THE INVESTMENT BEHAVIOR OF TELECOMMUNICATION OPERATORS:

AN AGENT-BASED MODELING APPROACH

SERCAN USTA

BOĞAZİÇİ UNIVERSITY

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AN AGENT-BASED MODELING APPROACH

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Sercan Usta

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DECLARATION OF ORIGINALITY

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ABSTRACT

The Investment Behavior of Telecommunication Operators:

An Agent-Based Modeling Approach

In this study, Turkish mobile operator's investment strategies to new and old mobile communication technologies is modelled with the agent based modelling and simulation approach. There are three operators in Turkish telecommunication market: Turkcell, Turk Telekom and Vodafone. The model is designed to explore the relationship between investment of mobile operators to mobile communication technologies and profit obtained from these technologies. In this model, the basic principle is technology adoption. There are many factors effecting technology adoption behavior of mobile communication subscriber. Our model is aimed at investigating determinants of investment strategies of operators. These strategies are sensitive to the adaptive behavior of subscriber to new generations of mobile communication technologies.

The simulation results indicate that: For each operator the revenues from the old technology declines when the new technology is in operation. The expected revenue from the new technologies is lower than the old technology revenues. As the percentage of the investments made to new technology increases present value of the operators' increases. Based on this finding, it can be suggested that all operators should increase their investments to the new technology.

ÖZET

Mobil Operatörlerin Yatırım Davranışların İncelenmesi:

Ajan Tabanlı Modelleme Yaklaşımı ile

Bu çalışma, Türkiye'deki mobil operatörlerin yeni ve eski mobil iletişim teknolojilerine yaptığı yatırım stratejilerinin, ajan tabanlı modelleme ve simülasyon yaklaşımı ile incelenmesi üzerinedir. Türkiye'de, Turkcell, Türk Telekom ve Vodafone isimlerinde 3 mobil iletişim operatörü bulunmaktadır. Bu model, mobil operatörlerin mobil iletişim teknolojilerine yatırımı ve bu teknolojilerden elde edilen kazanç arasındaki ilişkiyi araştırmak için tasarlanmıştır. Bu çalışmanın dayandığı temel ilke teknoloji adaptasyon modelidir. Mobil iletişim abonesinin teknoloji adaptasyonu birçok faktöre bağlıdır. Modelimiz operatörlerin yatırım davranışlarının belirleyici niteliklerini ortaya çıkartmaktadır.

Benzetimlerden elde edilen sonuçlar; Her operatör için, eski teknolojinin gelirleri, yeni teknoloji kullanılmaya başlandığında azalmaktadır. Yeni teknolojilerden beklenen gelir, eski teknoloji gelirlerinden daha düşüktür. Yeni teknolojiye yapılan yatırımların yüzdesi arttıkça operatörlerin teknoloji yatırımlarının bugünkü değeri artmaktadır. Bu bulguya dayanarak, tüm operatörlerin yatırımlarını yeni teknolojilere yöneltmeleri önerilebilir.

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CHAPTER 1

INTRODUCTION

In the last two decades all over world wireless technology is an indispensable and essential aspects of everyday life. Mobile communication is among one of the most widely used wireless technologies. Nowadays, 95% of the members of US population over age 13 use mobile phones in 2016, 77% of each are smartphones. These devices need to communicate via internet that's why they need mobile communication technologies. On the other side, mobile communication technology is always evolving and improving itself.

Mobile communication technology generations named as "G", has different specifications. The first "G" started with analog technology (1G) in 1990s and nowadays communication technology has reached 4G. When looked at the recent history there is a generation change in mobile technologies in approximately every 5 years. In that fast technology change mobile operators need to make investment for new technologies to serve best user experience for their customers in mobile communication. At the same time, they need to make profit and return of investment as much as possible. As more investment is made for these technologies, quality and speed of the service increases, hence the users are more satisfied and increase the usage of the mobile services.

An agent based model is a class of interactions of autonomous agents with a view to assessing their effects on the system as a whole and computational models for simulating the actions. This modelling technique combines elements of complex systems, computational sociology, game theory, emergence, multi-agent systems and evolutionary programming. Normally, scientific models are limited with the mathematical tractability. In the agent based modelling individuals or agents are described as unique and autonomous entities which usually interact with their environment locally and with each other. In the agent based modelling agents could be any kind of entity which pursues a certain goal such as organisms, humans, businesses or any other. This model approaches especially useful when the problem could not be solved by pure mathematical techniques such as differential equations.

In this study, Turkish mobile operator's investment behaviors to new and old mobile communication technologies is modelled with the agent based modelling and simulation approach. There are three operators in Turkish telecommunication market: Turkcell, Turk Telekom and Vodafone. The model is designed to explore the relationship between investment of mobile operators to mobile communication technologies and profit obtained from these technologies.

In this model, the basic principle is technology adoption. There are many factors effecting technology adoption behavior of mobile communication subscriber. Our model is aimed at investigating determinants of investment strategies of operators. These strategies are sensitive to the adaptive behavior of subscribers to new generations of mobile communication technologies. Hence, technology acceptance model as being the theory of adaptive behavior of users is constitutes the basic principles of this study.

This thesis is organized as follows; in Chapter 2 the literature about technology acceptance model and mobile technology usage behavior are surveyed. In Chapter 3 the methodology of agent based modelling and simulation is introduced. Chapter 4 describes the model with Overview Design and Detail (ODD) documentation standard protocol. Chapter 5 presents the experimental design and results. Finally, Chapter 6 concludes with future extensions.

CHAPTER 2

BACKGROUND

In this chapter literature review about Technology Adoption Model (TAM) is presented. Then background information about mobile communication technologies is given.

2.1 Literature survey

The technology adoption is a sociological model which describes the acceptance or adoption of a new product or innovation. Adoption process over time is typically described with a classical normal distribution or bell curve model. The model describes the first group as “innovators”, after that “early adapters”, then “early majority” and “late majority” and finally “phobic”.(see Figure 1)

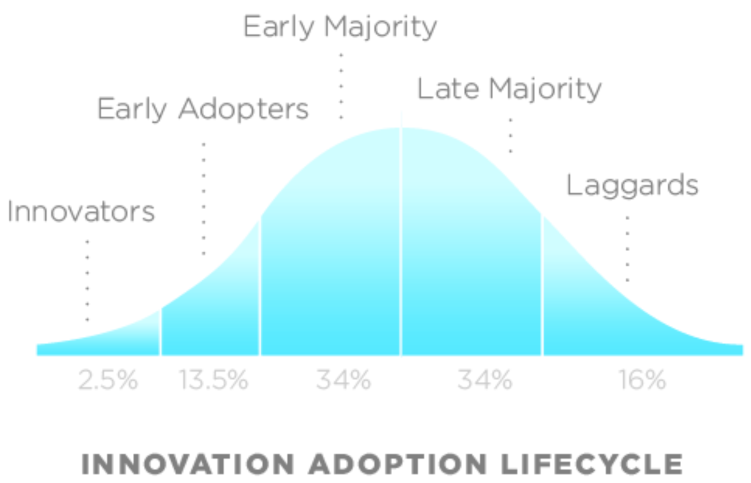


Figure 1.Innovation adoption lifecycle

The technology acceptance model (TAM) is a theory about information systems which models how users decide to accept and use a technology. The model introduce that a number of factors influence their decision about when and how they will use the new technology when there is a new technology presented to them.

An early model of diffusions is the Bass (1969) model. The Bass forecasting model became so important in the marketing field because it offers some reasonable answers to uncertainty connected with new product introduction in the market (Rogers, 1995)

- Perceived usefulness (PU): This was defined by Fred Davis as "the degree to which a person believes that using a particular system would enhance his or her job performance".
- Perceived ease of use (PEOU): Davis defined this as "the degree to which a person believes that using a particular system would be free from effort" (Davis 1989).

The TAM has been continuously studied and expanded; the two major upgrades being the TAM 2 (Venkatesh & Davis 2000 & Venkatesh 2000) and the Unified Theory of Acceptance and Use of Technology or UTAUT (Venkatesh et al. 2003). A TAM 3 has also been proposed in the context of e-commerce with an inclusion of the effects of trust and perceived risk on system use (Venkatesh & Bala 2008). Technology is the most essential and significant part of everyday life. Nowadays almost every people use wireless technologies because technology has infiltrated in almost every area that people live in. All this technology dynamically changes and velocity of this change forces people into adopt new technology. New technology adoption could be changeable by technology type, some kind of technology could easily live in people life, on the other hand some of them die.

Actually technology sustainability depends on people who use it. When mobile communication technology is investigated, the adoption depends on various factors such as age, gender, living style, education etc. Karim et al (2009) described that people reasons to adopt new technology. This study made an investigation why people are willing to use mobile phone and reasons of people to use mobile phone. According to Karim et al (2009) the most significant reason of begin to mobile phone usage is easy communication with more than %89 of the focused group. The other factor on technology adoption that is cultural effect focused by another investigation. This deep research shows significant roles of the needs, social environment and technology development for change technology (Su, 2010a). In another study of Su (2010b) is about the role of age, gender and occupation in the technology adoption(Su, 2010b). All of the researches showed that all the factors of technology adoption could be changeable from person to person.

The relationship between technology adoption and age is another research topic and Moris and Vankatesh's study shows how important the age in technology adoption (Moris, Vankatesh, 2000).

Miranda and Lima (2013) approach the topic from a different standpoint and described the importance of the innovation in the technology and how people adopt it. This study showed people's reactions to new technology by years in the last 15 years. There is significant data in this time period and showed the adoption of the new digital picture technology with the deep research. It is really useful for modeling a new technology adoption.

There are some survey companies which made a wide participating surveys about technology adoption. In Nielsen's survey there is significantly depends on between technology adoption and age. This survey made for smart phone ownership and it was clearly seen that technology adoption rate decrease while age increase. Gender is another main factor for technology adoption. The same research showed that technologies abilities and features can directly affect the adoption (Nielsen, 2016).

Another research company Pew Research Center made an investigation about mobile communication. This research outputs are also parallel with the Nielsen. Mobile communication adoption change by gender, color, age, education, income and living area. This research shows technology change not directly contacting with income. %1 of the rich people do not use mobile phone at the same time %7 do not use smart phone. The same research shows that when people gets older, they are conservator for their own technology and do not want to lose their comfort area. Hence the adoption level decrease with the increasing age. Also mobile phone adoption increases with the education level (Pew Research, 2016).

There is some other research for technology adoption except people specialties, Lai et al. said that there are steps for adoption a new technology (PC Lai, 2017). Firstly, innovators adopt the new technologies, after that adoption rate increase then it decreases till the end of the adoption.

2.2 Technologies study

First of all, the "G" means that the generation of mobile technology which installed in phones and on cellular networks. Each "G" generally needs a new device to adopt it. The first one was analog technology (1G) and after that digital communication came with complicated systems.

Third generation mobile networks (3G) came to Turkey in 2009. It reached 21 Mbps internet speed in the final stages of 3G, however the average speed of 3G in Turkey is about 10 Mbps.

4G technology even faster than 3G, but that's not always the case. There are so many technologies called "4G," and so many ways to implement them, that the term is almost meaningless. 4^{th} generation mobile communication name is actually Long Term Evaluation (LTE) which has so many ways to implement. This 4G technology starts with HSPA+ and reached LTE Advanced. LTE has various speeds which actually starts with 35 Mbps and reached 1Gbps. However, because of some financial and technological factors, some 4G speed could decrease till 1 Mbps. Average 4G throughput in Turkey about 20 Mbps.

On the other hand, with the improving on the technology not only measured with speed of internet. With the new generation mobile communication technology, delay times decreased, connection type changed from connect when needed to always connected with 4G. Because new type of devices need always connect to the network and technology evolve for this type.

CHAPTER 3

METHODOLOGY

This chapter introduces the agent based modeling (ABM) approach comparing it with analytical modeling and introduces the agent based modeling benefits and drawbacks with the other modelling techniques.

3.1 What is agent based modeling?

An agent based model is a class of interactions of autonomous agents with a view to assessing their effects on the system as a whole. An ABM is a computational model for simulating these actions. This modelling technique combines elements of complex systems, computational sociology, game theory, emergence, multi-agent systems and evolutionary programming.

Normally, scientific models are limited with the mathematical tractability. These models to be solved by differential calculus methods and which limits people's creativity.

On the other side computer simulations are passed over the mathematical tractability and people started to create less simplified models to solve their systems characteristics. In the agent based modeling approach system simplification is less in the individual components and their behaviors. In the agent based simulation the systems are modelled as individual agents and not only variable like other simulations.

In the agent based modelling individuals or agents are described as unique and autonomous entities which usually interact with their environment locally and with each other. In the agent based modelling agents could be any kind of entity which pursues a certain goal such as organisms, humans, businesses or any other. Every agent has unique identity and different from each other such as location, size, history and resources. Also local interaction means that agents usually do not interacting with all other agents they only interact with the geographical neighbors like a network. On the other side agents act as autonomous independently of each other and try to reach to their objectives. Traders try to make more money; organisms try to reproduce and survive; businesses try to catch profit targets and grow the business. In addition, agents use adaptive behavior; they adjust their behavior with current status of themselves, of other agents and of their environments.

System dynamics that arise from how the system's individual components interact with and respond to each other and the environment. That's why when agent based modelling is used, systems behavior and behaviors of its individual components are studied. There are some examples:

- How tropical forests can be managed in a sustainable way, maintaining both economic uses and biodiversity levels critical for forests" stability properties? (Huth et al. 2004)
- What causes the complex and seemingly unpredictable dynamics of a stock market? Are market fluctuations caused by dynamic behaviour of traders, variation in stock value, or simply the market's trading rules? (LeBaron 2001, Duffy 2006)

- What drives patterns of land use change during urban sprawl, and how are they affected by the physical environment and by management policies? (Brown et al. 2004, Parker et al. 2003)

Agent based modelling is also useful for emergence problems because they are across-level models. Traditionally, scientist studies only systems and tries to model it with differential equations. Others studies focus only agents such as plants, animals, people, organization etc., their adoption to external conditions. But agent based modelling is different from both of them, it uses both standpoints; what happens to the individuals because what the system do and what happens to the system because what its individuals do. It is important to understand the behavior of the system made up by agents and model behavior of agents.

Agent based models are mostly not like the traditional models because individuals and the environmental variables affect them with various dimensions such as space and time. Agent based models often include the complex processes.

Agent based modelling ability to solve complex multilevel problems comes with additional requirements. Normally mathematical abilities can be enough to solve equation based models, however the agent based modelling simulation needs additional skills as listed below:

- The simulation modeller needs to learn a new language.
- The simulation modeller needs software skills for the implementation of the model on computers.
- It is needed to have strategy for designing and analysing models. There is need a way to determine what entities, variables, and processes should and should not be in a model, and there are need methods for analysing a model.

In a fully designed agent based model, all the agents should be different from each other and interact with some of others. They change over time in their lifecycle and they make adaptive decisions to achieve their aims. However, because of difficulties in modeling individual agents differently, a set of representative agents are used to model agents with similar characteristics and behavior. After that it is needed to test and adjust the model to see whether it is covering our requirements or not. While adjusting the model it is needed to make changes in model structure and parameters.

3.2 Agent-Based models vs. Equation-Based models

Equation based modeling(EBM) is the most common form of the scientific models. Parunak, Wilensky, and their colleagues (Parunak et al., 1998; Wilensky, 1999; Wilensky & Reisman, 2006) discuss many differences between ABM and equation-based modelling (EBM). First of all, agent based models create individual samples and create a heterogeneous population, however equation based models typically just make assumptions of heterogeneity. At the same time most models need heterogeneous samples to better approximate the real situations. It is very important to have sustainable populations, in the simulation of population dynamics. For instance, if there is less than two wolves in a simulation they cannot reproduce and population cannot grow. However, this is not important for EBM, even there is only one wolf left they can reproduce and grow the population which is called as "nano-wolf" (Wilson et al., 1998). As a result, for EBMs to work correctly, they must make an assumption that the population size is large and that spatial effects are unimportant (Parunak et al., 1998; Wilensky & Reisman, 2006; Wilkerson-Jerde & Wilensky, 2010).

Another advantage of ABM over EBM is that ABM does not require knowledge about aggregate phenomena. One does not need to know what global pattern results from individual behavior. When modeling an outcome variable with EBM, you need to have a good understanding of the aggregate behavior and then test out your hypothesis against the aggregate output. For instance, in wolf-sheep example it is modelled by the help of equation based modelling, it is understood relationship between wolf and sheep population. To encode this aggregate knowledge such as in the classic Lotka-Volterra equations (Lotka, 1925; Volterra, 1926), it is needed to have knowledge of differential equations. On the other side agent based modelling allows to write simple rules for simple entities, which requires only behaviors of individual wolves and sheep. Also if there is no information about this relationship, model can be still created and generate outputs. Because, ABMs describe individuals and not aggregates, that's why the relationship between real life and agent based modelling is closely matched. It is much more easy to create a model without a deep knowledge about the model. That's why there is no need to special training for agent based modelling. Many ABM languages like NetLogo is easily understandable as syntax and people can easily read the codes to learn what's going on. The "glass box" approach to modeling (Tisue & Wilensky, 2004) enables all interested parties to talk about the model all the way down to its most basic components.

Finally, ABMs results are generally more detailed than EBMs'. Agent based modelling can give aggregate and individual level details at the same time. Because ABMs each individual and their decisions, it is possible to examine the history and life of any individual in the model and it can give overall results. This approach of ABMs is often in contrast with EBMs. Many EBMs assume that one aspect of the model directly influences, or causes, another aspect of the model, while ABMs allow indirect causation via emergence to have a larger effect on the model outcomes.

3.3 Benefits of ABM

Agent based modelling technique has some benefits over other modelling techniques. ABM can model any natural phenomenon, however in some cases building ABM can be hard and when compared with benefit, it could not be feasible. It could be hard to decide ABM is beneficial or not, but there are a few guidelines that can help to identify the situations where ABM will be particularly valuable.

