moderator to that model (See fig.6). Also for this new model, 1000 bias corrected bootstrap samples were run with a 95% confidence interval (Hayes, 2013). Analysis showed that the full moderated mediation model was marginally significant only for people whose current hardware choice was Windows, $\beta = -0.30$, $z(86) = -1.59$, $p = 0.11$, 95% CI = [-0.3841, -0.0127], but not Apple, $\beta = 0.0001$, $z(86) = 0.0001$, ns.

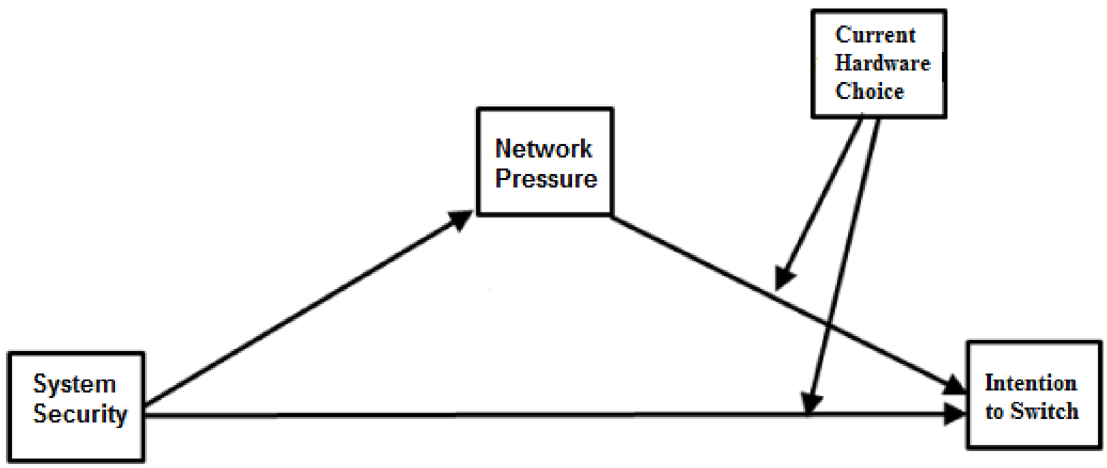

Figure 6 – Advanced model of switching behaviour

3.2.4. Discussion

Results show that there is a direct and indirect effect of degree of satisfaction of consumers from security measures and their switching behaviour toward other technology. This is consistent with real world data. Also, our results show that the combination of shifts in social network and advice of current consumers of a rival technology play a mediating role on the decision-making process. But this is only half the story. We don't know if the same problems happen in the other standard, and how this will influence people's behaviour. That's why we designed a simulation to test our conceptual model in different scenarios.

4. Agent-based Simulation

This chapter elaborates on the details of designing and conducting the second study, an agent-based simulation. Section 4.1 presents a short general introduction to agent-based simulation. Next section 4.2 provides an overview of the methodological strategy implemented, and a description of the process of design and programming for our simulation. Section 4.3 describes the implementation of the simulation and its results. To conclude, section 4.4 discusses the findings of this approach.

4.1. Introduction

It is difficult to understand and analyze a complex system due to the complex relations within these systems. However, we know that each of these systems contains a number of individuals or agents whom connect to each other with a few interaction rules. The best way to understand such a system is to develop an agent-based simulation, to create these individuals and simulate their relations.

In agent-based modelling (ABM), a system is modelled as a collection of autonomous decision-making entities called agents (Bonabeau, 2002). Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system they represent—for example, producing, consuming, or selling.

4.2. Methodology

We use an agent-based simulation to explore different possible scenarios of the market to recognize and understand the conditions under which a negative indirect network effect could appear. "In agent-based modelling (ABM), a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviours appropriate for the system they represent—for example, producing, consuming, or selling" (Bonabeau, 2002, p. 7280). There are several advantages to applying ABM; it is flexible, it can capture emergent phenomena, and it provides a natural description of a system. According to Bonabeau, the most important benefit of ABM is capturing emergent phenomena, it drives the other benefits. Whole system performance is more than the sum of individual performances, which is called system performance. It means that, although performance of an individual is not that significant, what would be developed in the system from interaction between these individual actors, could appear as a significant phenomenon. Traffic jams, for instance, essentially result from misbehaviour of one or two drivers, but could end up with a gigantic social occurrence (Bonabeau, 2002).

4.2.1. Procedure

According to Epstein and Axtell, we need three components of environment, agent equipment, and rules for communications between agents (Epstein, 1996). Therefore, we start with a model that includes these three components, then we write a logical algorithm for our model, write a simulation program in NetLogo, followed by testing it in different scenarios, and finally we discuss its results.

4.2.2. The Model

After the theoretical review in chapter 2 and case-survey of chapter 3, we now introduce the empirical model (See Fig.7) for behaviour of individuals in the network environment. This model comes as close as possible to the real world situation of individuals and their use of computer hardware, and we try to design a simulation as close as possible to this model. For that reason we start with the determination of three components of agent-based simulation.

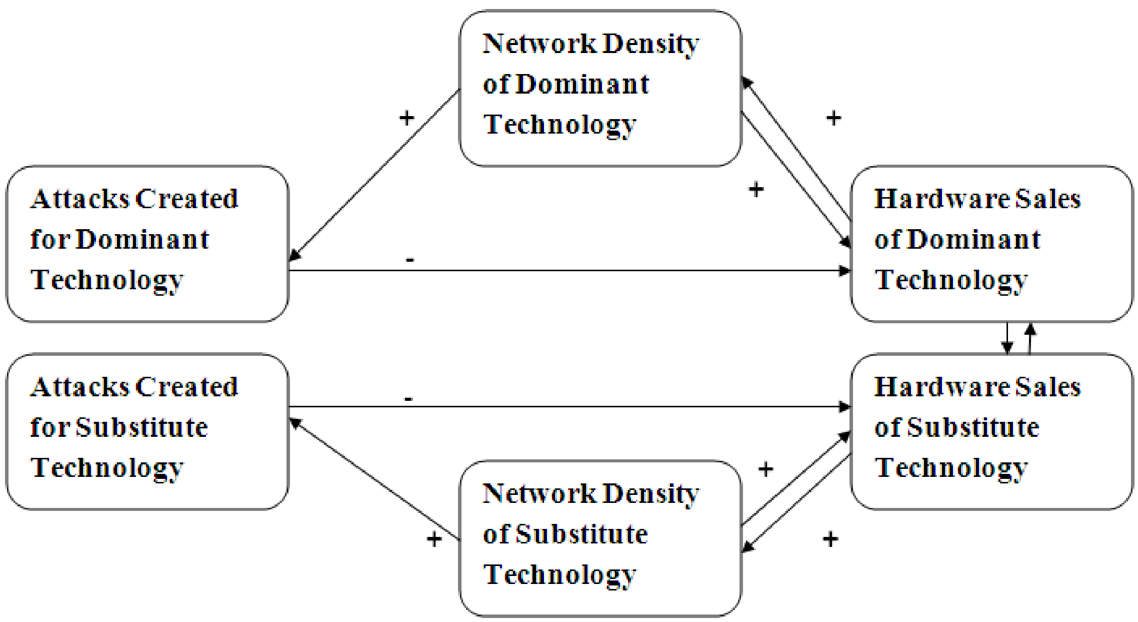

Figure 7 - Graphical Overview of Empirical Model

4.2.2.1. Agent-based Model

As mentioned before, Epstein and Axtell (Epstein, 1996) have a specific terminology to explain a general agent-based model. They argue that an agent-based model should contain three components: the environment, agent equipment, and rules for communications between agents. With the help of our empirical model, we will try to explain each of these terms in more detail:

A) Environment:

Our environment has no edges, there is possibility for adding an unlimited number of agents. Agents have no limits for connecting to each other. They could connect to as many neighbours as possible, but there is minimal number of five connections determined for them up front to allow for a decent spread of connections through the network (Granovetter, 1978).

To capture the real world situation, we start with the number of agents that reflects the market share in the year 2010 in which was 90% for Windows OS to about 10% for Mac OS (Brodkin, 2011), and with the real market share of each technology in this year. Right from the start, agents have a given connection to other agents, but some of them are randomly infected, and capable of spreading virus attacks through the network (See 3.1.6.)

B) Agent Equipment and Specification:

- Each agent has a fixed life expectancy with an average of three years (it can be given for different simulation). This life expectancy reflects the product-life cycle for laptops in the real world, which is set to three years by looking at maximum manufacture warranty (Baxter, 2006).

To simulate it as close to real world we further suppose that not everybody uses their device for the same period of time. Therefore we give a random life expectancy number with average of expecting life.