Some problems with large number of homogenous agents are often better modeled (i.e., they will provide more accurate solutions to aggregate problems faster) by using an aggregate solution like mean field theory or system dynamics modeling (Opper & Saad, 2001; Forrester, 1968). For instance, if temperature of a room is concerned, then tracking every individual molecule and its history is not necessary. On the other hand, if a problem has only a handful of interacting agents, then you usually do not need to bring to bear the full power of ABM and instead can write detailed equations describing the interaction—two billiard balls colliding, for example, does not require ABM. As a rule of thumb, agent-based models are most useful when there are a medium number (tens to millions) of interacting agents (Casti, 1995).

Agent based modelling is more useful when agents are not homogenous. For example, modelling a stock market with all trades and events requires a richer and detailed examination of individual level behavior. All the agents in this stock market have different risk thresholds and their decisions are different from each other in the same environmental state. Agent based modelling is very useful when the agents are heterogeneous and agent's heterogeneous behavior affects the overall performance. Since ABM enables each individual to be tracked and described at the individual level, it is much more powerful than techniques such as systems dynamics modelling (Forrester, 1968; Sterman, 2000; Richmond & Peterson, 1990). System dynamics modelling requires a separate stock for each group to create. This makes the model more complex and hard to model, track and integrate. Agent based modelling program needs to specify only how agent's properties and defined. That's why using agent based modelling is especially beneficial when agents are heterogeneous.

At the same time having heterogeneous agents allow to see the interaction between agents and this interaction makes the model more complex. Instate of creating a number of agents and adjust their behaviors, it can be specified just a few simple rules for the agents and interaction rules in the agent based modelling. This small amount of information allows us to create huge number of heterogeneous agents. Furthermore because of the interactions with each other, they can learn and change their behaviors. That's why agent based modelling is very useful to model a complex interaction of adaptive agents.

As stated before agent based modelling is very useful when the interaction between agents is complex and interaction with environment is complex. The environment in an ABM is often composed of stationary agents, and thus modelling agent-environment interactions have all of the power of modelling any agent-to-agent interaction. For instance, in a fish ecology in ABM system, a fisherman has an idea about a place which he has gone a place and cached all the fishes and now there is no fish. This environmental interaction enables location dependent and geographic information has to be included in the model, and then we can get richer data than a geographic independent model. In that fish model, it can be known that the average fish population is steady over time but it's density depends on location in a particular time. This features makes the model more detailed and more complex. This makes agent based modelling to generate spatial patterns of results as opposed to spatially homogeneous aggregate results.

Another beneficial usage of the agent based modelling compared to other modelling approaches is through its rich conception of time. In agent based modelling, interactions occur temporally. ABM allows to take snapshot to system in a particular time to see its behavior. For instance, in stock market traders buying and selling stocks can be observed individually instead of just stock prices. By enabling a detailed conception of time, ABM vastly expands on the detail of the resultant model.

3.4 Trade-offs of ABM

Agent-based modelling has some positive sides over the other modelling methods, however sometimes it is not the right tool because of time limitation or type of job. For instance, because of the individual agents, computational power is very important. These agents need very strong computers to solve the model. On the other hand, equation based models work with very simple mathematical calculations. That's why when rich individual data is wanted from agent based modelling it needs more computation power. This big computation needs will continue with the track and development of the rich histories of individuals. On the other side, if the model is well organized, this computational power need could be decreased with the black box technique. In this technique some parts of the system can be modeled with differential or difference equations.

In the modelling decisions have to be made by the modeler. This make the model under control. On the other side in agent based modelling, parameters are not directly adjusted by modeler, every parameter is set by themselves and they have to be calibrated. With few parameters it could take some time to calibrate each of them to reach desired results.

In agent based modelling modeler needs to have a knowledge about individual elements of the system to set or modify them. To gain this knowledge about the system takes time and effort which is not necessary in other models.

CHAPTER 4

DESCRIBING THE MODEL

In the last two decades all over the world wireless technology is an indispensable and essential aspects of everyday life. Mobile communication is among one of the most widely used wireless technologies. Nowadays, almost every people has a mobile phone and the percentage of people having mobile phone reached more than 95% in 2016. And smartphone ownership ratio reached 77%. Most of the mobile phone owners use it very much in daily life. These devices need to communicate via internet that's why they need mobile communication technologies to achieve this requirement. On the other side, mobile communication technology is always evolving and improving itself.

In this study, Turkish mobile operator's investment behaviors to new and old mobile communication technologies is modelled with the agent based modelling and simulation approach. There are three operators: Turkcell, Turk Telekom and Vodafone.

This chapter describes the ABM with the Overview, Design and Detail (ODD) protocol developed by Rails back & Grimm (2012). "ODD" stands for "Overview, Design concepts, and Details": the protocol starts with three elements that provide an overview of what the model is about and how it is designed, the second element is design concepts that depict the ABM's essential characteristics, and finally the details part consists of three elements that provide the details necessary to make the description complete. The ODD protocol has seven elements which are shown in figure 2.

	Elements of the ODD protocol
Overview	1. Purpose
	2. Entities, state variables, and scales
	3. Process overview and scheduling
Design concepts	4. Design concepts • Basic principles • Emergence • Adaptation • Objectives • Learning • Prediction • Sensing • Interaction • Stochasticity • Collectives • Observation
Details	5. Initialization
	6. Input data
	7. Submodels

Figure 2.Overview of the ODD protocol for describing ABMs (as described by Grimm et al. 2010).

4.1 Purpose

Mobile communication has been started with 1G in 1990s but now 4G is the most widely used generation and 5G is to be tested. In that fast technology change mobile operators need to make investment for new technologies to serve best user experience for their customers in mobile communication. At the same time, they need to make profit and return of investment as much as possible. As more investment is made for these technologies, quality and speed of the services increases, hence the users are more satisfied and increase the usage of the mobile services.

All over the world in mobile communication technologies, mobile operators try to give best service to their customers. To achieve this aim, operators have to catch the new technology and make huge investments on it. However, because of the fast innovation on mobile communication, sometimes it could be hard to recover their new investments for the operators. In addition, when starting to new generation operators legally have to enter a frequency tender organized by governmental institutions. As an essential part of investment to the new technology, they also spend huge amount of money to purchase broad frequency bands to increase the speed and service quality. As the operators serve new generation mobile communication technology, some users decide to adopt to these new generations (such as from 3G to 4G). However, some others still use old technology after new technology started. New technology use means more internet usage which increases revenue and profits from these new generations. Therefore, investment strategy is critically important for the operators. The decision about right amount of investment for the operators is essential because of intensive competition among operators.

When looked at the recent history there is a generation change in mobile technologies in approximately every 5 years. The model was designed to explore the relationship between investment of mobile operators to mobile communication technologies and profit obtained from these technologies. In the model some users adopt to the new technology after new technology starts, the quality difference between new and old technologies observed by subscribers is the driving force for adopting to the new technology. Which is effected by age and gender of the users. If a user decides to adopt new technology they will not turn back to the old one anymore.

4.2 Entities, state variables, and scales

In this model agents are mobile phone subscribers in Turkey. There are 720 turtles which represents actually 72 million people which is the total number of mobile phone subscriber in Turkey. Each agent subscribes one of the three operators. In addition, each agent has an age and gender as their socio demographic variables. In the current version of the model operators are proto agents. Proto agents do not have individual properties, states, or behaviors but instead inherit some or all of their characteristics from a global agent type. (Wilensky, 2015) At each time period operators decide how much money to invest to new and old technologies.

In this model timescale is quarter based. As historical evidences show at every 5 years a new mobile communication technology generation is introduced. The essence of the model focus on the investment decisions of operators and adaptive behavior of users after a new generation is introduced. In the model to better investigate and compare the investment and adaptive behavior there are 8 time periods (8 quarters) before introducing the new technology. Therefore, the timespan of the model is 7 years (28 quarters/time period). There are 20 time periods after the new technology is introduced, hence the investment of new technology is very high at 8^{th} time period.

4.3 Process Overview and Scheduling

At each time period the following processes are realized: forms investments decisions to new or old mobile communication technologies, adaptation and usage behaviors of subscribers, revenue accumulation of operators.

As mentioned in the previous section in the first eight quarters there is only old technology. In the 8^{th} tick there is a frequency tender and operators make decision about how much investment to make to new technology to get biggest advantage. Afterwards two technologies are available simultaneously, hence the operator make an investment allocation decision to both new and old technologies. There are two technology options to the subscribers. In general, new technology is more beneficial to the users because of its high quality and speed.

There are two types of investments by operators. At each period to keep up and improve the quality, each operator makes investments to both old and new mobile communication technologies. Otherwise the quality of the technology decreases at each time period. Second important type of investment is the initial investment including the frequency tender made to the new technology at the 8^{th} quarter.

Agents perceive the quality of two technologies, after the introduction of new technology the quality difference between two technologies is the basic determinant to adoption rate to the new technology. In addition, age and gender are the other factors effecting the adaptation behavior to new technology. The usage of technology by the agents is directly related to the quality of the technology.

The operators get revenue from the amount of usage of technologies by the agents. The revenue is related to the usage of the technology.

4.4 Design concepts

In this model, the basic principle is technology adoption. There are many factors effecting technology adoption behavior of mobile communication subscriber. Our model is aimed at investigating determinants of investment strategies of operators. These strategies are sensitive to the adaptive behavior of subscribers to new generations of mobile communication technologies. Hence, technology acceptance model as being the theory of adaptive behavior of users is constitutes the basic principles of this study.

There is no learning in this model. Subscribers neither learn from their own experience nor from the behavior of others. Hence, there is no interaction among the agents as well. Sensing is important in this model because users sense the quality of new and old technologies. They can calculate the difference between qualities of these technologies and decide to adopt to the new one proportional to the quality difference.

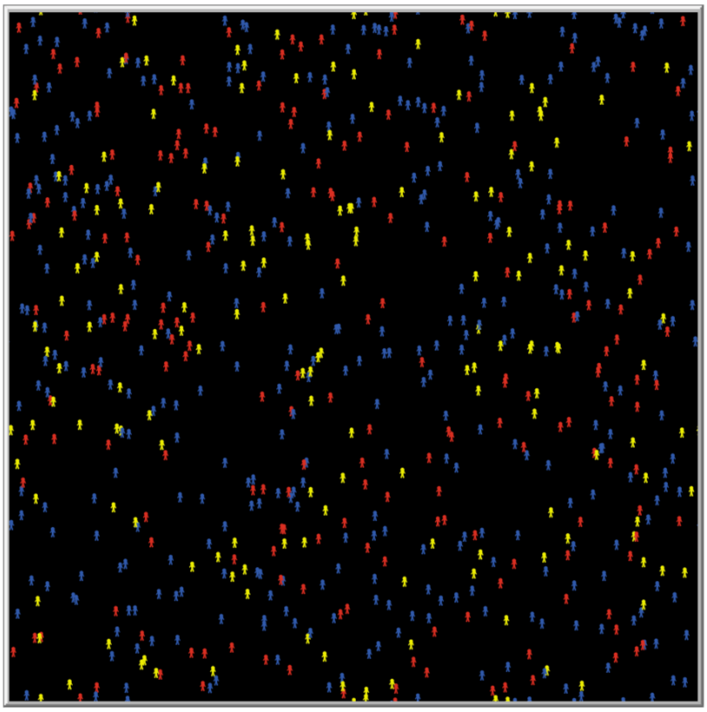
Increasing investment increases the quality of the system. More quality makes happier customer and fast mobile communication; fast mobile communication brings more mobile phone usage.

Quality of a technology depends on the investments made to this technology. If no investment is made to a technology in any time period, the quality of the technology in the next time period is proportionally decreased. The usage rate of a technology is proportional to the square root of its quality. The proportionality constant of the new technology is higher than the old one. The proportionality constant is uniformly distributed between 0,95 and 1,05. In brief, as the quality of each technology increases, more usage is realized from this technology. While considering to adapt a new technology subscribers' primary objective is to increase their utility and benefit from high communication services. After the new technology is introduced at each time period, adaption probability of each agent is primarily determined by quality difference between new and old technologies as well as their gender and age.

Some outputs are generated in the model to measure the performance of the operators. First of them is the old and new technology usage rates as a function of time, the second one is investments and revenues of the companies over time, and finally from these revenue and investment figures present value of investments to both new and old technologies are calculated for each company. Number of users and quality of the two technologies together with the investments made by the operators to these technologies are also plotted as time series graphs.

4.5 Initialization

The topography of the landscape (locations of the users) is initialized when the model starts. At the same time; age, gender and operator distributions assigned randomly at the beginning of each run. There are no agents who use new technology at the beginning. Quarter counter is set to zero to start a 28 quarter lifecycle. At the beginning of the first quarter old quality set to 17 for Turkcell, 6 for Vodafone and 9 for TT and new quality set to 0 for all operators. In the subsequent quarters quality change with investment.



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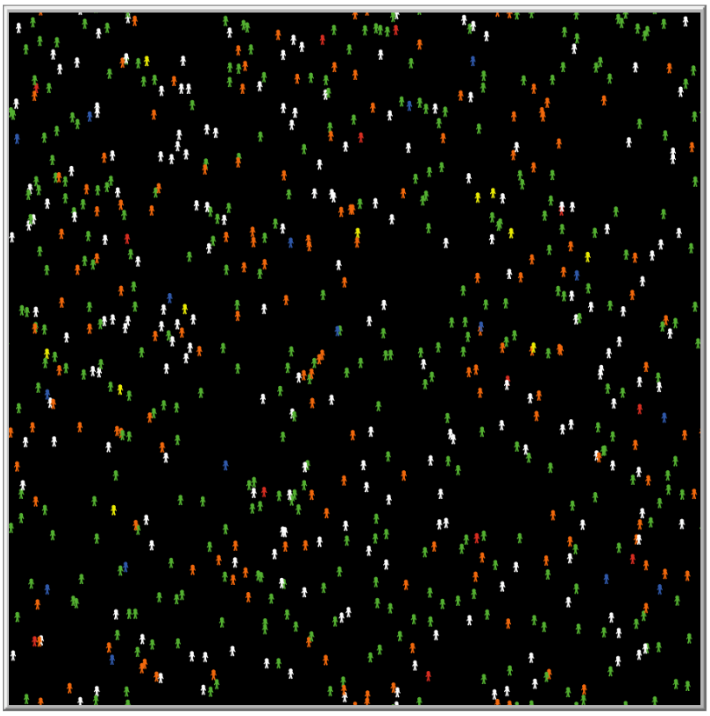


b)

Figure 3.Random initial and final status of the landscape

In this model initially 720 subscribers are created which represents approximately 72 million mobile phone subscribers in Turkey (see Figure 3) and number of subscriber agents does not change. The percentage of male and female subscribers are 51% and 49% respectively. The distribution of the subscribers to different age groups are shown in table 1. Gender and age distribution data is obtained from NVI (Central Population Administration System) official website.

Table 1.Demographic Distribution of the People in Turkey

Age	Percentage
10-17	13.00%
18-29	20.00%
30-49	29.00%
50-64	14.00%
>65	8.00%

The subscribers are distributed to 3 main operators according to their market share data which is obtained from BTK (Bilgi Teknolojileri Kurumu in Turkish) (Information and Communication Technologies Authority). The market share of each operator and number of agents assigned in each operator are shown in table 2.

Table 2.Operator Market Share Rates in Turkey

Operator	Market Share	Number of Agents
Turkcell	48.20%	347
TT	22.70%	163
Vodafone	29.10%	210

Neither the operator distribution of subscribers nor their age groups change throughout each run.

4.6 Input data

For each operator investments for new and old technologies at each quarter are given as input to the model. The nominal investment figures are taken from official website of Information and Communication Technologies Authority (BTK) which are published quarterly. Then they are adjusted by the consumer price index these indices are obtained from Turkish Statistical Institution. Inflation adjusted investment figures for operators are shown in table 3.

Table 3.Quarter Based Operator Investments in Turkey

Quarter	Turkcell Inv	Vodafone Inv	TT Inv
2014-1	230	235	125
2014-2	174	243	92
2014-3	364	232	184
2014-4	592	233	381
2015-1	221	368	158
2015-2	429	201	192
2015-3	277	262	233
2015-4	5845	3022	3528
2016-1	470	401	471
2016-2	482	312	296
2016-3	404	175	142
2016-4	520	283	328
2017-1	331	144	118
2017-2	430	281	117
2017-3	403	288	123

4.7 Submodels

As mentioned before there are 3 Submodels in every time period. Details of the Submodels are explained below:

4.7.1 Investment submodel:

The real investment figures from 2014 Q1 to 2017 Q3 are obtained as inputs from an external file at each time period. From 2017 Q4 to 2020 Q4 forecasted values of investments for each operator are included in the model. The forecast is performed by taking the moving average of trend root of investment at each quarter.

$$I_{i,t} = \frac{\sum_{t-14}^{t-1} I_{i,t}}{14}$$

In the first eight quarters (2014 Q1 – 2015 Q4) operators makes investments only to the old technology(3G). In the 8^{th} quarter all operators make initial investments to the new technology an essential part of which is the money spend on the frequency tender. After the 8^{th} quarter operators make an investment allocation between new and old technologies. The percent of investment made to the new technology by operator i (kI_i) is a strategic decision variable for operator i. The investments made at each time period to old and new technologies at each time period t by operator i is as follows.

$$NI_{i,t} = I_{i,t} \, * k_i$$

$$OI_{i,t} = I_{i,t} * (1 - k_i)$$

To preserve the quality of each technology, operators have to make quarterly investments to these technologies. The quarterly made investments to each technology the functions to preserve the quality of these technologies to be declining. The relation between quality and investments are given by the following equations.

$$q_{new_{i,t}} = ki * q_{new_{i,t-1}} + kinv * NI_{i,t}$$

$$q_{old_{i,t}} = ki * q_{old_{i,t-1}} + kinv * OI_{i,t}$$

The initial quality of the new technology is directly proportional to initial investment made at the 8th quarter.

$$q_{new_{i,t}} = kinv * I_{i,t}$$

where t is 8.