- Each agent has an age limited to life expectation. For start they have a random age, but agents who will be newly created in each period (new buyers of a laptop) are brand new, so they will have age of zero.

- Each agent has a counter for the number of attacks he received during his life expectation. This means that we have a clear picture of the history of attacks for each agent in the simulation throughout his product-life cycle.

C) Rules for Communications Between Agents:

- Each period, a given number of agents will be added to the system, and distribute in the environment randomly. These agents will have a random life expectancy with an average of three years, but because they are brand new they will have age "Zero".

- New agents will have a given connection with their close neighbours.

- After agents look at their neighbours' decisions, they will choose their technology according to "Bandwagon Effect".

- In each period, some infected agents will protect themselves and become uninfected.

- In each period, new attacks will be created and spread randomly in the system. As a result, agents with the same technology could be infected.

- In each period, agents which aged to their life expectancy have to choose a new technology. That is, they cannot continue working with their existing laptop. They can stay in the same technology if the agent history of infection shows his satisfaction, or can change to the other technology (negative indirect network effect), or even change due to “Bandwagon Effect” and “Snob Effect”.

- There is no limit in time, and the agent-based model continues to simulate infinitely.

4.2.2.2. Empirical Model

In chapter 2 we reviewed all sorts of network externalities and effects. Here we try to test it in our model (See Fig.7). Increase in hardware sale of dominant technology leads to network externalities, therefore network density of dominant design will increase (Katz & Shapiro , 1986) (Farrell & Saloner, 1985). This notion is identified in the model as positive arrow from “Hardware Sale of Dominant Technology” to “Network Density of Dominant Technology”. With increase of the network density, new consumers in which surrounded with specific technology may be interested to utilize same technology, it has some sort of feedback effect called “Bandwagon Effect”. Some of new users may want to be exclusive, for that reason few of them may chose subsidiary technology which called “Snob Effect” (Leibenstein, 1950), but snob effect is negligible, therefore in our simulation we assume that randomness of new entrant technology chose will cover this effect. The notion of Bandwagon effect is identified in the model as positive arrow from “Network Density of Dominant Technology” back to “Hardware Sale of Dominant Technology”.

When network become denser, it attract software developer to produce complementary goods for that technology. More software produced for that technology, attract more users to adopt some hardware “Positive Indirect Network Effect” (Basu, Mazumdar, & Raj, 2003) (Church, Gandal, & Krause, 2008) (Church & Gandal, 2012) (Clements, 2004) (Clements & Ohashi, 2004) (Farrell & Klemperer, 2006) (Gupta, Jain, & Sawhney, 1999).

In the other hand, when market is open and there is no control on entrance of software; dens network always catch attention of misuse and attack to the network. As a result it increase possibility of attacks from unwanted agents. Our survey in chapter 3 also conclude that increasing in such unwanted attacks may decrease satisfaction of end-users. Magnitude and abundance of attacks, compatibility of substitute technology, low switching cost, and lack of locked-in may play a big rule in behaviour of consumer in their next decision-making moment. Therefore increase of attacks has negative influence on hardware sale of dominant technology and some costumers may shift to substitute hardware.

Same story with same pattern, may happen in substitute technology. In duopoly market, consumers has no choice other than this two. So if technologies survive long enough, there is possibility of same shift between two technologies for and backward.

In this chapter we try to check these hypothesis and see future behaviour of market by implementing of agent-based simulation.

4.2.3. Algorithm and Program

To test the validity of our model, we simulate our model by using NetLogo program. NetLogo is an open source agent-based modelling program in which it is possible to create an environment of interacted agents, and which has tools to visualize these interactions between agents. We use NetLogo in order to simulate multi-agent models for natural or social phenomena by following rules of engagement to validate or model and see if there is any prediction for the future (What is NetLogo, 2013) (Kornhauser, Rand, & Wilensky, 2007).

4.2.3.1 Mathematical equation

First of all, we have to write the mathematical algorithm and equation for this model. Stremersch et al. (2007) referred to the notion of Granger causality (Granger, 1969) for indirect network effects. They conclude that a process x_t causes process y_t if the future value of y_t can be better predicted using both the previous values of x_t and y_t. In mathematical formulation, x_t does not cause y_t if

$$\textbf{(1)} \qquad f(y_t | y_{t-1}, x_{t-1}) = f(y_t | y_{t-1}).$$

Importantly, Stremersch et al. (2007) just focus on positive indirect network effects, but because of similar nature of positive and negative indirect network effects, we could use the same mathematical equation in our model given that the principle of Granger causality rests on the extent to which a process x_t leads to process y_t.

Because of the nonlinear nature of their variables, Stremersch et al. (2007) used log-transformation to make their model nonlinear in most cases. Therefore they predict that as time passes, the process will grow, thus leading to adoption/diffusion. For the same reason we need to capture a nonlinear trend, which we can simply obtain by using the same method, and use a linear trend in the log-transformed data. Prior network effects models included the same trend as well (e.g., Gendal 1994; Shy 2001; Basu, Mazumdar, and Raj 2003).

On basis of these considerations we came up with the following model:

$$\textbf{(2)} \quad \log(S_t^H) = \alpha + \beta \times \log\left(S_{t-1}^H\right) + \gamma \times \log\left(D_{t-1}^N\right) + \delta \times \log\left(A_{t-1}^S\right) + \varepsilon \times \log\left(S_{t-1}^S\right) + \epsilon \times t + \zeta_t$$

$$\textbf{(3)} \quad \log(A_t^S) = \eta + \theta \times \log\left(A_{t-1}^S\right) + \vartheta \times \log\left(D_{t-1}^N\right) + \tau \times t + \kappa_t,$$

In which S_t^H is hardware sale at time t, A_t^S is software attack at time t, D_t^N is network density at time t, S_t^S is the snob effect at time t, α and η are intercepts, and ϵ and τ capture the time trend. This model specification is a flexible time-series model, which has to be estimated separately for each market, using unrelated regression.

In these equations there are some coefficients that represent different effects:

β: *Represents prior hardware sales, in which agents are satisfied with their hardware, and will buy the same product.*

γ: *Represents the bandwagon effect, in which agents decide to adopt hardware, because many consumers are also doing so.*

ε: *Represents the snob effect, in which agents decide to adopt hardware, because not so many users are doing so.*

δ: *Represents the negative indirect network effect, in which agents decide to adopt substitute technology, because many of dominant technology's consumers are not satisfied with their hardware performance.*

4.2.3.2 Program

There are two ways to find out the value of coefficients in equation (2). We could gather empirical data (as was done for chapter 3), or simulate an agent-based model to find out what these thresholds are. It is hard to find sufficient empirical data; almost no technology tracks the record of it, because the ecosystem of these technologies is complex and there are many actors involved. The second way is agent-based simulation. By applying environment and rules of engagement from agent-based model in 4.2.1.1, we tried to design a simulation with NetLogo that is as close to reality as possible. First, we wrote a programming algorithm (See Appendix 2), then we wrote a program (See Appendix 3).

4.3. Simulation

In all simulations we started with 100 agents and continued each simulation up to about 500 periods. Each period represented about one month, so 500 periods would be equivalent to 40 years. We kept network connection constant so that each new user connected with his five nearest neighbours. Increasing or decreasing the number of connections could only increase change speed of attack spreading and consequently speed of switching behaviour. Blue, red, gray, and orange dots represent agents with dominant technology, dominant technology with infection, substitute technology, and substitute technology with infection.

4.3.1. Validation of Simulation

To validate this simulation, we first tested it with a "No Attack" Situation. Suppose there is no attack and both technologies have equal values; in that case, there should be no preferences to choose any of them over the other. It would, however be possible that people change their technology according to bandwagon effect, because of other people that were also choosing the technology. Therefore we would have to see slightly changes, while both technologies remained in their market share. (See Fig. 8).

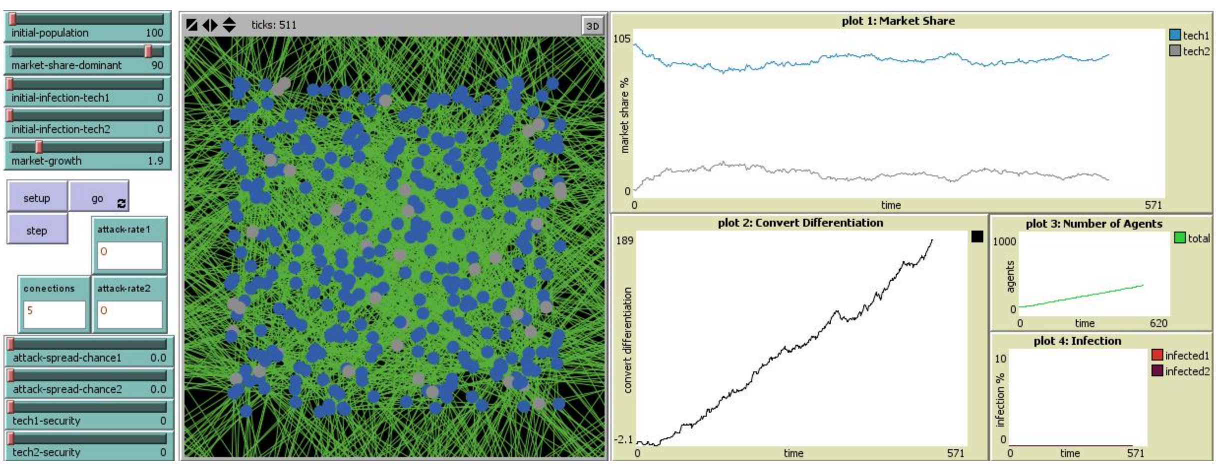

Figure 8 – Test of simulation with "No Attack" situation

As is shown in Figure 8, in 511 periods, the number of agents increased from 100 to 350. No infection happened, market share remained steady, and there was little technology switch. This indicated that agents did not engage in switching behaviour due to a “Bandwagon Effect”.

Then we tested our simulation with an “Attack” Simulation, but in the similar environment with same ratio. In this scenario we chose a 50-50 market share (See Fig. 9).

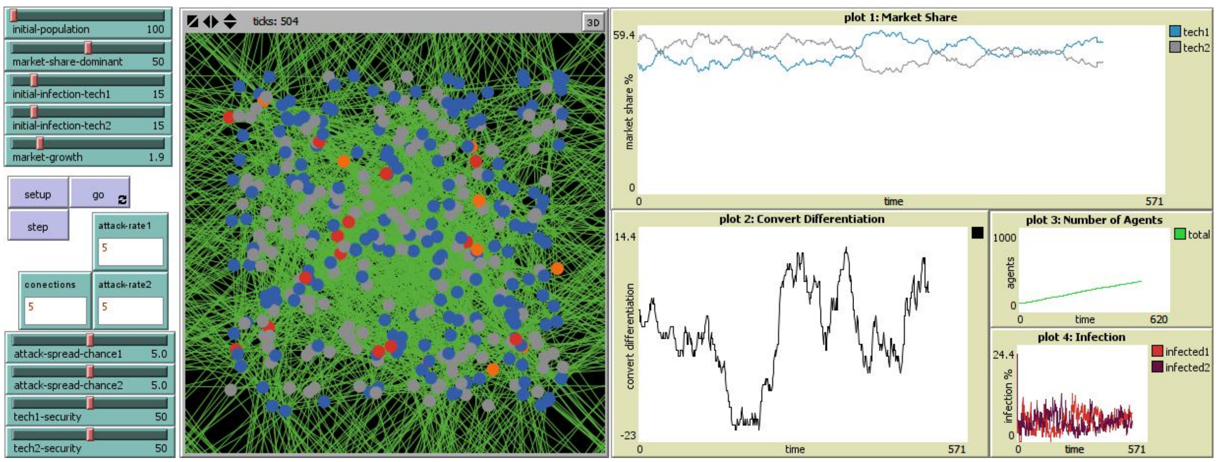

Figure 9 - Test of simulation with “Attack” situation

As is shown in Figure 8, in 504 periods, the number of agent increased from 100 to about 350. Both technologies faced similar rates of attack. In this case, however, also some technology switching was observed due to a “Bandwagon Effect”, we see in plot 2. Although many switching happened in this period because of dissatisfaction of consumers, market share remain steady, because there were no preferences programmed between two technologies.

With these two tests, we could conclude that our simulation is valid and presents the real world situation as well as model preferences.

4.3.2. Simulating The Real World, First Step

For testing the real market situation, we chose the same technologies as in chapter 3: Windows vs. Apple OS. We assumed that Mac OS characteristically represented high security measures due to the company-controlled policy at Apple. Then we tried to pair this high-security Mac OS with three different scenarios of low, medium, and high security for Windows. This was intended to find out if a negative indirect effect was going to influence any of these scenarios, and what the thresholds for this effect could be.

4.3.2.1. High vs. Low Security

To simulate the real world situation, we chose the 90-10 ratio of market share that was the real ratio in the laptop industry in the year 2010 (Brodkin, 2011). Although APWG report shows that 48% of 22 million scanned computers are infected with malware, we assumed lower rate that only 30% of initial population of Windows and no Apple users would be infected at time zero (Danchev, 2010). To simulate the low rate of security, we assumed attack spread chance was 10%, and Windows security was about 25% in average. Also, we assumed that 10 new attacks would take place in each tick (See Fig. 10).

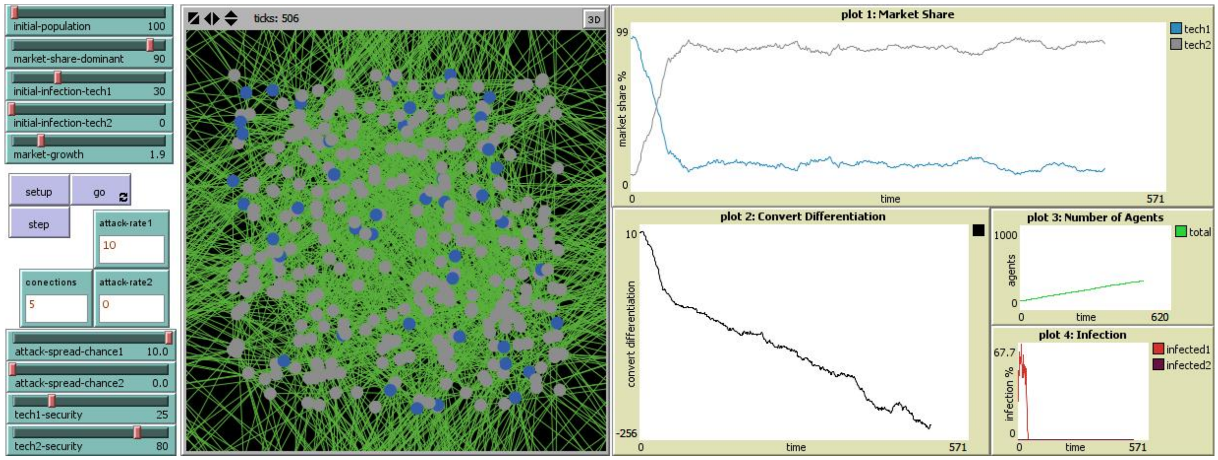

Figure 10 – Simulation of High vs. Low Security

As we see in Figure 10, the high number of attacks decreased the initial satisfaction with Windows, the dominant design, dramatically, and in less than 25 periods, Windows users had faced so many crashes that they preferred to switch to the substitute technology Apple OS, because of the safety of the substitute. Also, they remained with that substitute technology. New market share after about 500 ticks showed a reversal of the initial situation: about 90-10 in favour of former substitute technology.

4.3.2.2 High vs. Medium Security

Then we simulated high vs. medium rate of security, where we assumed that the attack spread chance would be 5%, and Windows security about 50% in average. Also, 5 new attacks would happen in each tick. As before, the substitute technology remained super protected in this scenario (See Fig. 11).

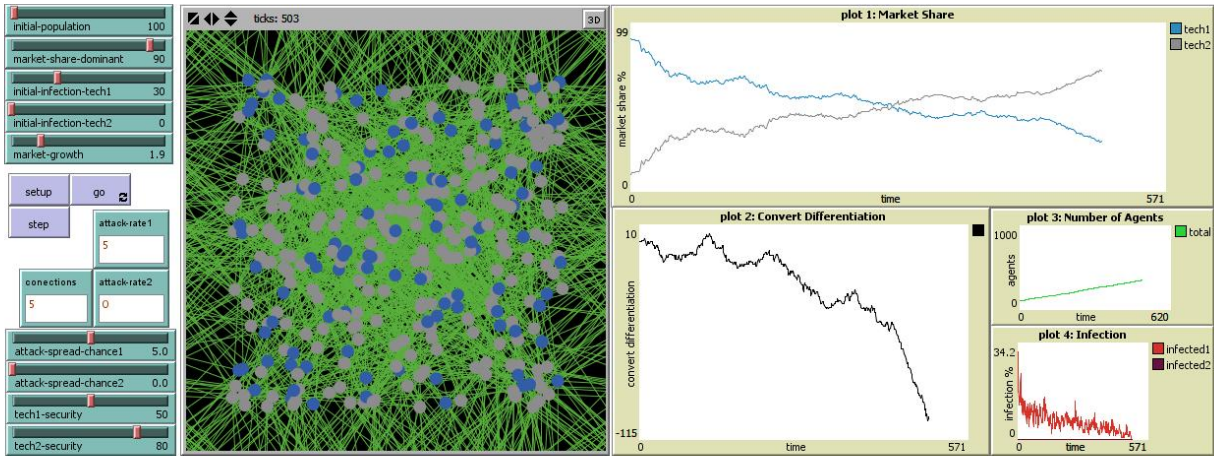

Figure 11 – Simulation of High vs. Medium Security

The results of this scenario show that with medium rate of attacks, the number of dissatisfied consumers of dominant design Windows increase, but that the rate of change is slower. It takes about 280 ticks for Windows to lose domination, and the market share ratio after 500 ticks is 69-31 in favour of substitute technology Apple OS.