4.7.2 Adaptation and usage behavior:

Observing the quality of new and old technologies agents decide to adopt to the new technology probabilistically. The adoption probability depends on the quality difference as well as age and gender of the subscribers. The adoption probability is given by the logistic equation.

$$P = \frac{(\, kage \ * \ ksex \,)}{(1 \ + \ e^{-0{,}01((q_{new_{i,t}} - q_{old_{i,t}})+25)})}$$

where kage and ksex are constants effecting the probability of adaption by age and gender respectively. ksex values for males and females are 0.76 and 0.71 respectively. This values are based on research made by pew research center (Pew Research, 2016). kage values, based on the same research studies are given in table 4 for different age groups. kqual and shf are the multiplication and shift parameters in the logistic equation.

Table 4.Age and Adoption level

Turtle Age	kage
10-17	0.98
18-29	0.92
30-49	0.87
50-64	0.72
>65	0.34

The usage of technology by the agents is related to square root of the quality of the technology. Technology usage of agent j from operator i at time t is given by the following equations:

$$usage\_old_{j,i,t} = ku * u * \sqrt{q_{old\,i,t}}$$

$$usage\_new_{j,i,t} = kun * u * \sqrt{q_{new\,i,t}}$$

ku an kun are proportionally constant for old and new technologies. At each time period ku and kun are 0,4 and 0,3 respectively. u is a random variable uniformly distributed between 0,95 and 1,05 at each time period for each user.

4.7.3 Revenue:

The revenue of each operator from each technology is proportional to the usage rate of that technology. Total usage is the sum of individual agents' usages.

$$R\_old_{i,t} = \sum_{J=1}^{720} usage\_old_{j,i,t}$$

$$R\_new_{i,t} = \sum_{J=1}^{720} usage\_new_{j,i,t}$$

$$R_{i,t} = R\_old_{i,t} + R\_new_{i,t}$$

For the three operators at each time period discounted revenues and investments are used to compute the present value of the old and new investment projects. The discounted values are calculated as follows.

$$DV\_old_{i,t} = \frac{R\_old_{i,t} - OI_{i,t}}{(1+r)^t}$$

$$DV\_new_{i,t} = \frac{R\_new_{i,t} - OI_{i,t}}{(1+r)^t}$$

Where t greater than 8. r is the quarterly discount factor (r=0.025)

The present value is the sum of the discounted values for each project for each operator.

$$PV\_old_i = \sum_{t=1}^{28} \frac{R\_old_{i,t} - OI_{i,t}}{(1+r)^t}$$

$$PV\_new_i = \sum_{t=1}^{28} \frac{R\_new_{i,t} - NI_{i,t}}{(1+r)^t}$$

$$PV_i = PV\_old_i + PV\_new_i$$

All variables used in these models are shown in Table 5.

Table 5.Variables Used in the Models

Parameter Name	Explanation
$NI_{i,t}$	New technology investment of operator i, at time t
$OI_{i,t}$	Old technology investment of operator i, at time t
$I_{i,t}$	Total investment of operator i, at time t
$q_{new\,i,t}$	New technology quality of Operator i, at time t
$q_{old\,i,t}$	Old technology quality of Operator i, at time t
$usage\_old_{j,i,t}$	Old technology usage of operator i, at time t, for customer j
$usage\_new_{j,i,t}$	New technology usage of operator i, at time t, for customer j
$R\_old_{i,t}$	Old technology revenue of operator i, at time t
$R\_new_{i,t}$	New technology revenue of operator i, at time t
$R_{i,t}$	Total revenue of operator i, at time t
PV_old_{i}	Old technology present value of operator i, at time t
PV_new_{i}	New technology present value of operator i, at time t
PV_{i}	Present value of operator i, at time t
$DV\_old_{i,t}$	Old technology discounted value of operator i, at time t
$DV\_new_{i,t}$	New technology discounted value of operator i, at time t
P	The adoption probability, at time t
age	Age of subscriber
sex	Gender of subscriber
u	U is uniformly distributed between 0.95 and 1.05 at time period for each user.

i refers to operator: 1 as Turkcell, 2 as Vodafone, 3 as Turk Telekom. t refers time. j refers user.

CHAPTER 5

ANALYSIS OF THE SIMULATION MODEL

In this chapter two versions of the model are investigated. In the first version –called base model- the effect of operator investments to both new and old generation technologies on revenue and present value of these operators are investigated. In this model the users' adaption behavior is primarily determined by quality difference between new and old technologies. In the second version users' age and gender are also included as additional variables effecting the adaption behavior of users. These simulation models are calibrated to real data, sensitivity analysis and uncertainty analysis are performed, different scenarios are evaluated.

All the parameters which are used in these models are shown in Table 6.

Table 6.Parameter Values of the Models

Parameter Name	Explanation	Value
$n - people$	Number of people in the model	72
$Market\_share_i$	Operator i's market share	1 : 48.2, 2 : 29.1, 3 : 22.7
$q_{old_{i,0}}$	Operator i's Initial old technology quality	1 : 17. 2 : 6. 3 : 9
k_i	Operator i's investment strategy. Percentage of investments made to the new technology by operator i.	0.7
$kinv$	Normalization factor of the investment	To be calibrated
ki	Decay factor of the quality	0.95
ku	Usage multiplier factor of old technology	To be calibrated
kun	Usage multiplier factor of new technology	To be calibrated
$kage$	Age multiplier	can be find in table 4
$ksex\_male$	Gender multiplier for males	0.76
$ksex\_female$	Gender multiplier for females	0.71
$kqual$	Logit function value	-0.01
shf	Logit function shift value	25
d	Discount factor	0.1

i refers operator: 1 as Turkcell, 2 as Vodafone, 3 as Turk Telekom.

The real investment figures (inflation adjusted) and their forecasted values are shown in table 7. Real investment values from 2014 Q1 to 2017 Q3 are obtained as inputs from an external file at each time period. From 2017 Q4 to 2020 Q4 forecasted values of investments for each operator are included in the model. The real data and forecasts are shown in Table 7.

Table 7.Nominal and Real Investment Values

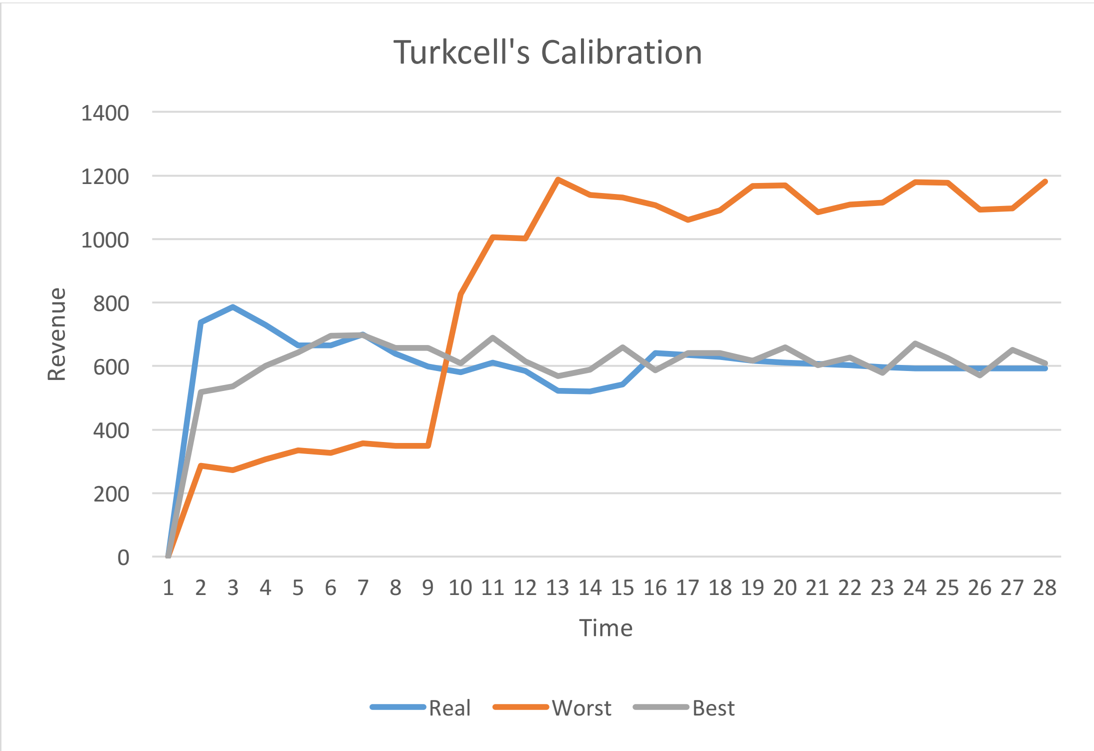
Quarter	Turkcell's Nominal Inv.	Vodafone's Nominal Inv.	TT's Nominal Inv.	Discount Factor	Real Turkcell's Inv.	Real Vodafone's Inv.	Real TT's Inv.
2014-1	230	235	125	1	230	235	125
2014-2	174	243	92	1.0175	171	239	91
2014-3	364	232	184	1.0254	355	226	180
2014-4	592	233	381	1.0441	567	224	365
2015-1	221	368	158	1.0728	206	343	147
2015-2	429	201	192	1.0916	393	184	176
2015-3	277	262	233	1.108	250	237	211
2015-4	5845	3022	3528	1.1363	5144	2660	3105
2016-1	470	401	471	1.1548	407	347	408
2016-2	482	312	296	1.1756	410	265	252
2016-3	404	175	142	1.1882	340	148	120
2016-4	520	283	328	1.2322	422	230	266
2017-1	331	144	118	1.2829	258	112	92
2017-2	430	281	117	1.303	330	216	90
2017-3	403	288	123	1.3213	305	218	93
2017-4	Forecast				332	230	187
2018-1					339	230	191
2018-2					351	229	198
2018-3					351	230	200
2018-4					335	230	188
2019-1					344	222	191
2019-2					341	225	192
2019-3					347	224	191
2019-4					343	215	175
2020-1					338	211	170
2020-2					338	216	173
2020-3					332	215	167
2020-4					338	222	172

5.1 Basic model

In this model the primary variable effecting the user adaption is the quality difference between old and new technologies hence *kage*, *ksex_male* and *ksex_female* parameters are set to 1.

5.1.1 Calibration

For this basic model *ki*, *ku* and *kun* parameters are used to calibrate the model. Figure 4 shows actual revenue and revenue generated by the model as a function of time for the three operators. In figure 4 the worst (best) revenue figures shows the combination of calibrated parameters corresponding to the worst largest (smallest) difference between actual and generated output. Calibrations are repeated 10 times for each combination of the parameter values.



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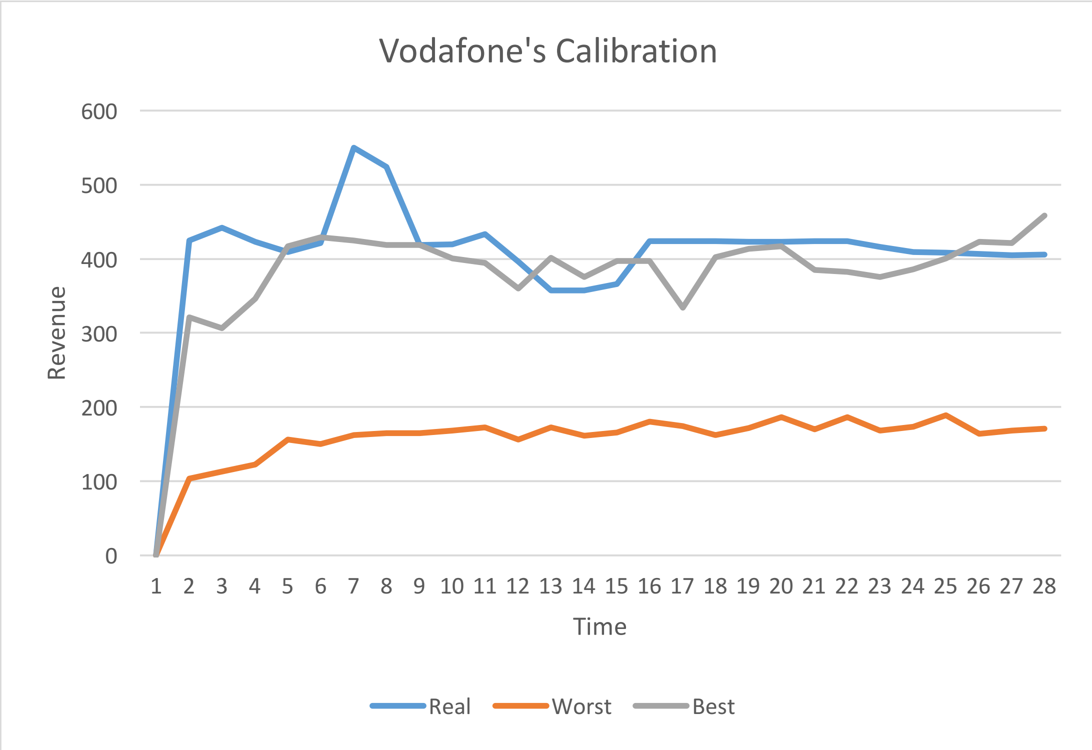

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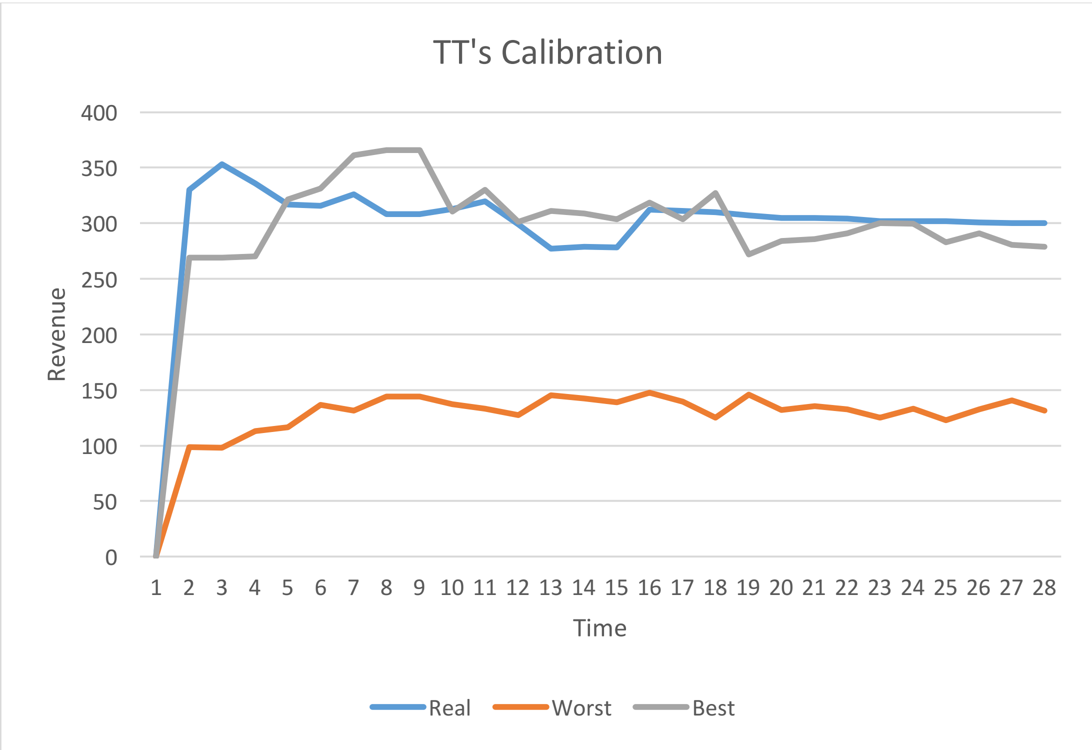


c)

a) for Turkcell, b) for Vodafone, c) for Turk Telekom

Figure 4.Calibration outputs for the three operators

Table 8.Effects of the Calibrated Parameters on Average Revenue of Operators

Actual Revenues				599.21	405.68	297.18
ku	kun	kinv		Turkcell	Vodafone	TT
0.2	0.2	0.006		343.63	157.07	126.77
0.3	0.2	0.006		398.87	190.62	150.78
0.4	0.2	0.006		453.56	219.45	172.79
0.5	0.2	0.006		508.18	254.34	200.29
0.2	0.3	0.006		472.03	203.30	164.95
0.3	0.3	0.006		510.28	234.14	188.67
0.4	0.3	0.006		576.13	261.91	216.82
0.5	0.3	0.006		606.81	301.95	239.82
0.2	0.4	0.006		600.97	250.69	206.61
0.3	0.4	0.006		652.64	279.51	229.76
0.4	0.4	0.006		694.53	315.46	253.86
0.5	0.4	0.006		747.93	341.14	278.61
0.2	0.5	0.006		724.90	293.92	244.05
0.3	0.5	0.006		761.67	324.91	268.46
0.4	0.5	0.006		820.86	353.14	295.94
0.5	0.5	0.006		863.42	390.80	318.61
0.2	0.2	0.007		373.72	166.55	137.54
0.3	0.2	0.007		424.18	195.51	155.55
0.4	0.2	0.007		471.64	224.47	177.35
0.5	0.2	0.007		534.36	248.88	197.45
0.2	0.3	0.007		508.57	226.96	184.24
0.3	0.3	0.007		549.72	255.50	204.43
0.4	0.3	0.007		600.55	279.17	226.15
0.5	0.3	0.007		649.31	310.73	248.70
0.2	0.4	0.007		642.83	281.72	229.85
0.3	0.4	0.007		686.07	311.19	252.41
0.4	0.4	0.007		758.06	334.40	275.98
0.5	0.4	0.007		794.94	361.72	294.05
0.2	0.5	0.007		770.49	337.60	277.94
0.3	0.5	0.007		840.74	366.53	304.13
0.4	0.5	0.007		874.22	392.40	322.77
0.5	0.5	0.007		921.07	417.32	338.15
0.2	0.2	0.008		397.25	178.99	145.25
0.3	0.2	0.008		453.18	202.48	164.05

Table 9.Effects of the Calibrated Parameters on Average Revenue of Operators

(Continued)

Actual Revenues				599.21	405.68	297.18
ku	kun	kinv		Turkcell	Vodafone	TT
0.3	0.2	0.008		453.18	202.48	164.05
0.4	0.2	0.008		494.37	231.71	188.15
0.5	0.2	0.008		551.53	251.29	206.47
0.2	0.3	0.008		531.29	243.77	195.30
0.3	0.3	0.008		585.39	268.06	215.92
0.4	0.3	0.008		648.66	288.44	239.04
0.5	0.3	0.008		701.67	315.00	259.72
0.2	0.4	0.008		681.73	307.41	249.12
0.3	0.4	0.008		730.89	329.99	271.22
0.4	0.4	0.008		789.22	358.61	286.80
0.5	0.4	0.008		822.72	378.96	309.39
0.2	0.5	0.008		839.02	368.43	300.28
0.3	0.5	0.008		881.85	392.85	324.63
0.4	0.5	0.008		940.89	413.22	341.35
0.5	0.5	0.008		992.88	456.68	368.54

Shaded lines indicate the best combination of parameters.