4.3.2.3. High vs. High Security

Finally, we simulated the high vs. high rate of security, where we assumed that the attack spread chance would be 2.5%, and Windows security about 80% in average. This time, 3 new attacks would happen in each tick. Again, the substitute technology remained super protected in this scenario (See Fig. 12).

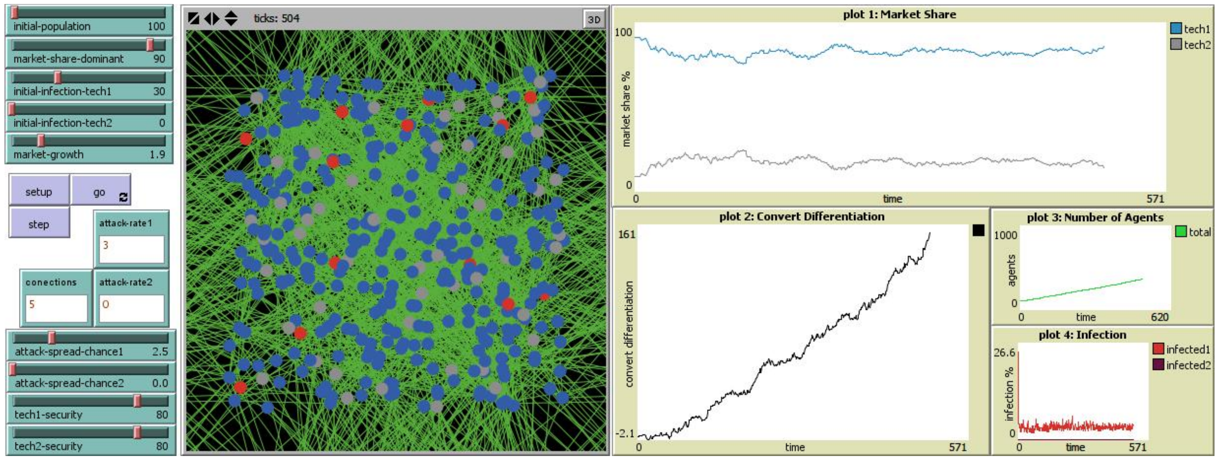

Figure 12 – Simulation of High vs. High Security

As we can see, this scenario shows that with the high security measures from the two competing parties, the laptop market remained stable and without many losses.

4.3.3. Simulating The Future

For this final part, we assumed that Apple OS, the substitute design, would not remain safe for ever – and eventually become a target of attacks as well. Therefore we tested our simulation model also with medium and low level of security for the secondary technology (See Fig. 13 & 14).

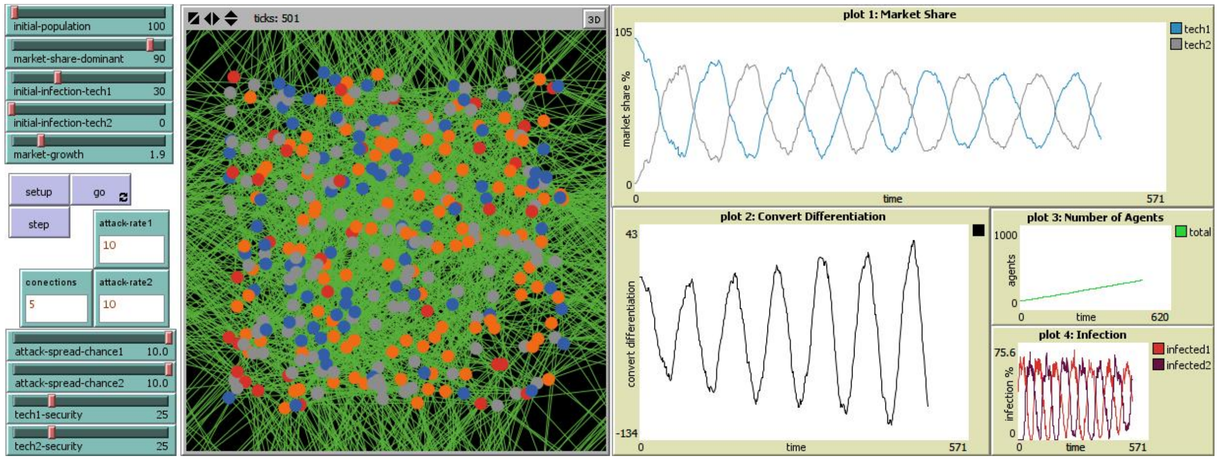

Figure 13 – Simulation of Future With Low Security of Secondary Technology

With low security of both dominant (Windows) and substitute (Apple OS) technologies we could see dramatic market fluctuations. Almost every 36 ticks equivalent of three years in which it is less than five years life expected of laptops (Jönbrink, 2007). That meant that with high levels of attack on both technology and low security performance, none of the customers were satisfied with their laptop, and therefore display a NINE.

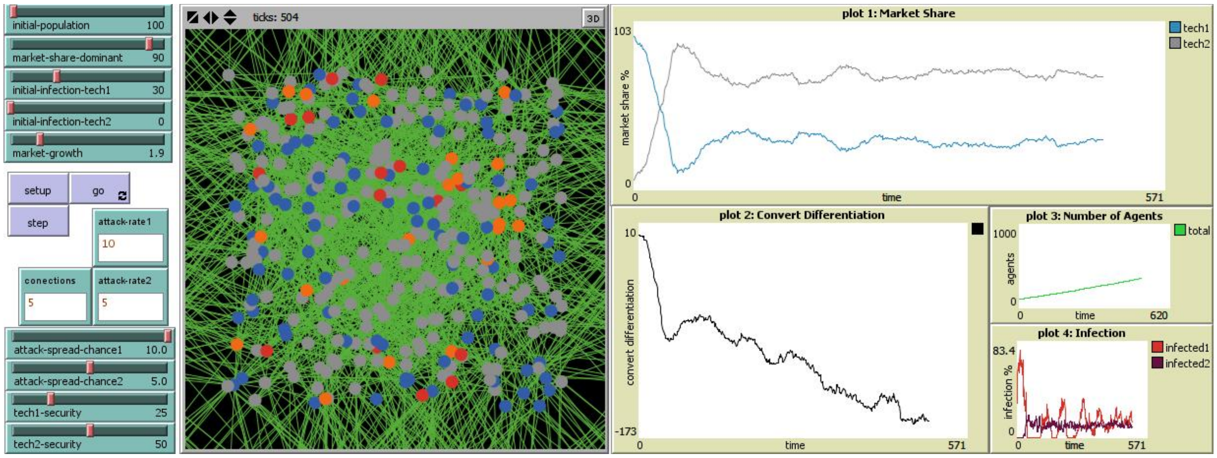

Figure 14 - Simulation of Future With Medium Security of Secondary Technology

Finally, with medium security performance of Apple OS, the substitute technology, against a low degree of security for Windows, the dominant technology, we would have the same situation as Figure 10 and 11, but Figure 14 showed that the market changed after 35 ticks. This meant that people were not satisfied with the dominant technology's level of security, although the secondary technology did not have a huge advantage. People would prefer it, another sign for NINE. Another difference is that the market share would change fast to a 70-30 ratio in favour of more secure technology and remain steady in that level.

4.4. Discussion

This agent-based simulation has three main findings. First, we find that although the NINE is less pervasive than any other kind of network externalities, it exists under specific conditions. In chaotic situations like huge and long endurance attacks, the NINE could play a key role in consumers' decision-making process, causing them to switch to other technology, also new entrant may look at the people around them, and dissatisfaction of existing consumers have influence on their decisions. The same story could happen when a technology would face large numbers of weak attacks.

Second, even small advantage in security measures could make a big difference for costumers preference.

Third, there are attack spread chance can play as significant as security software. Having vertical integration and close market could help to prevent many of attack and sick -behaviour software.

5. Conclusion

The present chapter offers a discussion of the findings for study 1 (the survey) and 2 (the agent-based simulation) in the light of their theoretical and practical relevance. Section 5.1 provides a short summary of the research questions and related hypotheses. Next, section 5.2 elaborates on the theoretical and scientific relevance of the present research, while section 5.3 focuses on the practical relevance. Sections 5.4 and 5.5 discuss the limitations of the present research and the possibilities for future studies, respectively. To finalize, 5.6 confers an ending remark.

5.1. Summary

In this thesis, we investigated the main research question: ***"Does expansion of network lead to Negative Indirect Network Effects?"*** To answer this main question, we focused on the following problems (sub-questions):

1: Is there any correlation between expansion of a network and the increase of problems in such a network?

2: Will the increase of these problems lead to Negative Indirect Network Effects?

3: What are the possible negative effects of network growth?

4: Under what conditions will consumers become less satisfied with a network and prefer to change the network from the standard one to a subsidiary?

5: Is there a positive correlation between expansion of a network and these conditions?

6: Is there any "Herd Behaviour" in "Negative Indirect Network Effects"?

After a literature review of prior research on network externalities and network effects, we came up with a conceptual model that allowed us to raise the following hypotheses:

Hypothesis 1: ***An increase of undesired complementary goods in the network will raise dissatisfaction of the dominant design's consumers such that hardware sale of the dominant design will decrease.***

Hypothesis 2: ***Highly dense networks attract more undesired complementary goods that dissatisfy consumers, leading fewer consumers to adapt the dominant design in the future.***

Hypothesis 3: ***If consumers feel less safe and satisfied with the dominant design because of the existence of undesired complementary goods, they may choose substitute design instead, leading to an increase in hardware sale of the substitute technology will increase.***

Hypothesis 4: ***An increase in hardware sales for a substitute design, because of switching of end-users due to unwanted actors in the dominant design's network will lead to a denser network that will attract more undesired actors and make this substitute technology vulnerable too.***

Hypothesis 5: ***The relation described under Hypothesis 4 is recursive in nature, leading some consumers to switch back to their old technology.***

To answer these general research questions and to test our hypothesis, we first conducted a case study on the history of three main operating systems (Windows, Apple OS, and Linux), the life cycle of these technologies, their network characteristics such as network size, density, and diversity, and reviewed the history of computers' viruses, worms, and malwares (See Section 3.1). Second, we conducted a small classroom survey to further explore this issue (See Section 3.2). Third and very last, we programmed a computer simulation to look into possible applications and implications (See Chapter 4).

We found that although the "Negative Indirect Network Effect" is less pervasive than the other kind of known network externalities reported in the literature, with expansion of open networks, NINE has a greater chance of occurrence. Second, agent-based simulation showed that laptop users in the absence of switching costs and learning difficulties, may switch to another technology, and also may drag new users to this secondary technology. We discuss these results in greater detail in the following paragraph.

5.2. Scientific Relevance

NINE has only recently captured research attraction (see Stremersch et al. 2007). Our study is in perfect agreement with prior literature on network externalities and network economics. But this study went further than that: So far, no empirical research combined analysis of network dynamics with inclusion of human behaviour (see also Rook, 2006).

Thus far, research on network externalities and network economics maintained the following: The adaptation process and learning by using, and increasing returns by adaptation and create a positive feedback (Arthur, 1989) (Arthur, 1988) (Arthur, 1994) (Rosenberg, 1982), which lead to more network density and direct network externalities (Katz & Shapiro , 1986) (Katz & Shapiro, 1985) (Farrell & Saloner, 1985). If a design becomes dominant in the market, it could lead to more adaptation which called “Herd Behaviour”, as a result of which switching cost and locked-in become an issue for competitors in the adaption process (Farrell & Klemperer, 2006). This competition is called a “Standard Battle” (Frank & Cook, 1988) (Knittel & Stango, 2004) (David, May 1985), which makes the dominant technology more attractive for complementary goods’ producers (Clements, 2004), therefore utility of the dominant technology increases due to greater availability of compatible complementary products which are called “Positive Indirect Network Effects” (Basu, Mazumdar, & Raj, 2003) (Cottrell & Ken, 1998). Many case studies also support this claim (Gupta, Jain, & Sawhney, 1999) (Clements & Ohashi, 2004), and even some researchers investigated the benefits of price reduction and an increase in the quality of products in competitive market for consumers (Church, Gandal, & Krause, 2008).

Stremersch et al established that there could be possible negative indirect network effects due to low availability, high price, and poor quality of complementary goods (Stremersch, Tellis, Franses, & Binken, 2007). They presented an empirical model and an algorithm for “Positive Indirect Network Effect”, but they did not investigate it any further. So, what we did was to implement all these prior researches in our model, and see under what conditions NINE comes into play, and leading to switching behaviour. Empirical testing of the model extends existing knowledge about network externalities. In addition, there was a gap between economics and psychology in the context of network externalities (Rook, 2006). Therefore, we looked into the interface of human and technology in the model, and tried to fill this gap with the aim of making more understanding between these two disciplines, and build a bridge between them.

The first problem we looked into was "***Is there any correlation between expansion of a network and the increase of problems in such a network?***" In our case study, we found that with expansion of technology network it become more attracted to online criminals to attack operating systems (Hypponen, 2011). Although Windows has a well-known history of attacks because of its market dominance (Computer viruses, 2008) (Number of Viruses, 2013) (Threats Detected, 2013), expansion of the Mac OS network is now also leading to unwanted complementary goods attention (Roberts, 2006) (Huffpost Tech, 2012). Computer security experts acknowledge this correlation as well show that expansion of a network leads to more virus attacks (Woodward, 2012) (Hypponen, 2011). In other words, there is a positive correlation between expansion of a network and an increase of problems within that network.

The second problem we looked into was "***Will the increase of these problems lead to Negative Indirect Network Effects?***" Industry reports show that dominant designs face huge security problems, an observation that found support in our case study. We also witness switching behaviour from the dominant product (Windows OS) to the substitute one (Mac OS), a secondary technology that just enjoys a few percent of the global market (PC OS Share Trend, 2013). Increasing of the problems for dominant design will lead to NINE.

The third problem we looked into was "***What are the possible negative effects of network growth?***" We explored this issue in our survey. Results show that there is a direct and indirect effect of degree of satisfaction of consumers to security measures and their switching behaviour towards other technology. This is consistent with real world data. Also, our results show that the combination of shifts in social network and advice of current consumers of a rival technology hint towards a mediating role on the decision-making process (See Section 3.2).

The fourth and fifth problems we looked into were "***Under what conditions, will consumers become less satisfied with a network and prefer to change the network from the standard one to a subsidiary?***" and ***"Is there a positive correlation between expansion of network and these conditions?"*** Our survey showed that in the OS technology, laptop consumers are aware of the existence of undesired complementary goods. They reported that they were not satisfied with the security measures of Windows, and some of them would like to switch to Mac OS, which is a compatible and secondary technology. Some say that such switching behaviour is caused by the fancy design of Apple laptops, but our survey showed that it is not true. People especially suffered from existing Windows security performance, like viruses and hacks, therefore they switch to the compatible Apple technology. This is in line with our main hypothesis that an increase of an undesired complementary good in the dominant technology's network will raise dissatisfaction among consumers of the dominant design.

Our case study showed that highly dense networks attract more undesired complementary goods that dissatisfy current and upcoming consumers, causing less consumers to stick with the dominant design in the future. Our survey confirmed this hypothesis. We also tested this scenario in our agent-based model (See Chapter 4), and saw that when there is low or even medium security, the dominant design will lose its costumers, but when the dominant design has a high degree of security, it will hold its market share and remain dominant. This fits with the existing literature on "Winner-Take-All" mechanisms (Schilling M. A., 2002). Further, our simulation confirmed our third hypothesis, and showed that when the dominant design has low or even medium security, and the competing technology has high security, consumers will switch to the secondary technology with high measures of security, and new uses will follow their example. Prior research did not study whether consumers with plenty of security problems would switch to a compatible technology or not, so this finding is new in the literature on network externalities.

Our fourth hypothesis simply asked whether the same problems would appear when the secondary technology would become popular as a dominant design. In our case study we found out that Mac OS gradually also is becoming attractive for viruses (Peeling & Satchell, 2001), worms and malwares (Roberts, 2006) (Huffpost Tech, 2012). In our simulation (See Section 4.3.3) we showed indeed that, if the secondary technology become dominant, and its security measures did not satisfy new condition, it will face the same problem as the former standard technology. Therefore, it confirms our model as well as forth hypothesis.