Table 8 and table 9 shows the effect of different combinations of the calibrated parameter values on operators' average revenues. Table 10 shows the best combinations of the calibrated parameter values for each operator. Here the notion of best is the absolute value of the difference between the actual and average generated values for each operator calculated independently. Turkcell's best combination minimizes the deviations of the other operators.

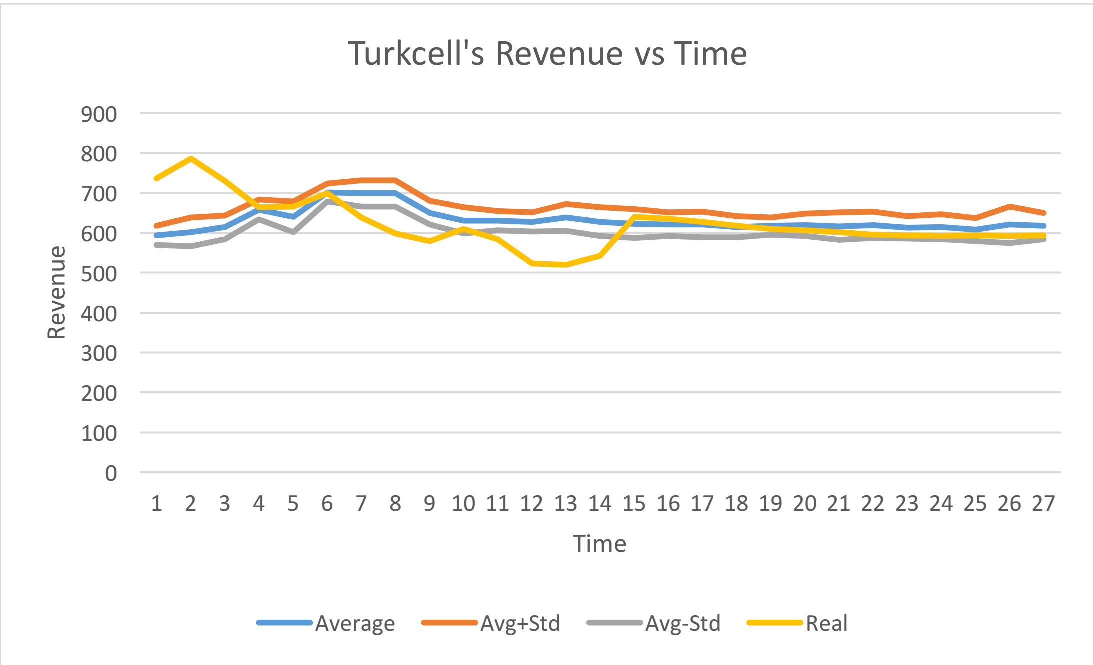
Deviation of other operators corresponding to Turkcell's best combination of parameter values are calculated by taking the arithmetic average of deviations of the two other operators.

Table 10.Calibrated Best Values of the Parameters

Operator	ku	kun	kinv	Turkcell	Vodafone	TT
Turkcell	0.4	0.3	0.007	1.3348763	126.5113744	71.0317265
Vodafone	0.5	0.4	0.008	195.7234778	43.9564834	3.1282714
TT	0.5	0.4	0.007	49.4452538	117.2370339	58.1370887

5.1.2 Repetition

The model is replicated 25 times with the parameter values shown in table 6 and the best combination of calibrated parameters shown in table 10. figure 5 shows the actual revenues and revenues generated by the model for each operator. The generated revenue is the average of 25 repetitions for each time period. By the model for each operator. Figure 5 shows the average of repeated outputs of the model and their standard deviation at the same time period together with the real data from the BTK.



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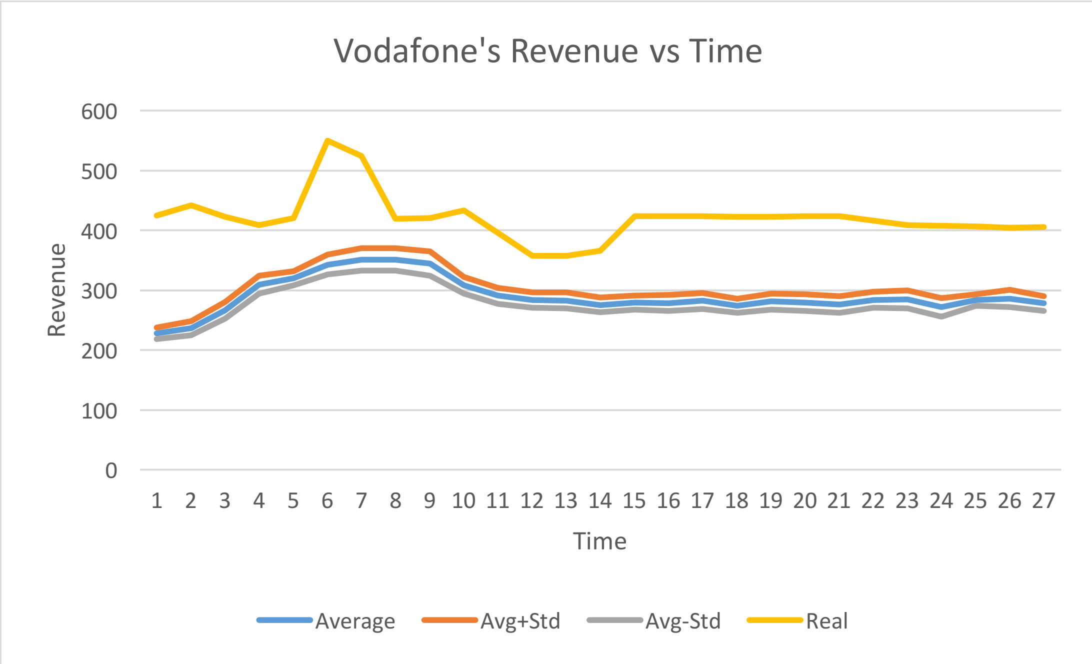

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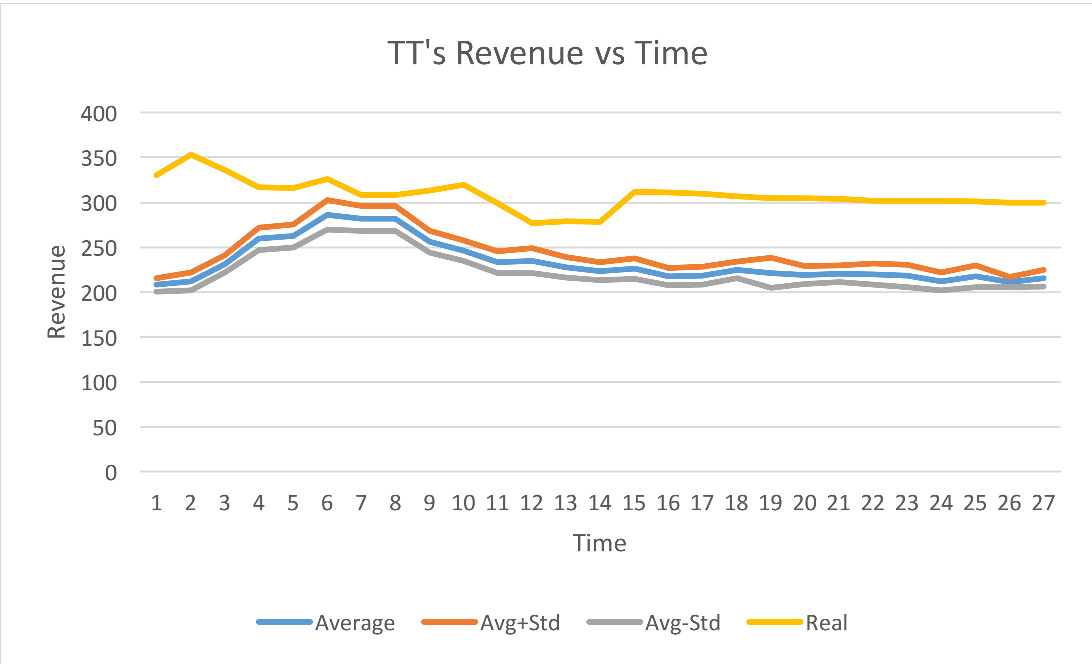
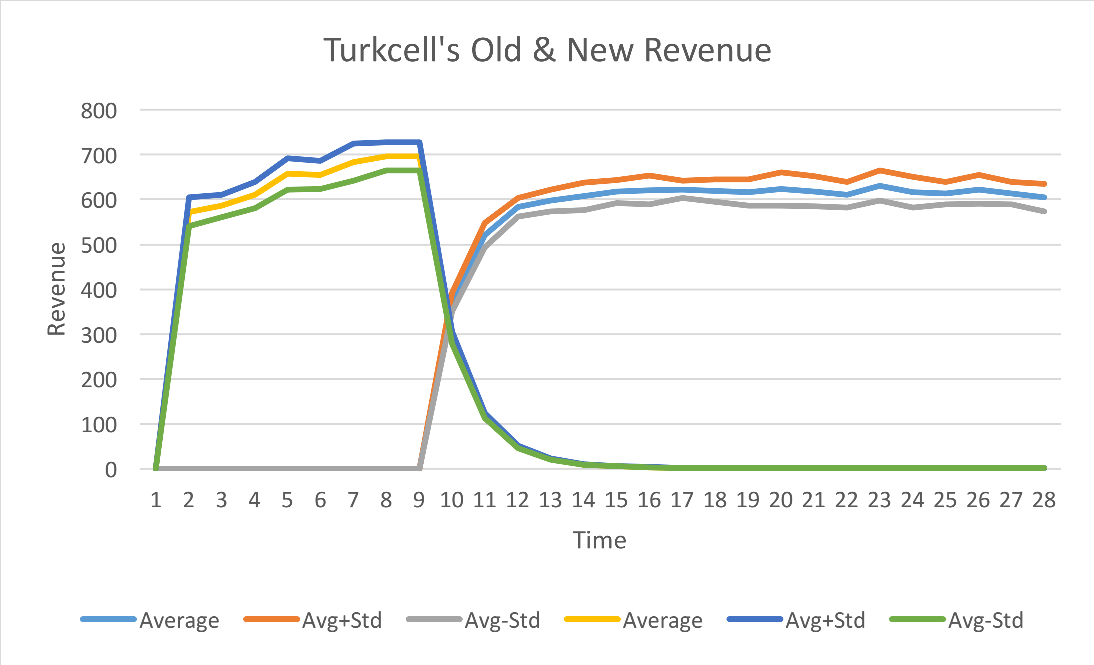


c)

Figure 5.Operators revenue as a function of time

Figure 6 shows the generated revenues from new and old technologies for each operator. Again generated revenues are the average of repetitions for each time period. One standard deviation upper and lower bounds for the old and new technologies are also shown in figure 6. As indicated in figure 5 and 6, the actual revenue values after time period 15 (2017 Q3) are forecasted values.



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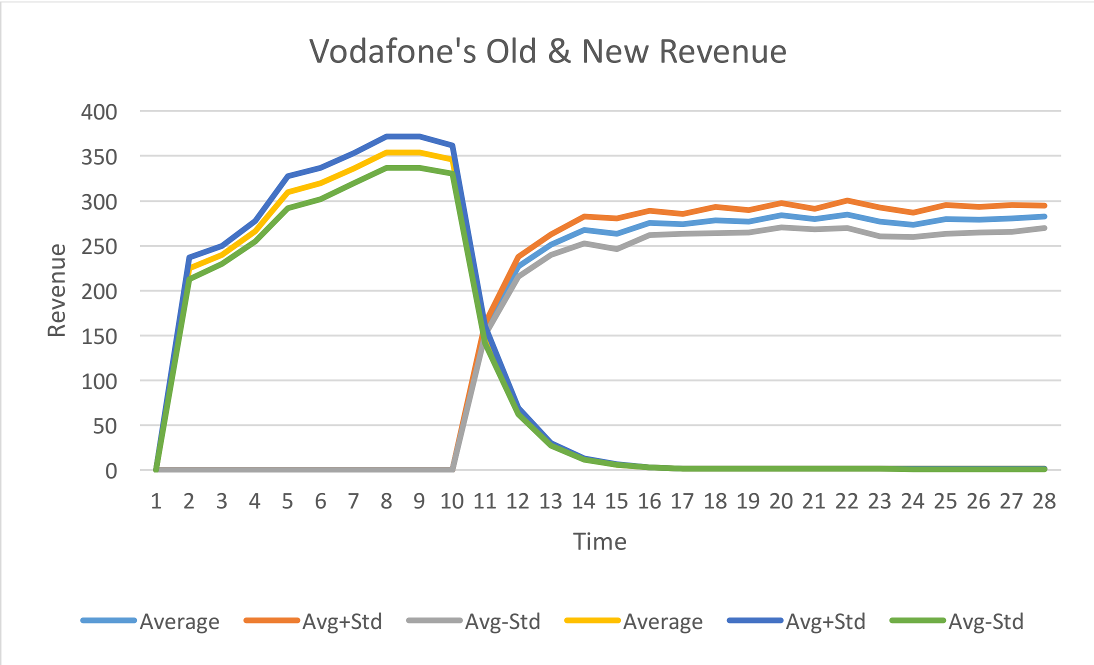

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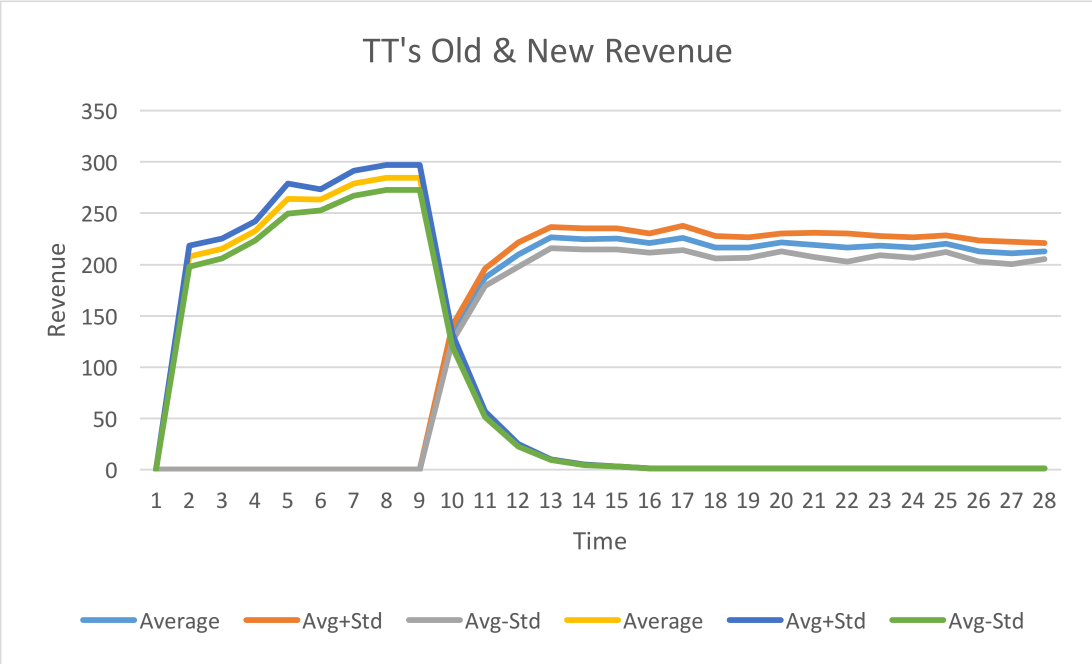


c)

Figure 6.Operators old & new revenues

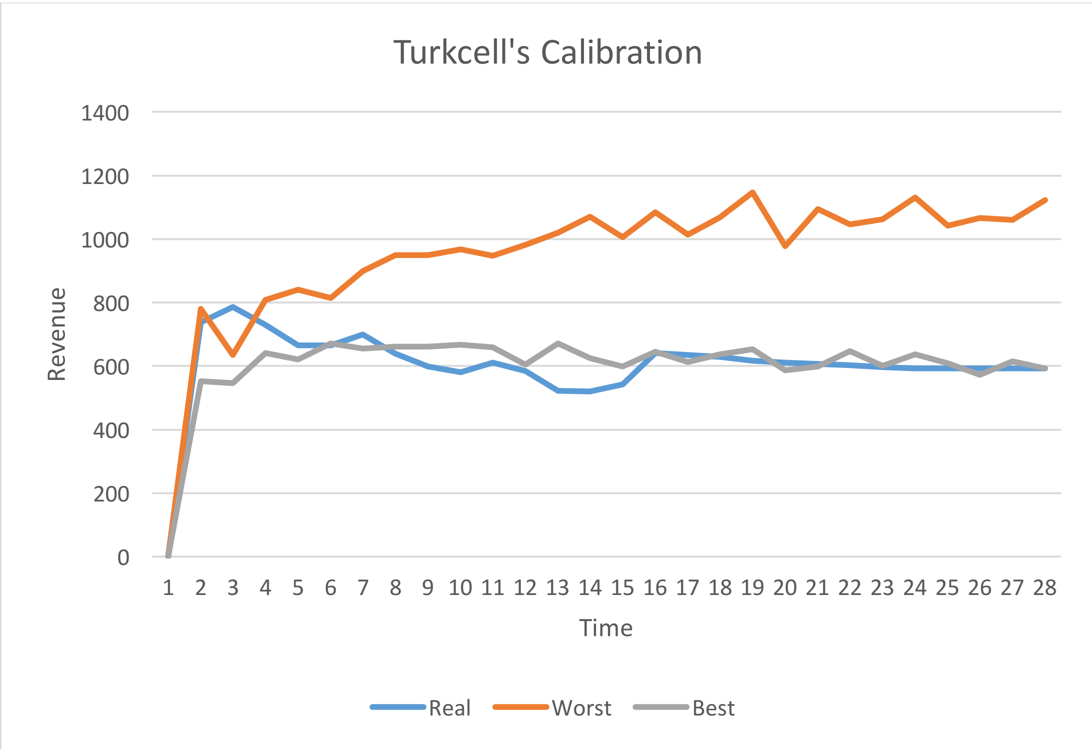
As seen from figure 5 deviation of Turkcell's generated revenues from the actual ones is the smallest. For each operator the revenues from the old technology declines when the new technology is in operation. The subscribers quickly adopt to the new technology. The expected revenue from the new technologies is lower than the old technology revenues. This is due to high competition in the mobile phone industry in Turkey.

5.2 Full model

In the full model subscribers age and gender are also considered as important features effecting adoption behavior. The age and gender parameter in table 5 are applicable for this model.

5.2.1 Calibration

For the full model, *ki*, *ku* and *kun* parameters are used to calibrate the model again. Figure 7 shows actual revenue and revenue generated by the model as a function of time for the three operators in the same manner as the basic model. Also in figure 7 the worst (best) revenue figures shows the combination of calibrated parameters corresponding to the worst largest (smallest) difference between actual and generated output values. Calibrations are repeated 10 times for each combination of the parameter values.



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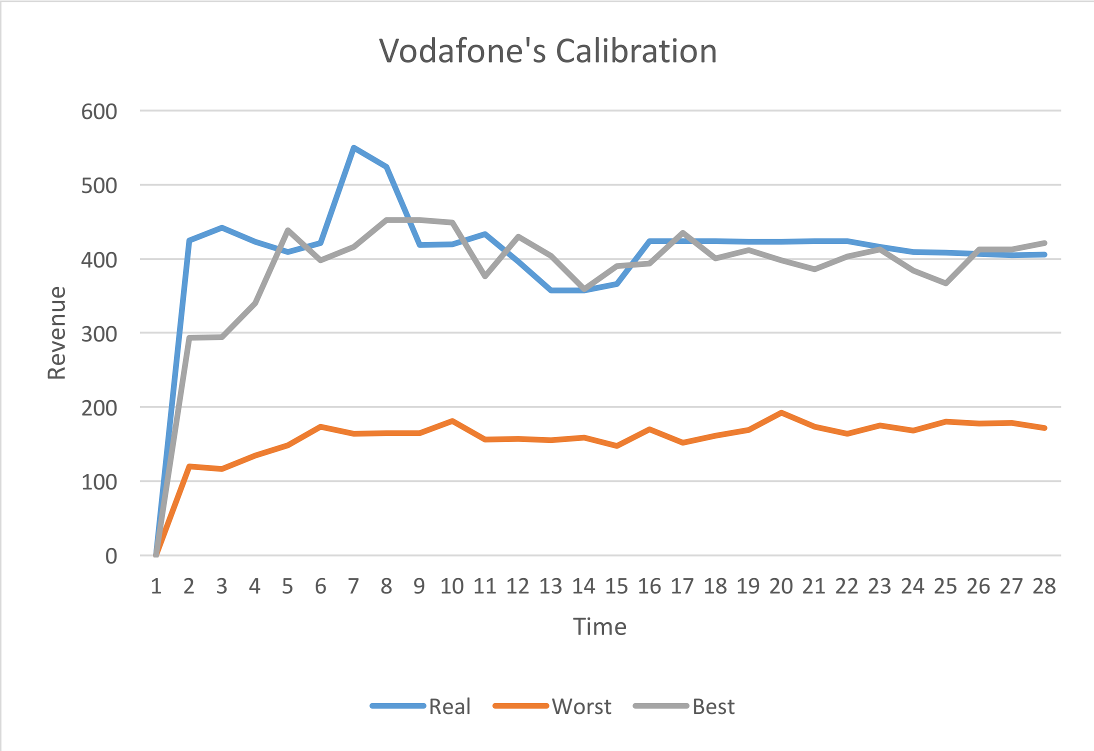

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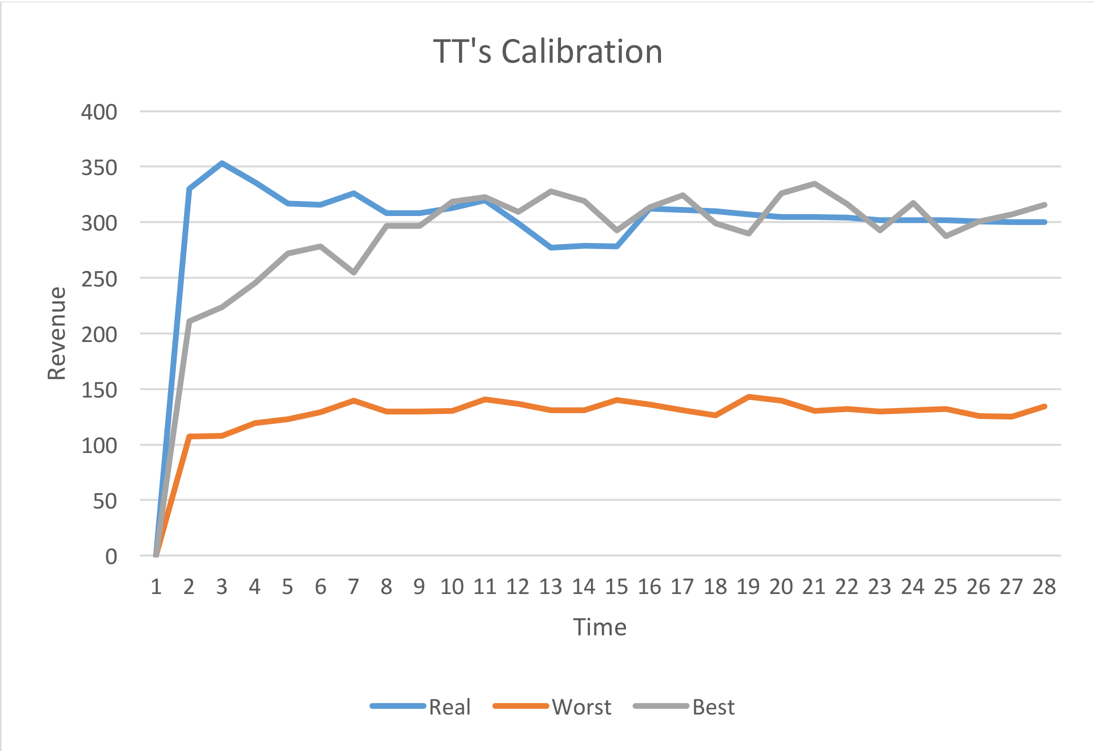


c)

a) for Turkcell, b) for Vodafone, c) for Turk Telekom

Figure 7.Calibration output for three operator

Table 11.Effects of the Calibrated Parameters on Average Revenue of Operators for the Full Model

Real Data				599.21	405.68	297.18
ku	kun	kinv		Turkcell	Vodafone	TT
0.2	0.2	0.006		343.01	156.20	125.39
0.3	0.2	0.006		407.76	192.45	160.16
0.4	0.2	0.006		484.18	237.09	189.42
0.5	0.2	0.006		533.56	270.69	217.39
0.2	0.3	0.006		441.47	190.60	156.21
0.3	0.3	0.006		514.31	234.89	188.63
0.4	0.3	0.006		578.02	271.25	218.29
0.5	0.3	0.006		641.30	308.50	252.62
0.2	0.4	0.006		540.70	230.15	191.16
0.3	0.4	0.006		618.42	268.37	221.04
0.4	0.4	0.006		693.11	306.25	247.79
0.5	0.4	0.006		746.63	354.22	284.47
0.2	0.5	0.006		644.89	263.84	222.26
0.3	0.5	0.006		713.83	309.58	251.30
0.4	0.5	0.006		793.56	347.61	287.00
0.5	0.5	0.006		856.89	391.44	311.25
0.2	0.2	0.007		360.74	163.81	135.73
0.3	0.2	0.007		428.96	202.07	161.70
0.4	0.2	0.007		502.65	237.67	194.40
0.5	0.2	0.007		571.42	275.09	218.87
0.2	0.3	0.007		470.04	209.17	173.92
0.3	0.3	0.007		540.08	247.40	206.31
0.4	0.3	0.007		601.43	280.36	230.41
0.5	0.3	0.007		669.04	320.89	256.28
0.2	0.4	0.007		579.51	264.72	211.78
0.3	0.4	0.007		653.91	291.15	240.37
0.4	0.4	0.007		729.44	330.86	268.06
0.5	0.4	0.007		809.19	369.28	301.15
0.2	0.5	0.007		702.30	307.46	251.77
0.3	0.5	0.007		776.42	341.26	276.34
0.4	0.5	0.007		826.35	381.02	307.23
0.5	0.5	0.007		921.25	413.20	338.49
0.2	0.2	0.008		380.50	174.76	142.97
0.3	0.2	0.008		445.85	211.91	171.36

Table 12.Effects of the Calibrated Parameters on Average Revenue of Operators for the Full Model (Continued)

Real Data				599.21	405.68	297.18
ku	kun	kinv		Turkcell	Vodafone	TT
0.3	0.2	0.008		445.85	211.91	171.36
0.4	0.2	0.008		527.98	246.71	200.78
0.5	0.2	0.008		599.55	277.75	227.57
0.2	0.3	0.008		503.26	229.11	184.35
0.3	0.3	0.008		582.84	266.65	213.85
0.4	0.3	0.008		643.83	306.31	242.82
0.5	0.3	0.008		727.15	336.67	270.24
0.2	0.4	0.008		630.50	286.85	230.59
0.3	0.4	0.008		686.51	316.82	253.00
0.4	0.4	0.008		756.71	353.07	285.47
0.5	0.4	0.008		834.90	383.33	314.88
0.2	0.5	0.008		738.00	342.97	265.66
0.3	0.5	0.008		815.78	375.97	301.36
0.4	0.5	0.008		896.02	400.57	326.49
0.5	0.5	0.008		949.46	436.58	353.94

Table 11 and table 12 shows the effect of different combinations of the calibrated parameter values on operators’ average revenues. Table 13 shows the best combinations of the calibrated parameter values for each operator similar to the basic model. Here the notion of best is the absolute value of the difference between the actual and average generated values for each operator calculated independently. Turkcell’s best combination minimizes the deviations of the operators.

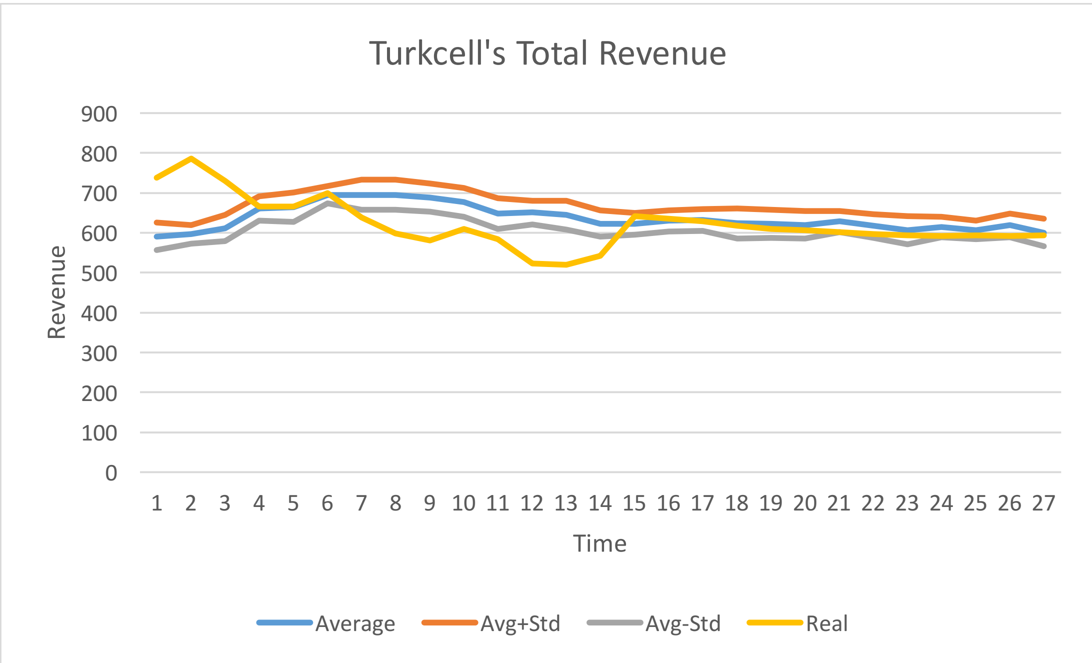
Deviation of other operators corresponding to Turkcell’s best combination of parameter values are calculated by taking the arithmetic average of deviations of the two other operators.

Table 13.Calibrated Best Values of the Parameters for the Full Model

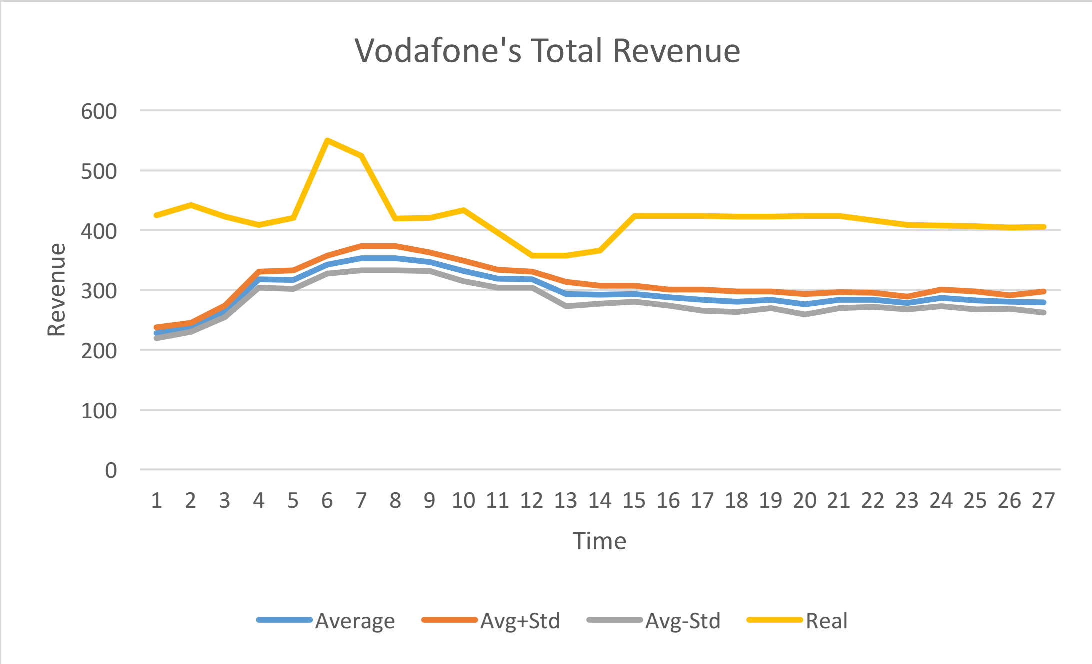
Operator	ku	kun	kinv	Turkcell	Vodafone	TT	Average
Turkcell	0.4	0.3	0.007	2.22	125.32	66.77	64.77
Vodafone	0.5	0.4	0.008	235.69	22.35	17.71	91.92
TT	0.4	0.4	0.008	157.50	52.61	11.71	73.94

5.2.2 Repetition

The model is replicated 25 times with the parameter values shown in table 6 and the best combination of calibrated parameters shown in table 10 again like basic model. Figure 8 shows the actual revenues and revenues generated by the models for each operator. The generated revenue is the average of 25 repetitions for each time period by the models for each operator. Figure 8 shows the average of repeated outputs of the model and their standard deviation at the same time period together with the real data from the BTK like the basic model.



a)