Our fifth hypothesis was, if consumers would switch back to their first technology or even go for third alternative when the secondary market also would expand, and get same problems. None of the existing markets was old enough to show such phenomena for real. For that reason, we modelled this scenario in our agent-based simulation, and we witnessed that with expansion of the secondary technology and the appearance of online criminals in that system, some of the consumers would switch back to the primary technology (See Section 4.3.3). Thus, this hypothesis may be valid under specific circumstances.

However, our empirical model was designed based on Stremersch et al. (2007), which was in fact an econometric model. It should be emphasized that our simulation model has a significant difference with their econometric model. As the simulation shows, ours comes close to a thermodynamic model. This approach has several consequences: as we mentioned in previous paragraph, our model represents dynamic systems that are more close to reality and are capable of predicting and explaining possible changes that could occur within a socio-technical environment. Rather than the linear econometric model, we have complete framework of the network.

The final problems we looked into were "***Is there any "Herd Behaviour" in "Negative Indirect Network Effects"?***" Psychologists believe that people are not totally rational in their decision-making process. According to Richard H. Thaler and Cass R. Sunstein in the book "Nudge", we have two systems of decision-making, an automatic system and a reflective system that is self-conscious and deliberate. Several psychological biases come from the automatic system (Thaler & Sunstein, 2008), one of them being "Herd Behaviour". Accept it or not, we are following the herd most of the time. If many of my friends buy an Apple laptop, I will try to buy it to be heard in the group, regardless of its high price and low performances. As the book Nudge said: "humans are easily nudged by other humans." – Thaler & Sunstein (2008), p.55. We also witnessed signs of herd behaviour in this study (See Section 4.3.2.1, 4.3.2.2, and 4.3.3). According to our case study, survey, and simulation there was a positive correlation between expansion of a network and all technical and psychological conditions which lead to switching from the dominant technology to the substitute one.

5.3. Practical Relevance

Our findings increase the understanding for industries and enterprises about the network dynamics of their technology and products, and consequences of adaption growth. Our results make clear that network expansion not only delivers positive results, but negative ones as well. Common knowledge was that if technology wins the battle of standardization and becomes market-dominant, the game will be over till the next technological breakthrough (Schilling & Esmundo, 2009). Maybe this statement was true for closed controlled technologies, but we showed that it is not valid for open-sourced technologies like operation systems. ICT based companies have to be alert about unwanted actors, and have to implement dynamic strategies to concern NINE. Therefore, industries have to increase their security measures to avoid these unwanted actors.

Further, our model was able to explain S-curve mechanisms, and further explain why after stabilization phase (See Section 3.1.2) and reaching maximum market share, it flattens out. This gives us the ability of forecasting the future of the technology by looking at boundary conditions of its network, its environment, and satisfaction degree of its actors. In addition, this model could forecast when NINE could occur in other network-based technologies such as game consoles, smartphones, and even social media.

Also, our research shows the importance of involving end-users in feedback processes, by creating coordination, in order to have participation of consumers to avoid NINE. Giving proper service, testing satisfaction of consumers (by using and testing beta versions), or creating feedback loops to fulfil end-users demands and eliminating problems.

Second, our model proves that the environment surrounding any technology is really important for ICT-based technologies. These technologies involve open-source networks of actors. It is not anymore like a car company that could control and standardize all or most parts of their production line. These kind of closed technologies even have a quality check in place before their customers receive their products. For example, Microsoft is not able to control all the software designed to work with its Windows. This kind of quality control is simply impossible. Nevertheless, this research shows that open-source technologies have to be conscious about unwanted complementary goods, and maintain their safety measures with the intention of preventing NINE to happen.

Interestingly, we show to the substitute technology holders that they are not eternal losers of this battle. Although they can survive in a niche market with high value and specified products, they can also keep one eye on the dominant technology's consumers. They could take advantage from such market opportunity to provide a more secure and efficient technology. It looks like “Second Mover Advantage”, but it is not the same. First or second mover advantages are in the process of domination of the market, but here we talk about the market situation after standardization and survival of a handful of the competing technologies. As we said, the secondary technology could take advantage from dissatisfaction of the consumers of a dominant technology. But as soon as its market expands, unwanted actors may also be attracted to this new dominant technology. Furthermore, secondary technology’s stakeholders have to take care of switching costs and possible locked-in of end-users to the old dominant technology. Thus, the secondary technology should be compatible, which means it should have almost the same complementary goods, software, and accessories. Yet, it should not suffer from same problems that increased in the rival design. Fulfilment of these conditions will make it easier for consumers to switch between these two technologies. Although it is important to mention that these after-sale services may generate more profit than the main product, companies could also design an innovative collaboration via IT interaction to improve satisfaction of consumers (Taisch, Alamdari, & Zanetti, 2012). In addition, as we said before, manufacturers could employ their customers’ feedback about complementary goods to forecast possible problems and/or provide extra services to avoid NINE.

Our findings could be implemented in any kind of (applied) social system with network characteristics, not just within a management of technology setting, but especially also on the more general level of political and social systems. Human behaviour is similar in any kind of participations. Historically there is much evidence of social systems that satisfied their stakeholders when they were small and had a small network, but attracted many unwanted actors when they grew bigger – leading to NINE-related dynamics that led people to switch to a rival social network. Political parties could be good example for this phenomenon. Since NINE is a core mechanism of the network we could even explain the fall of great empires like Rome and Persia out of these specific network dynamics. The vast territory, the lack of proper coordination, and absence of good control from the hub (here to be understood as the centre of power like the capital city) would lead to dissatisfaction of citizens, the emergence of NINE, leading to either separation from the network and the claiming of a new country, or migration to other territories, or uprising and revolution against the central government.

5.4. Limitations

First, our survey and agent-based model focused only on the laptop's operating system market, while tablets' and smartphones' operating systems are currently emerging. We did not include these upcoming operation systems, nor address possible threshold effects and total switches from laptop technology to these newer technologies. We did not investigate if such technologies are good substitutes for the laptop or not, although the increasing popularity of these newer alternatives may suggest so.

Similarly, this research did not investigate other technologies and markets such as game consoles or smartphones, which have similar characteristics. In the past, game consoles were controlled packages, but with the increase of online gaming, they become more vulnerable to viruses and hacks. For example, in May 2011 Sony game consoles' users faced a huge hack (Sony fined data hack, 2013). Nobody knows what is going to happen if these problems become more common. For smartphones, applications will also play a role as complementary goods. Some operating systems like Android have an open source store to buy an application. Many people use their smartphone for banking and to exchange valuable data, therefore hacks and viruses are become more and more common for this technology (Williams, 2011). Although both of these technologies are totally aligned with our simulation model, we cannot automatically generalize our model to them without any investigation. Consumers may show other NINE behaviour against a different technology.

Third, this research examined a complex and untouched phenomenon, although it was hard to find market evidence and suitable data for it. We thus distributed our questionnaire among students and staff of TU Delft. Its result could not be generalized to the whole market as well as to the whole population of consumers. Also, this sample may not have been representative, contacting people with different needs and priorities than other members of the society. Fourth, an agent-based simulation model was needed to confirm the existence of the negative indirect network effect. This simulation model was kept simple and reasonable. It did not evolve with dynamic strategies that holders of the dominant design may approach when facing NINE problems. Coordination and participations between enterprise and consumers were ignored.

5.5. Future Studies

First, future studies could randomly distribute a next questionnaire in a bigger field, not only in one university in one country. Second, a more complete agent-based model could be developed, including other technologies like game consoles, smartphones and so forth, to see if this effect is general in the market and to find other conditions that may influence consumers and new entrants' decision-making process. Third, finding thresholds of the market, when such effect change the dynamics and reverse market shares of two rivalry technologies could be interesting subject to investigate. Fourth, future studies could focus on developing a more complete simulation program in order to face more complex market situations and to avoid the limitations of current agent-based simulation, for instance by involving more dynamic strategies from manufacturers and more human behaviours into the account. Fifth, it is interesting to further research human factors like participation as well as coordination between manufacturers and end-users. That could lead us to better understanding of their decision-making process with the purpose of preventing such a negative effect for the dominant design or to take advantage of it for the substitute design with the intention of creating growth in the market and increase sustainable advantages. Sixth, the insights of the present research could be applied to societal domains outside of management of technology. It would be especially interesting to investigate NINE-phenomena in political and social environments, to see whether this model also has the ability to predict social changes, or even forecast election results.

5.6. Conclusion

This research has a number of important implication.