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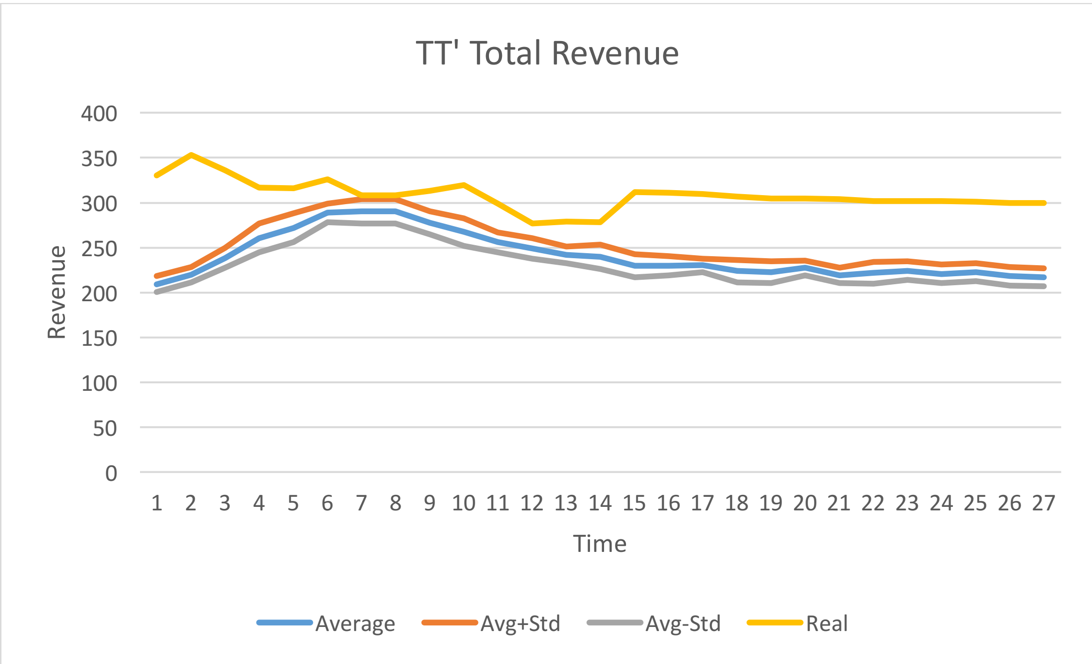
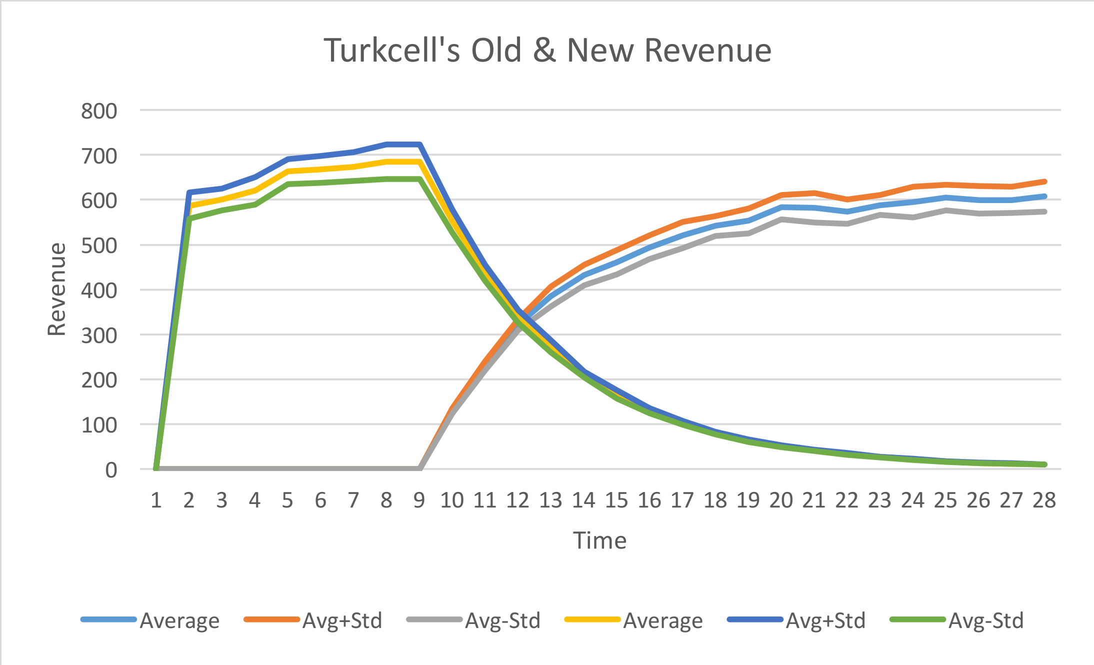


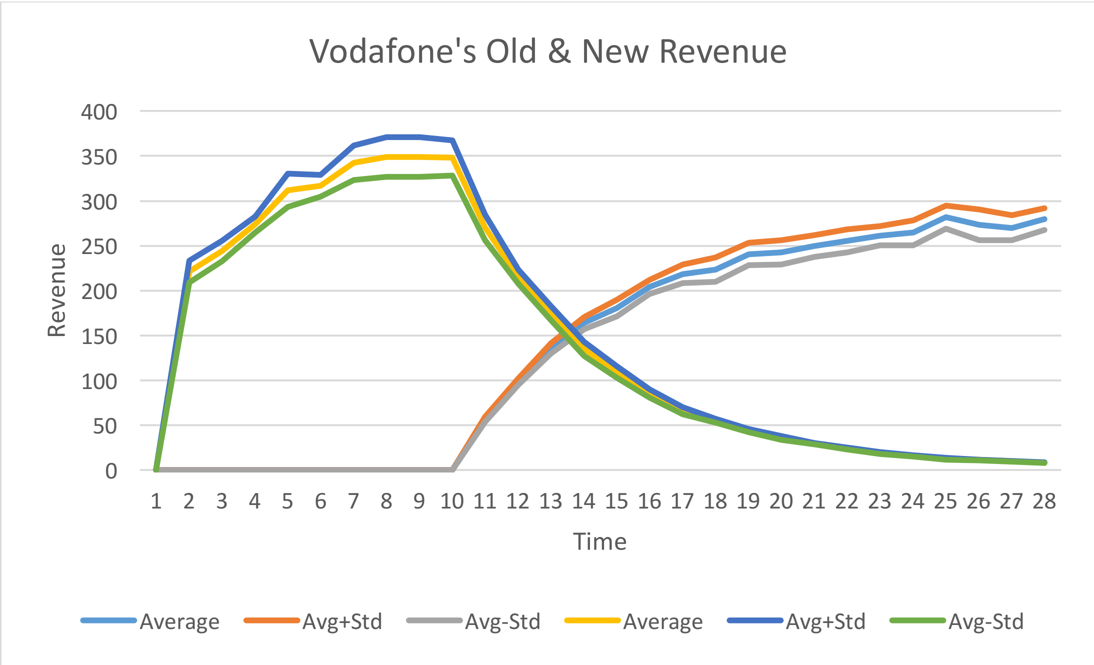
c)

Figure 8.Operators' total revenues

Figure 9 shows the generated revenues from new and old technologies for each operator. Again generated revenues are the average of repetitions for each time period. One standard deviation upper and lower bounds for the old and new technologies are also shown in figure 9. As indicated figure 8 and 9 the actual revenue values after time period 15 (2017 Q3) are forecasted like the basic model.



a)



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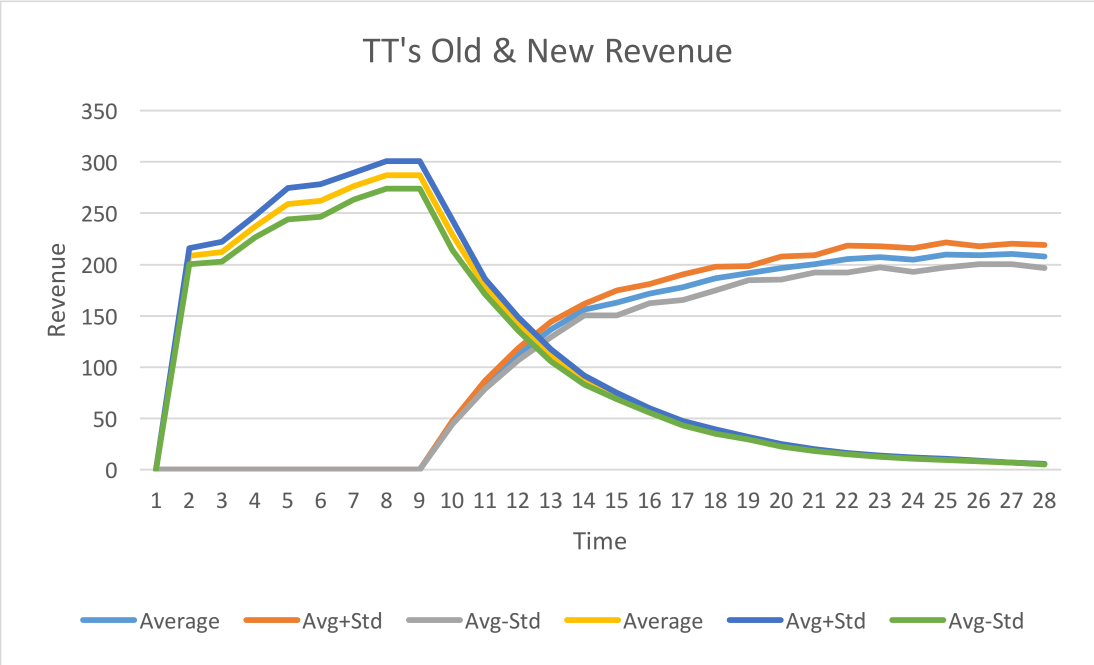


c)

Figure 9.Operators old & new revenues

As seen from figure 8 deviation of Turkcell's generated revenues from the actual ones is the smallest again. For each operator the revenues from the old technology declines when the new technology is in operation. The subscribers adopt less quickly to the new technology in this model. Which is closer to the real life situations The expected revenue from the new technologies is lower than old technology revenues. This is due to high competition in the mobile phone industry.

5.2.3 Local sensitivity analysis

Local sensitivity analysis measures the sensitivity of the interested output variable to the percentage change in a parameter as indicated in equations below.

$$S1 = \frac{\frac{C^+ - C}{C}}{\frac{\Delta P}{P}}$$

$$S2 = \frac{\frac{C - C^-}{C}}{\frac{\Delta P}{P}}$$

$$S = \frac{S1 + S2}{2}$$

Where C=Output for any parameter, $C^{+(-)}$= Positive (Negative) change values of the output corresponding to positive (Negative) percentage change in parameter.

Table 14 shows sensitivity of average revenue and present value for each operator to the corresponding initial value of the initial quality and new technology investment strategy variables.

The model is repeated 10 times for C, C^+, C^-. The sensitivity figures shown in table 14 are the average of these repetitions.

Table 14.Local Sensitivity Analysis Results of Revenues and Present Values for Operator Specific Parameters

Parameter	P-ΔP	P	P+ΔP	Revenue	Present Value
$q_{old_{1,0}}$	16.15	17	17.85	0.182	-0.004
$q_{old_{2,0}}$	5.7	6	6.3	0.035	-0.104
$q_{old_{3,0}}$	8.55	9	9.45	0.241	-0.083
k_1	0.665	0.7	0.74	0.019	0.076
k_2	0.665	0.7	0.74	-0.293	1.150
k_3	0.665	0.7	0.74	0.007	1.362

Table 15.Local Sensitivity Analysis Results of Revenues and Present Values for General Parameters

Parameter	P-ΔP	P	P+ΔP	Revenue	Present Value
$kinv$	0.0665	0.07	0.0735	0.136	-0.012
ki	0.9025	0.95	0.9975	3.375	0.228
kun	0.285	0.3	0.315	0.566	-0.085
ku	0.38	0.4	0.42	0.424	-0.011
$kqual$	-0.0095	-0.01	-0.0105	0.024	-0.031
shf	23.75	25	26.25	-0.037	0.113

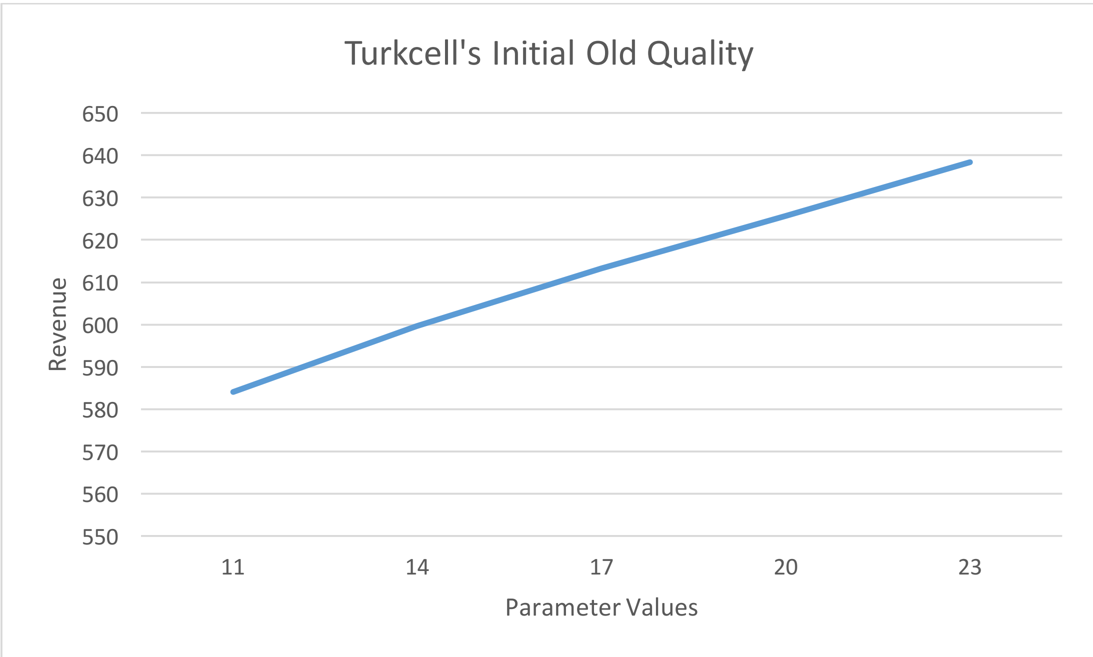
As seen in table 15 the most sensitive parameter is *ki*. Revenue of Turkcell is dramatically effected from the change of the quality of both old and new technologies, but the present value is not so sensitive as the revenue. The present value and revenue of operators are sensitive to their investment decisions. As the operator invest more to the new technology it's present value increases for all the operators. Whereas for Vodafone increasing the investment to the new technology makes a little reduction in average revenue.

5.2.4 Global sensitivity analysis

After local sensitivity analysis, global sensitivity analysis is performed on the full model by chancing the following parameter values: Operator i's initial old technology quality, decay factor of the quality, operator i's investment strategy, gender multiplier for male and female. In these sensitivity analysis, parameter ranges are much larger than that of local sensitivity analysis. For each value of the parameters, models are run 25 times and average value of the outputs are compared with each other. The parameter values for global sensitivity analysis are shown in table 16.

Table 16.Global Sensitivity Analysis Results

Parameter	P-2Δp	P-Δp	P	P+Δp	P+2Δp
$q_{old\,1,0}$	11	14	17	20	23
$q_{old\,2,0}$	4	5	6	7	8
$q_{old\,3,0}$	5	7	9	11	13
k_1	0.4	0.55	0.7	0.85	1
k_2	0.4	0.55	0.7	0.85	1
k_3	0.4	0.55	0.7	0.85	1
ki	0.85	0.9	0.95	0.97	1
$ksex$_male	0.46	0.61	0.76	0.91	1
$ksex\_female$	0.41	0.56	0.71	0.86	1



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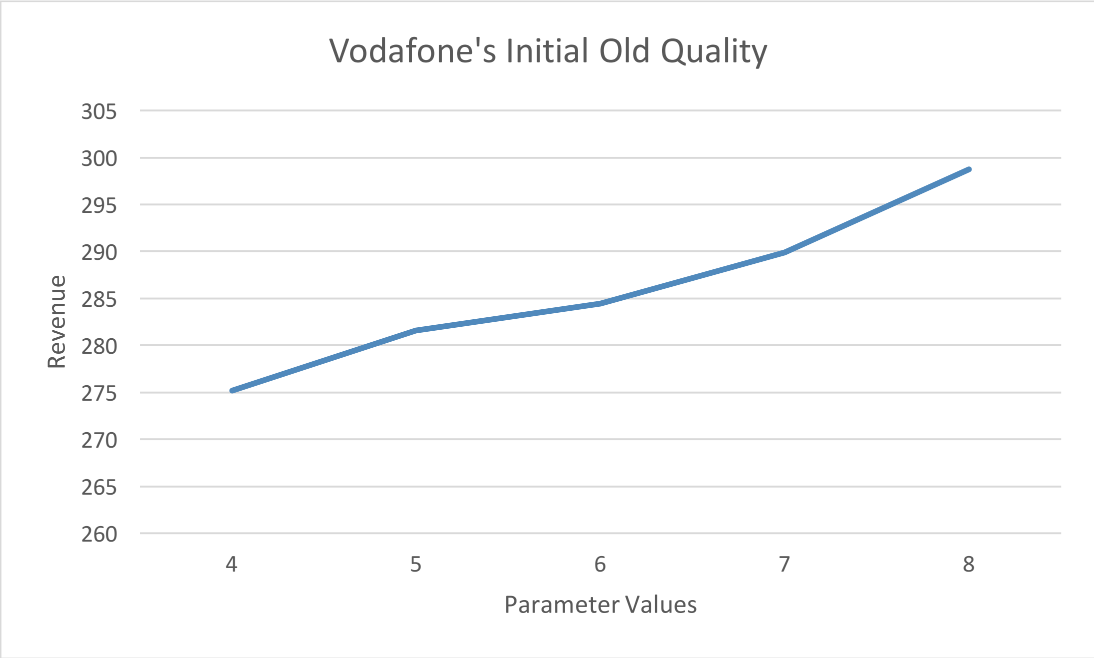

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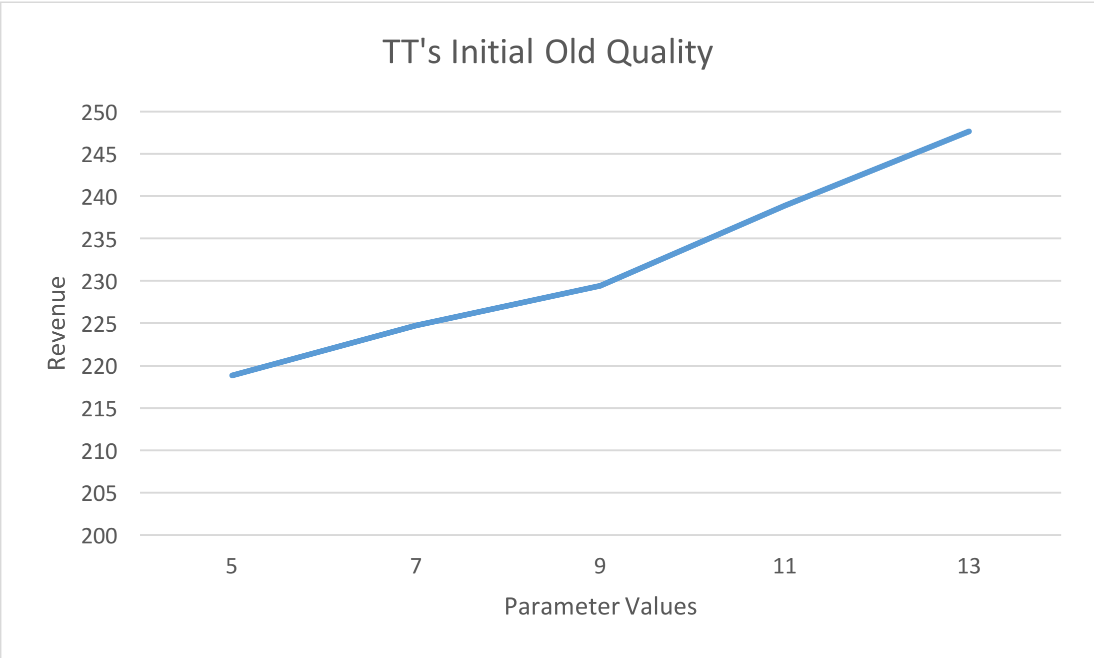
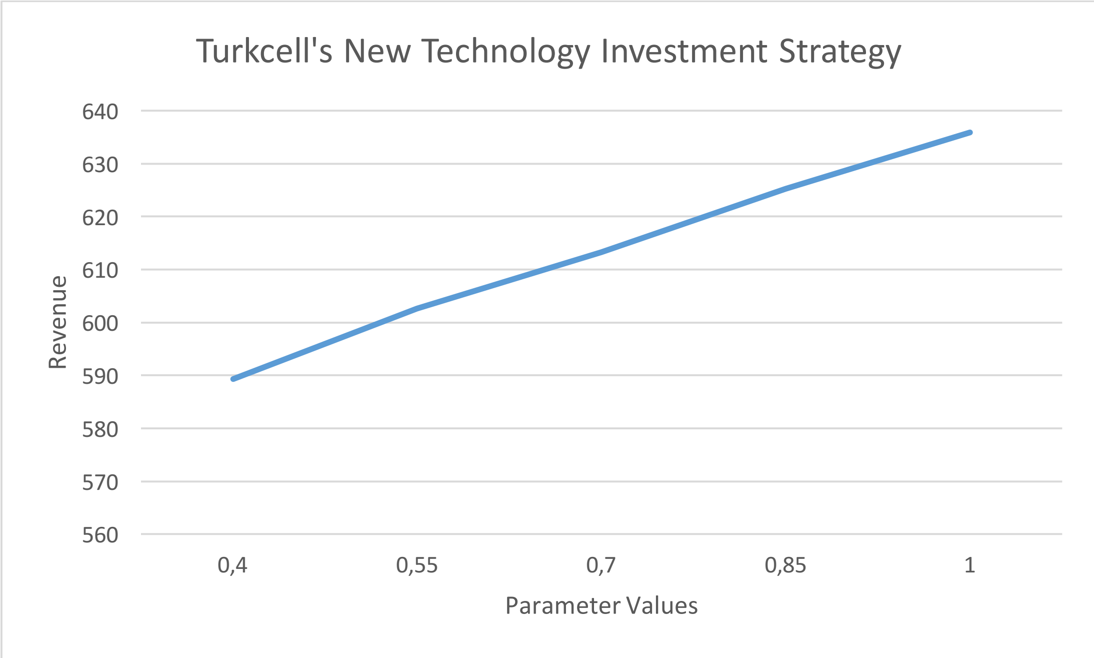


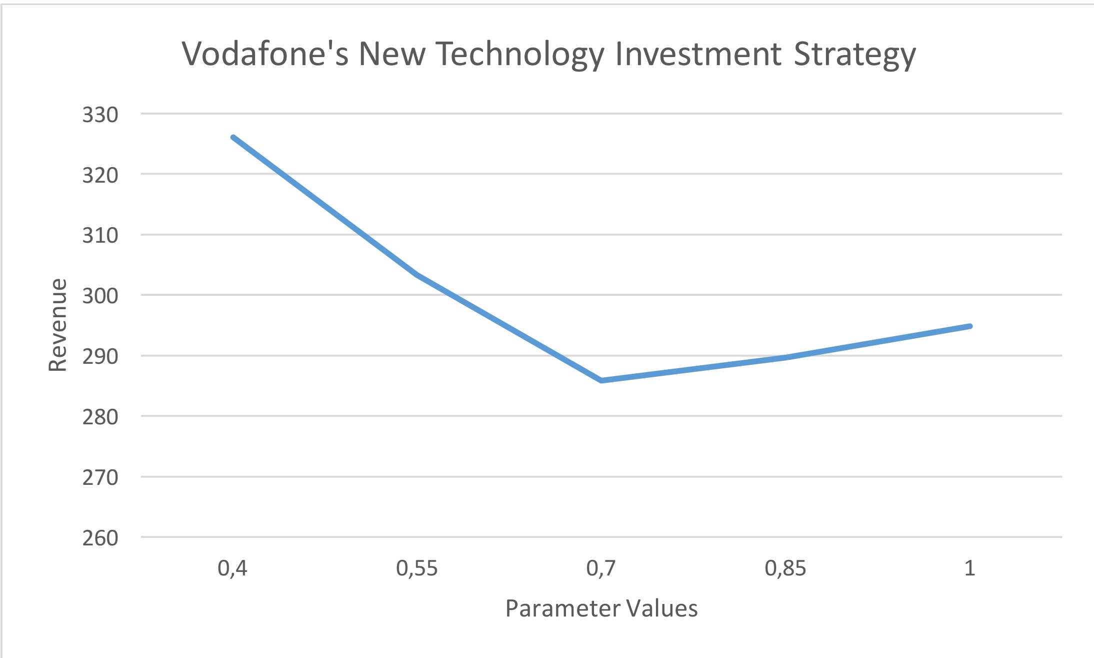
c)

Figure 10.Global sensitivity analysis for old quality parameter

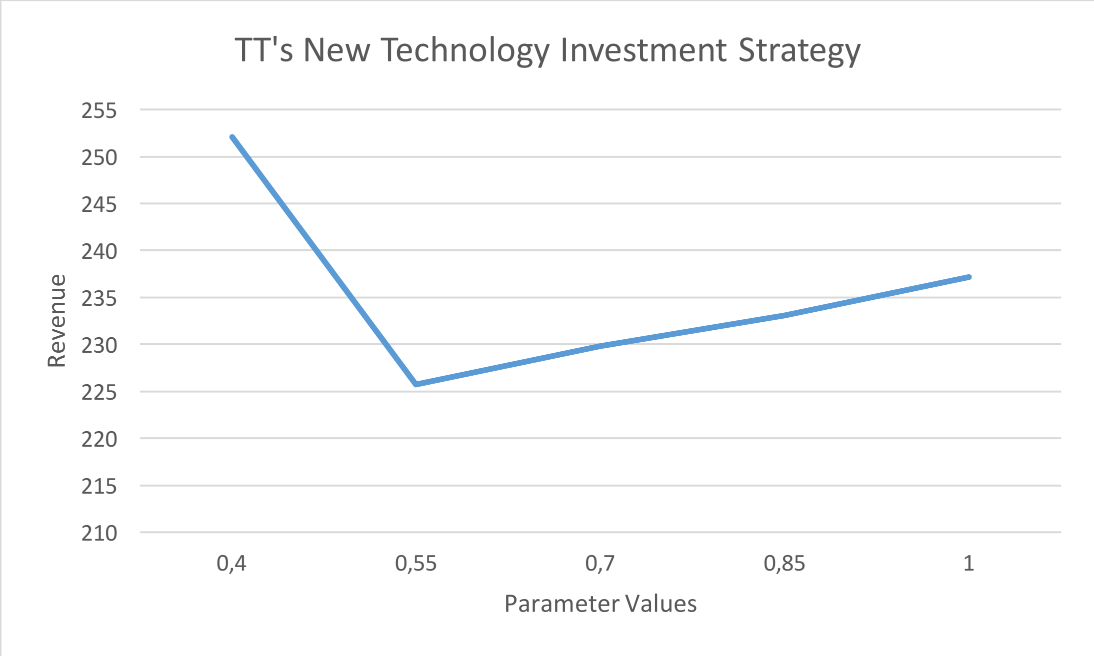
In figure 10 global sensitivity of average revenue to initial value of the old technology qualities are shown for each operator. As the initial value of the old technology quality increases operator revenue increases for all the three operators.


Turkcell's New Technology Investment Strategy
640
630
620
610
600
590
580
570
560
Revenue
0,4
0,55
0,7
0,85
1
Parameter Values

a)


Vodafone's New Technology Investment Strategy
330
320
310
300
290
280
270
260
Revenue
0,4
0,55
0,7
0,85
1
Parameter Values

b)



c)

Figure 11.Global sensitivity analysis for investment strategy parameter

In figure 11 it can be seen that investment ratio of the new technology directly effects operator's revenue. As the percentage of the investments made to new technology increases average revenue of Turkcell increases. For Vodafone and Turk Telekom investing on the old technology increases their average revenues. Based on this global sensitivity analysis, it can be suggested that Turkcell should increase its investments to the new technology whereas Vodafone and TT should invest more on old technology.

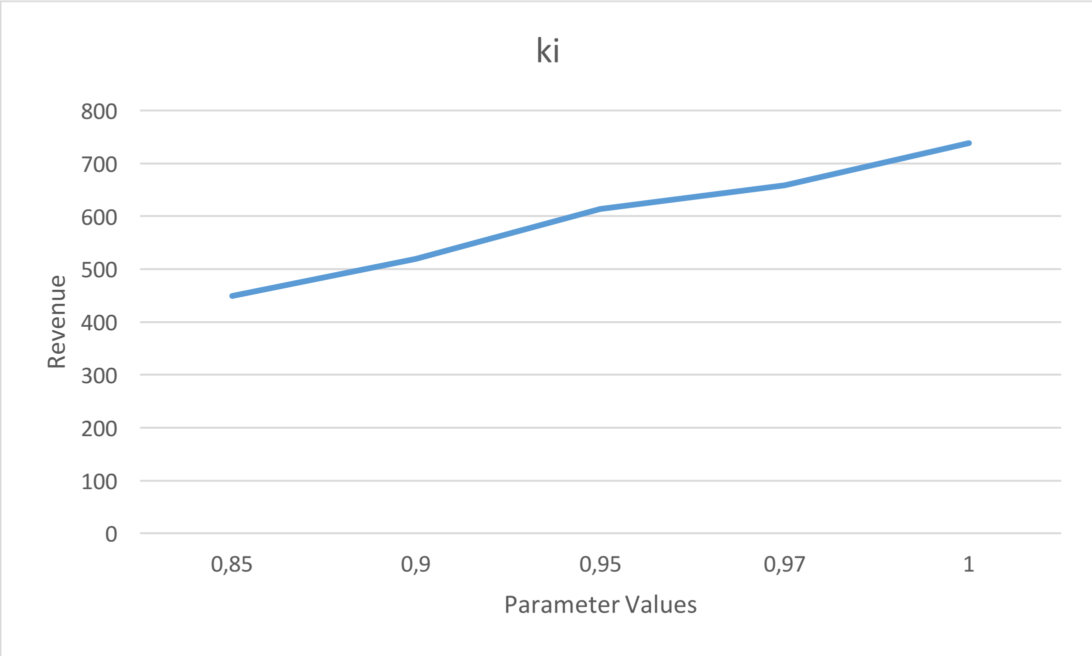
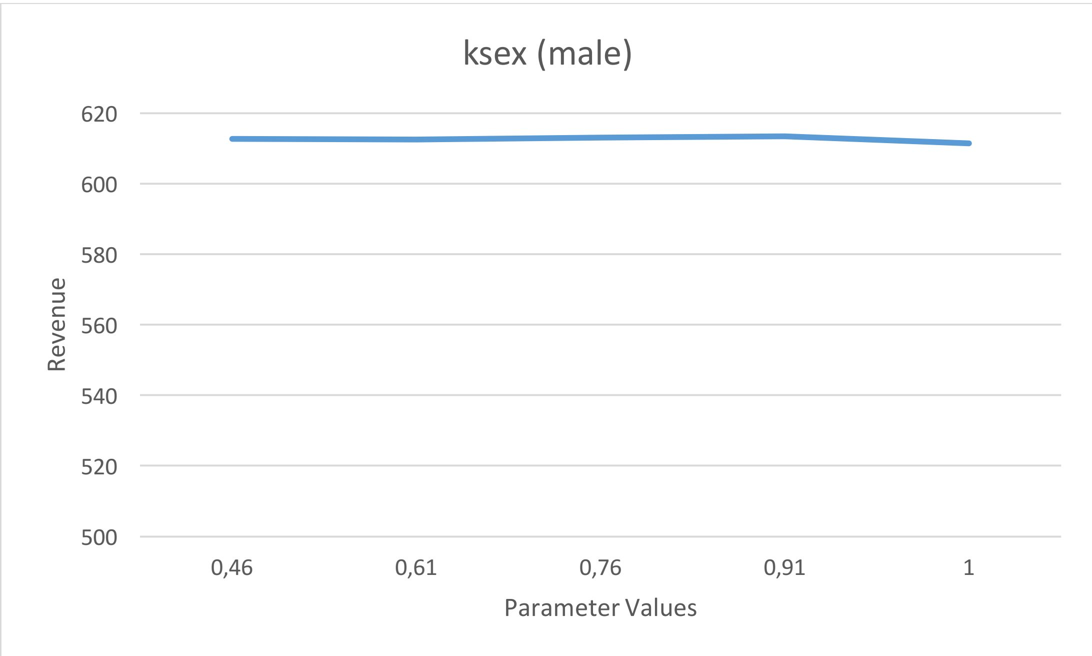
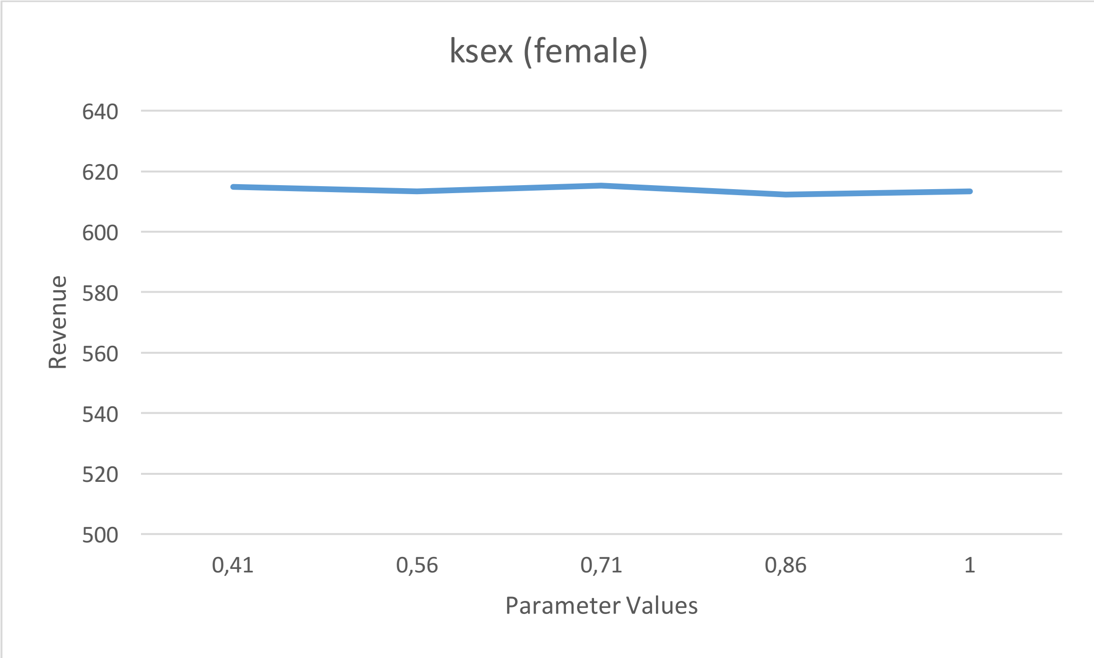


Figure 12.Global sensitivity analysis for ki parameter

Figure 12 indicates that, as the technology decay parameter increases Turkcell's revenue increases. This is expected because the higher decay factor means the technology will not lose its quality in the coming period.



a)

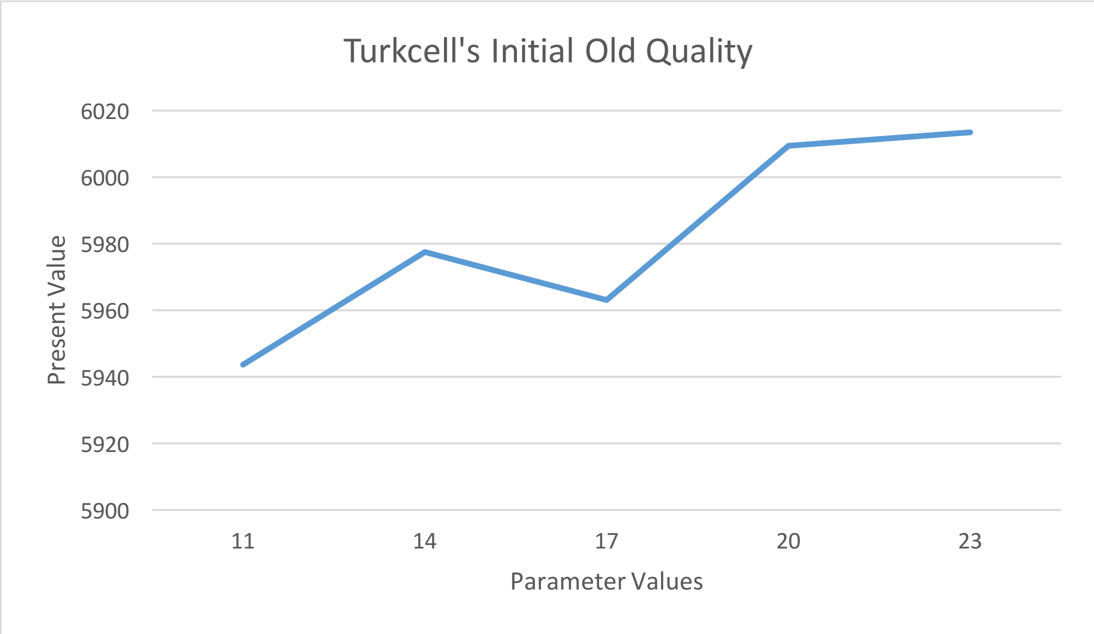


b)

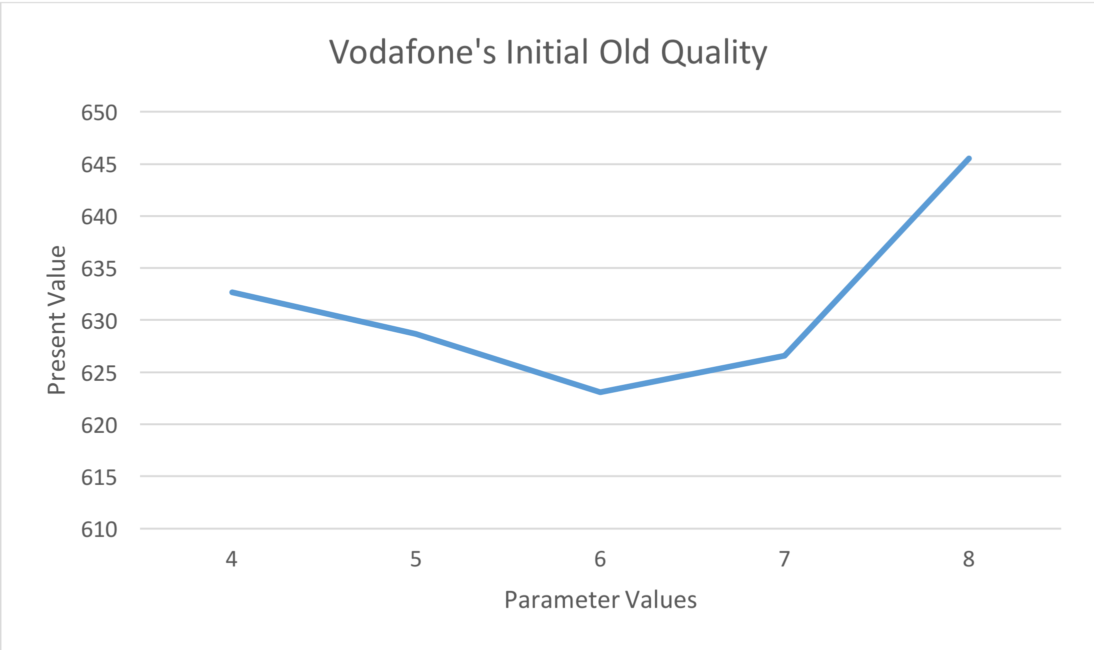
Figure 13.Global sensitivity analysis for gender parameter

Figure 13 shows that Turkcell's average revenue is not sensitive to the adoption rates of males and females.