Any dominant technology in a network-based market in which dynamic patterns exist and an entrant cannot control supplementary goods could face NINE. Consumers may grow dissatisfied by unwanted actors and reduce their interest in the dominant technology, and in absence of switching cost and lock-in prefer to change their hardware towards the substitute technology instead. Moreover, such unsatisfied end-users may engage in bandwagon behaviour and discourage people around them to stop using the dominant design, both of these two actions leading to the “Negative Indirect Network Effect” (NINE) even though the bandwagon effect is in devour of the dominant design. The scale of this effect and resulting change in market share depends on the rate and seriousness of attacks on the dominant technology. A standard design could prevent this negative effect from occurring via an increase of security measures. On other hand, the substitute design could also use NINE to its advantage and change the dynamic of the markets in its favour, but should be aware that the same situation could occur vice versa when it has become the bigger market player itself.

All and all, in the present thesis work, we came up with a sort of thermodynamic model for software markets that is capable of predicting and explaining switching behaviour of the end-users in a clear mechanism. For a long time, NINE was the missing link in the “Network

Externalities" literature; the present research not only completed this framework, but also allowed us to come up with a comprehensive model that integrates all network behaviours.

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Appendix

A1. Survey

General Introduction

Information and Communication Technology (ICT) is an ubiquitous part of our professional and daily life, so it is fair to say that we use various technologies and related services on a daily basis. Increasingly, such technologies are network-based, which means that a specific platform comes with unique and compatible services. The present research wishes to investigate the decision making process that comes with the potential purchase of such network-based computer technologies.

In the following, you will be confronted with two different purchasing scenarios. Please answer the attached questions.

Scenario 1

Imagine the following situation. You want to buy yourself a new laptop or computer and you go to media shop. At the shop, you can choose between two technologies – one Microsoft-based; the other Apple-based. All other things being equal, please answer the following questions:

How likely is it that you will choose a Microsoft-based laptop?

Not at all Extremely

1 2 3 4 5 6 7 8 9

How likely is it that you will choose an Apple-based laptop?

Not at all   Extremely

1   2   3   4   5   6   7   8   9

How likely is it that you will choose an alternative laptop (other than Windows and Apple OS)?

Not at all   Extremely

1   2   3   4   5   6   7   8   9

If so, please write down which alternative technology you are referring to:
____

Could you further (briefly) explain why you prefer this third alternative
____
____
____
____

Of course, various parameters are important for your decision to buy a new laptop or computer. One option is that you decide to stay with your old technology. Which technology are you using right now?

____

Could you please indicate below *__for each statement__* to what extent you consider it relevant for decision to stay with this computer technology? NOTE: Please provide an answer to all of these statements below!

Is it hard to learn and work with other technology?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Is it costly to change to other technology in terms of compatibility of software so you have to buy new applications?

Not at all Extremely

1 2 3 4 5 6 7 8 9

How sufficient is your current technology?

Not at all Extremely

1 2 3 4 5 6 7 8 9

How likely is it that you choose to be in this technology, because your friends use it (or you have to use it in your work)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Is your current laptop less costly than other one?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Are the software and application costs lower than other technology (that is, for practical software, including the use of cracked software and OS, anti-spy and anti-virus software)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Does your current technology sufficiently offer support and after sale services?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Do you choose your current laptop because of brand reputation?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with hardware performance (that is, matters such as battery performance, weight of laptop)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with software performance (including gaming, office, and other professional software)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with operating system performance (including speed of OS, possibility of crashes and bugs)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with security performance (referring to spyware and viruses)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with availability and performance of security software (anti-spy and anti-virus)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Satisfaction (with this OS)

Not at all Extremely

1 2 3 4 5 6 7 8 9

Scenario 2

Of course, you could also decide to change from one technology to another (for example: from Windows OS to Apple OS, or vice versa). Please indicate below for each item to what extent you consider it important to make that change from one technology to another:

Is it easy to learn and work with new technology (interfaces are easy and so forth)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Is it costly to change to new technology in terms of compatibility of software (so you have to buy new applications)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Does it have a better design (that is, is it more fashionable, beautiful, innovative)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with hardware performance (matters such as battery performance, weight of laptop)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with software performance (including gaming, office, and other professional software)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with operating system performance (speed of OS, possibility of crash and bugs)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Is this new laptop less costly than the technology you used before?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Are the software and application costs lower than of your current technology (for practical software, including the use of cracked software and OS, anti-spy and anti-virus software)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with security performance (problems with spy and viruses)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with availability and performance of security software (referring to anti-spy and anti-virus software)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with support and after sale services?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with compatibility (You can use my old files / photos / music in it)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with availability and differentiation of applications?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree are you satisfied with brand reputation?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree did friends' / or existing users' advice influence your choice?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree did advertisement influence your choice?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree did the prestige of this technology influence your choice?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree did you change your technology because of a shift in your social network (that is, your friends also changed / or are in the process of changing their technology)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

What is your estimation: How many of your friends adopt / or are in the process of adopting this technology? ___________________

To what degree did you change because of a shift in your professional network (that is, your company also changed their technology, so I'm obliged to adopt myself)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

To what degree did you change because this technology is more user-friendly (better interface could put it in the better application)?

Not at all Extremely

1 2 3 4 5 6 7 8 9

Anything else?

____
____
____

Your personal information:

Age ____

Gender ☐ Male ☐ Female

Education ____

Nationality ____

Student number ______________________________________

Thanks for your participation in this MSc thesis survey

A2. Programming Algorithm

To test a validity of our model, we designed a simulation by using NetLogo program. We have to write the logical algorithm for this program to meet and fulfil the conditions of our model.

To fulfil the conditions, we have to step by step design our algorithm in these phases:

A- Design starting point environment and initial conditions
B- Design ongoing process and rules of engagement for our environment
C- Decision-making process

Phase A:

This phase consist of three steps: 1- Create existing users for start. 2- Create network of those users. 3- Create initial attacks, which already exist in our environment .

A.1. Create Existing Users for Start

Users (or in program language agents) are our basic units. They represent end-users and carry different parameters such as:

- Technology: The technology they are currently utilize and bought a hardware for it.
- Lifetime: Is lifetime expected for the hardware they use.
- Age: Age of their hardware.
- Infected?: This parameter allow us to see Whether they are currently infected or not.
- Attack-history: Show us the number of attacks that any users may had during the lifetime of their current technology.

- Attack-check-timer: To show us when was the last time that hardware was checked for any kind of attacks. (((((this part was in my first version, but we did not apply for last version))))

The algorithm for this part is:

a) Asked number of agents, and create them
b) They have to be randomly distributed in 2D
c) Give random and normal life time expected n(36,3)]27,45[
d) Give a random Age between 0 and their life time expected. The reason is: not all existing users bought their hardware in the same time.
e) Ask ratio between two technologies (90%-10% for windows-based vs. Apple)
f) Change the colour of agents randomly according to ratio of technology to agents, therefore users with dominant technology will have blue colour, and users with complementary technology will have gray colour

A.2. Create Network of Users

To simulate network behaviour, we have to connect agents with their neighbours. To see how density of a network could effect , there should be possibility to change the number of connection from each of the agents.

The algorithm for this part is:

g) Ask value of number of connection we want to have from each agents, to represent the network of users
h) Create these connections randomly with nearest agents

A.3. Create Existing Infected Users for Start

With creating early attacks, we try to bear a resemblance of the real word. Any networked-based system of users would attract some attacks. We have to distribute these attacks randomly at the start and then in each stage (ticks). Then we could find out if they have significant negative effect on network or not.

The algorithm for this part is:

i) Ask number of initial infection of each technologies
j) Infect randomly agents from each technologies

Phase B:

In this phase we have to design the algorithm of ongoing process of simulation. In reality, attacks could spread in the network and in other hand hardware should have some system of protection and security. There are new attacks related to density of each technology's network to fulfil our hypothesis predictions. We suppose hardware are vulnerable to new attacks, so security step should be before creating new attacks. Therefore steps of this phase are: 1- Spread-attack 2- apply security 3- Create new agents 4- Create new attacks.

B.1. Spread Attack

In this step, infected agents have to spread their infection to their neighbours according to given ratio.

The algorithm for this part is:

k) Chose each of infected agents
l) Find connected neighbours with same technology
m) Spread infection randomly with given ratio of attack-spread-chance
n) Save that these agents has been attacked once

B.2. Apply Security

In this step, infected agents will checked randomly according to technical security measures of each technologies.

The algorithm for this part is:

o) Ask agents with infection randomly to be cured if they meet security measure ratio of that technology

B.3. Create New Agents

To create new agents, we follow same logic with two differences. First of all, their age is “zero” because they are new users in which adapt either of technologies. To implement bandwagon effect, we create connections first, then agents look to their surroundings and chose their technology.

The algorithm for this part is:

p) Asked number of new agents, and create them
q) Distribute them randomly in 2D
r) Give random and normal life time expected n(36,3)]27,45[
s) Their age should be “zero”
t) Create connection with nearest agents
u) Look to his connections, chose a technology of majority of neighbours

B.4. Create New Attacks

To create new attacks is not same as initial infected. Here we want to give more weight to density of network. To show again how Negative Indirect Network Effect create new attacks. For that reason we measure density of network, also apply attack rate for each of technologies, then we calculate approximate number of new attacks and then distribute it randomly in environment.

The algorithm for this part is:

v) Calculate number of connection in which both end of them are from same technology
w) Calculate density of those technologies' networks
x) Ask attack rate for each of these technologies
y) Estimate number of new attack for both technologies
z) Infect agents randomly according to given number for new attacks
aa) Count number of attacks that each agents has in their lifetime

Phase C:

In this phase we have to apply proper decision-making process for agents. However there are many factors which have influence on users to stay and buy new hardware from the existing technology, or change their technology to the competing technology. To avoid any complexity, we chose only to major factors: Satisfaction and Bandwagon Effect. We already determine satisfaction with counting number of attacks that happened during hardware lifetime. If they are more than threshold number, it means user is not satisfied with that hardware.

The algorithm for this part is:

bb) Find agents which their lifetime is over
cc) If attack history is more than threshold, then change the technology
dd) Look around to connected users; if the number of connected neighbours with other technology is twice as number of agent technology, then change technology
ee) Set age of them to zero
ff) Set attack history to zero

A3. NetLogo Program

```
globals
[
  number-of-users        ;;; Total number of users created
  market-share           ;;; Market share of each technology
  newlink                ;;; Creating new links
  mac-converts           ;;; Number of users convert to Mac
  win-converts           ;;; Number of users convert to Windows
  number-of-new-users    ;;; Number of new users
]

turtles-own
[
  technology
  infected?              ;;; If true, the turtle is infectious
  lifetime               ;;; Create random lifetime
  age                    ;;; Agents get old to take life time and then decide again if want same
technology or other one
  attack-check-timer     ;;; Number of ticks since this turtle's last attack-check
  attack-history         ;;; Count number of attacks
  ]

to setup

  clear-all
  setup-users            ;;; Create requested number of users
  set number-of-users initial-population
  setup-network;;; Set the network to be shown

  reset-ticks
end

to go

   spread-attack         ;;; Spreading attack in the network
   apply-security        ;;; Apply Security command to cure problems
   setup-new-users       ;;; Command to create new users
   create-attack         ;;; Command to create new attacks
```

```
  switch-technology       ;;; Command to check the possibility of switching between technologies
  ;ask  n-of  newlink links [die]
  ask turtles [set age age + 1]

 tick
end

to step

  spread-attack
  apply-security
  setup-new-users
  create-attack
  switch-technology
  ask  n-of  newlink links [die]
  ask turtles [set age age + 1]

  tick
 end

to setup-users

 set-default-shape turtles "circle"
 crt initial-population    ;;; Make number of agents
 [ ;;;print initial-population
  setxy (random-xcor * 0.80) (random-ycor * 0.80)        ;;; for visual reasons, we don't put any
users *too* close to the edges
  ifelse random 100 < market-share-dominant
  [
   make-tech1
   if random 100 < initial-infection-tech1
   [set infected? true
    set color red
    ]
   ]
  [
   make-tech2
   if random 100 < initial-infection-tech2
   [set infected? true
    set color orange]
   ]
```

```
   set lifetime random-normal 36 3        ;;; Create random lifetime between 27 and 45 tick
(month)
   set age random lifetime                ;;; Create age random number less than lifetime

  ]
end

to setup-new-users

 set-default-shape turtles "circle"
 set number-of-new-users random (number-of-users * (market-growth / 100))
 crt number-of-new-users
   [
    setxy (random-xcor * 0.80) (random-ycor * 0.80)
    setup-new-network
    let x count link-neighbors
    let y count link-neighbors with [ technology = 1 ]
    let z count link-neighbors with [ technology = 1 and attack-history >= 3 ]
    let w count link-neighbors with [ technology = 2 and attack-history >= 3 ]
    ;;print (y / x) * 100
    ifelse w >= z
    [
      ifelse random 100 >= ( (y / x) * 100 )
    [make-tech1]
    [make-tech2]
    ]
    [make-tech2]


   set lifetime random-normal 36 3        ;;; Create random lifetime between 27 and 45 tick
(month)
   set age 0

  ]
end

to setup-new-network

   set newlink 0
   ask turtles with [ count(link-neighbors) = 0 ]
     [
    create-links-with n-of conections other turtles
```

```
    set  newlink newlink + conections
   ;print newlink
     ]
  ask links [ set color green ]                    ;;; Set color of network-links

 end

 to switch-technology

  ;;;print "000000000000000000000000000000 "
  ask turtles with [technology = 1 and age >= lifetime]
  [ set age 0
  ;;;print "TIME TO CHANGE !!!!!!!!!!!!!!!?????????????????????????????? "
    if attack-history >= random 10 or (count link-neighbors with [ technology = 2 ] >=  2 * count
link-neighbors with [ technology = 1 ])
    [make-tech2
      set  mac-converts  mac-converts + 1
      print "I CHANGED TECHNOLOGY TO MAC"
      print  mac-converts

    ;;;print attack-history

    ]
    set attack-history 0
   ]
  ask turtles with [technology = 2 and age >= lifetime]
  [ set age 0

    ;;;print "TIME TO CHANGE !!!!!!!!!!!!!!!?????????????????????????????? "
    if attack-history >= random 10 or (count link-neighbors with [ technology = 1 ] >= 2 * count
link-neighbors with [ technology = 2 ])
    [make-tech1
       set  win-converts  win-converts + 1
   print "I CHANGED TECHNOLOGY TO WIN "
   print  win-converts
    ;;;print attack-history

    ]
    set attack-history 0
   ]
 end
 to make-tech1
```

```
  set color blue
  set technology 1
  set infected? false
end

to make-tech2

  set color gray
  set technology 2
  set infected? false
end

to setup-network

ask turtles
  [
   create-links-with n-of conections other turtles
   ]
  ask links [ set color green ]                    ;;; Set color of network-links
end

to spread-attack

 ask turtles with [technology = 1 and infected? = true]
   [ ask link-neighbors with [ technology = 1 ]
      [ if random 100 < attack-spread-chance1
         [
          set infected? true
          set color red
          set attack-history attack-history + 1
          ; print attack-history
          ]
         ]
   ]
  ask turtles with [technology = 2 and infected? = true]
   [ ask link-neighbors with [technology = 2]
      [ if random 100 < attack-spread-chance2
         [
          set infected? true
          set color orange
          set attack-history attack-history + 1
          ]
```

```
        ]
      ]
end

 to apply-security

   ask turtles with [infected? = true and technology = 1]
   [
     if random 100 < tech1-security
     [set infected? false
       set color blue

     ]
    ; set attack-history attack-history + 1
   ]
   ask turtles with [infected? = true and technology = 2]
   [
     if random 100 < tech2-security
     [set infected? false
       set color gray

     ]
    ; set attack-history attack-history + 1
 ]
end

 to create-attack

  let network1 0
  let network2 0

  ask links [
   let a 0
     ask end1 [ if technology = 1 [set a a + 1] ]
     ask end2 [ if technology = 1 [set a a + 1] ]
     if a = 2
       [ set network1 network1 + 1]
   ]


  ask links [
   let a 0
```

```
      ask end1 [ if technology = 2 [set a a + 1] ]
      ask end2 [ if technology = 2 [set a a + 1] ]
      if a = 2
        [ set network2 network2 + 1]
    ]
   ;print network1
   ;print network2

   ;;print ( network1 / (network1 + network2) )

  ; let newinfect1  ( attack-rate1 / 100 ) * count turtles with [technology = 1]
  ; let newinfect2  ( attack-rate2 / 100 ) * count turtles with [technology = 2]
  let newinfect1 ( network1 / (network1 + network2) ) * (attack-rate1 / 100 ) * count turtles with
[technology = 1]
  let newinfect2 ( network2 / (network1 + network2) ) * (attack-rate2 / 100 ) * count turtles with
[technology = 2]
   print newinfect1
   print newinfect2
   ask n-of newinfect1 turtles with [technology = 1]
   [
   set infected? true
     set color red
    ]
    ask n-of newinfect2 turtles with [technology = 2]
   [
     set infected? true
     set color orange]

end
```