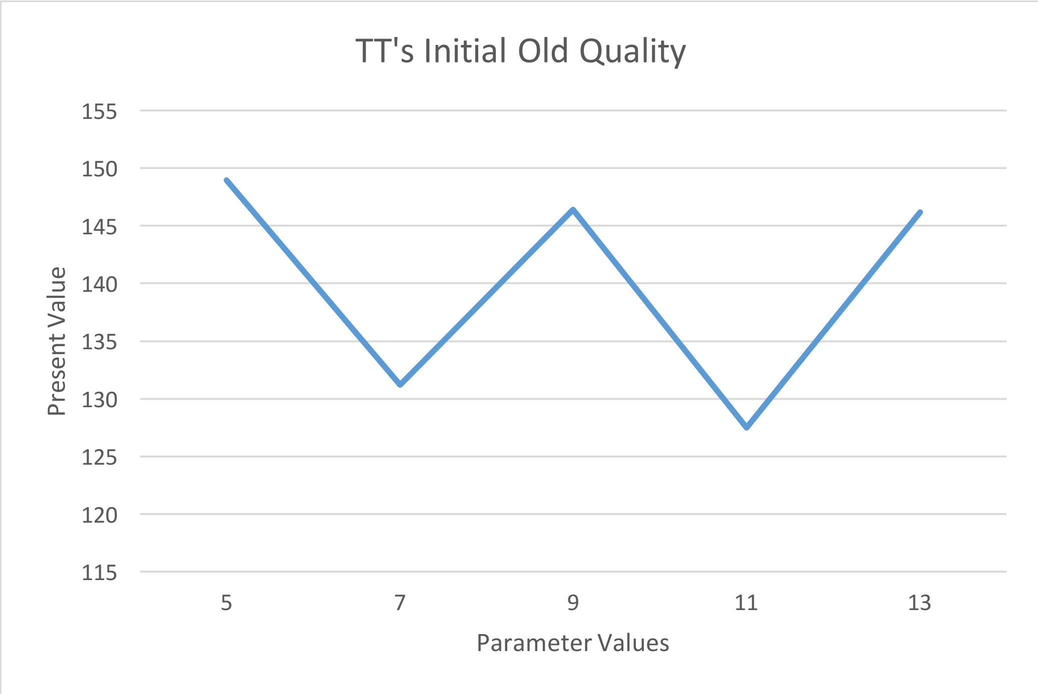
Global sensitivity of present values of operators to these parameters are shown in figure 14-18.


Turkcell's Initial Old Quality
6020
6000
5980
5960
5940
5920
5900
Present Value
11
14
17
20
23
Parameter Values

a)


Vodafone's Initial Old Quality
650
645
640
635
630
625
620
615
610
Present Value
4
5
6
7
8
Parameter Values

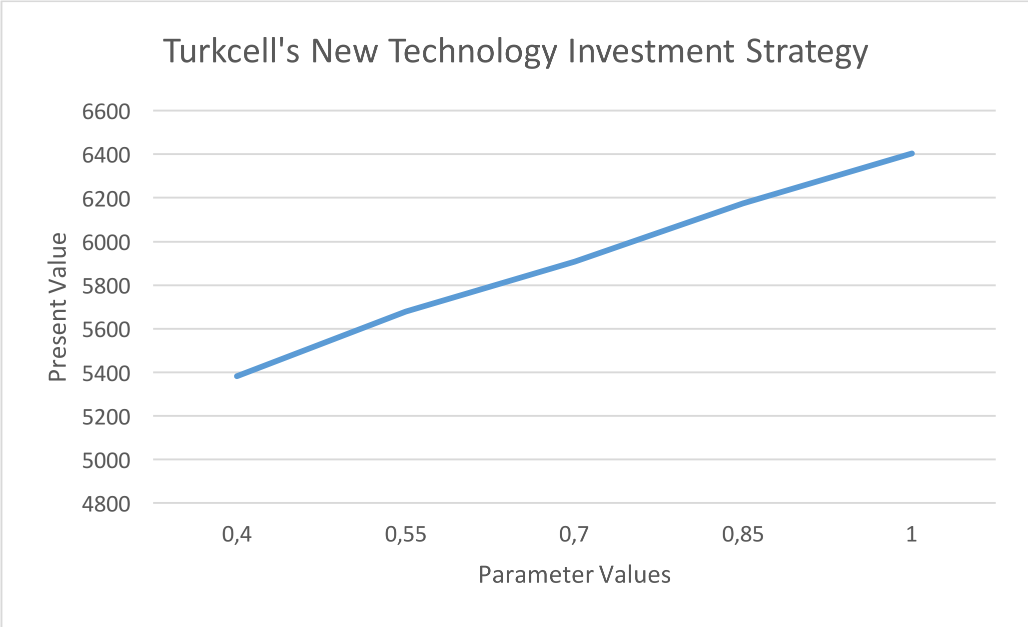
b)



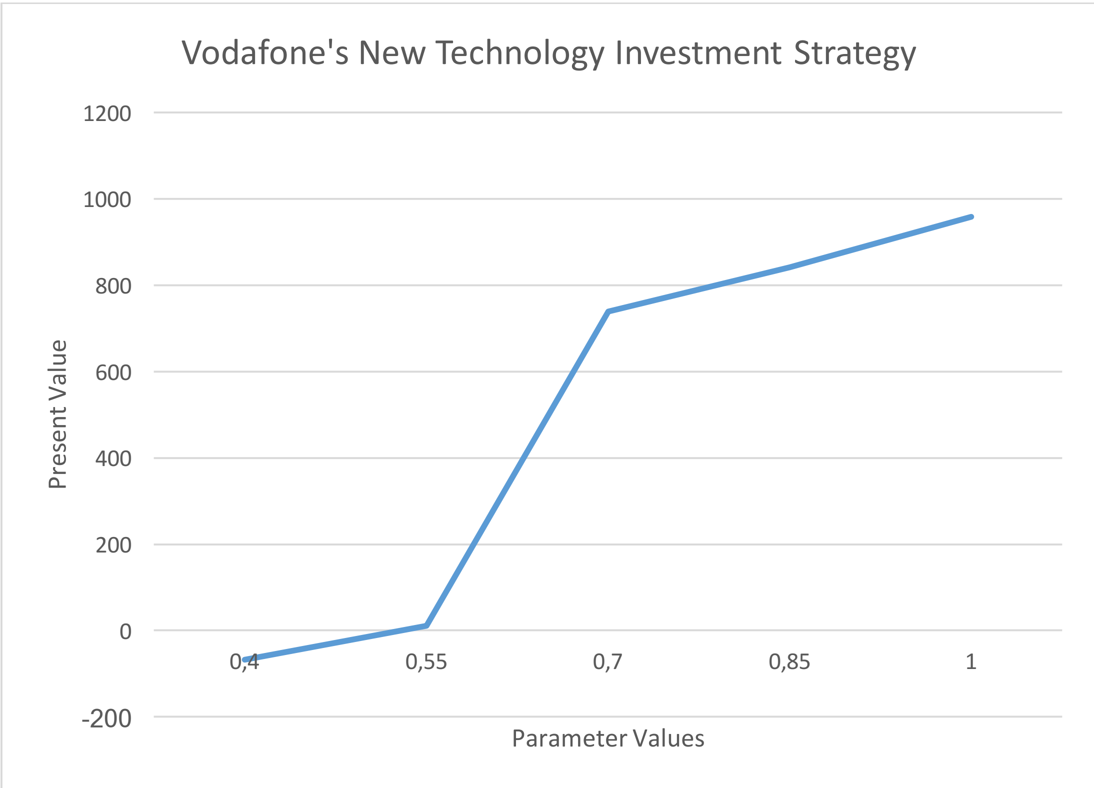
c)

Figure 14.Global sensitivity analysis for old quality parameter

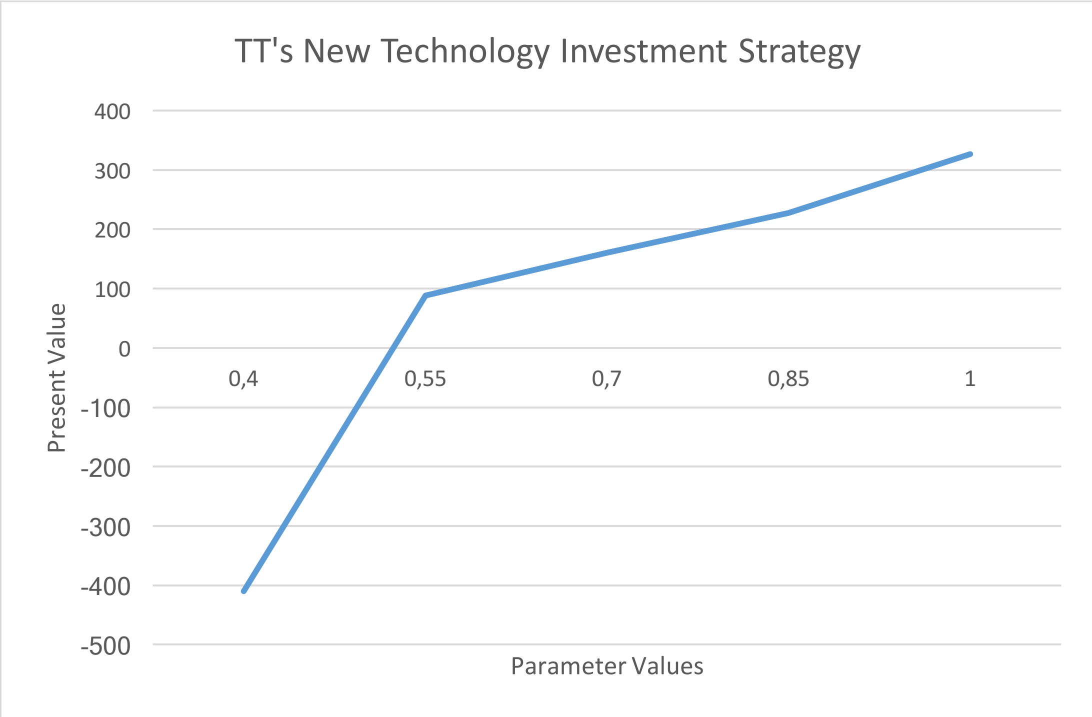
In figure 15 global sensitivity of present value to initial value of the old technology qualities are shown for each operator. As the initial value of the old technology quality increases operator present values increase for all the three operators.


Turkcell's New Technology Investment Strategy
6600
6400
6200
6000
5800
5600
5400
5200
5000
4800
Present Value
0,4
0,55
0,7
0,85
1
Parameter Values

a)


Vodafone's New Technology Investment Strategy
1200
1000
800
600
400
200
0
-200
Present Value
0,4
0,55
0,7
0,85
1
Parameter Values

b)



c)

Figure 15.Global sensitivity analysis for investment strategy parameter

In figure 16 it can be seen that investment ratio of the new technology directly effects to operator's present value. As the percentage of the investments made to new technology increases present value of the operators' increases. Based on this global sensitivity analysis of present value, it can be suggested that all operators should increase their investments to the new technology.

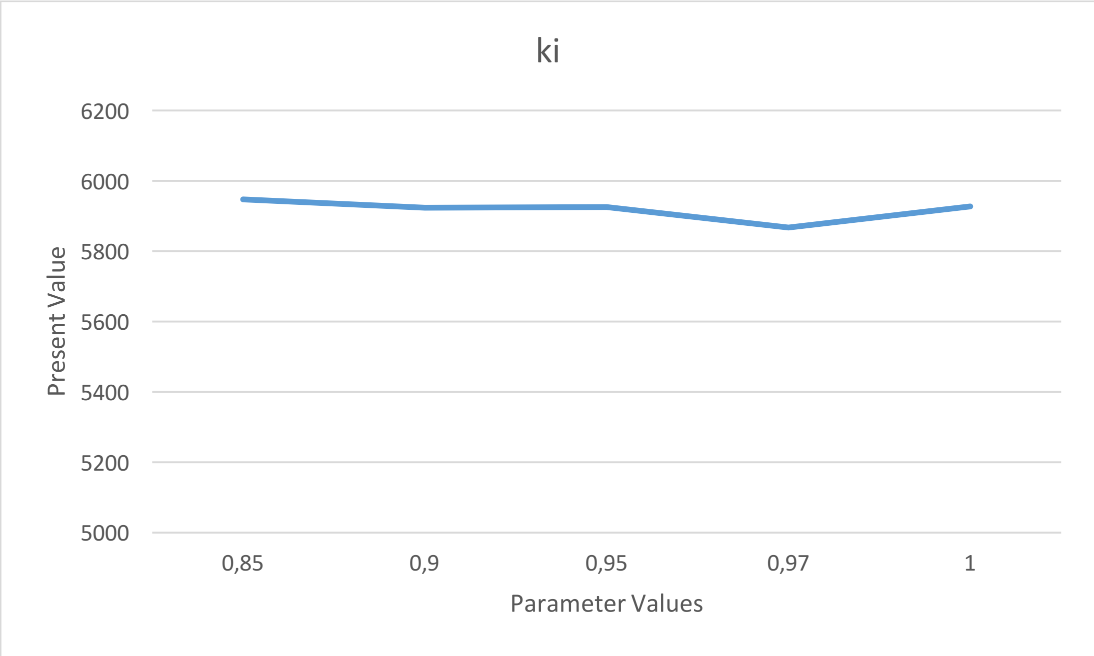
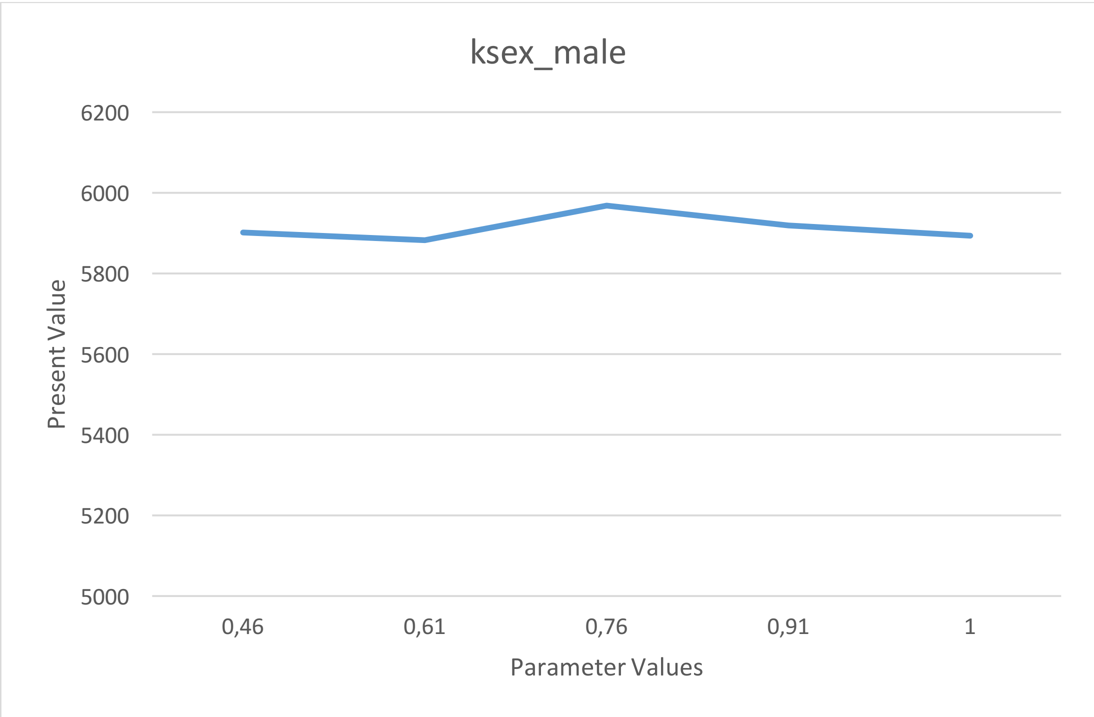
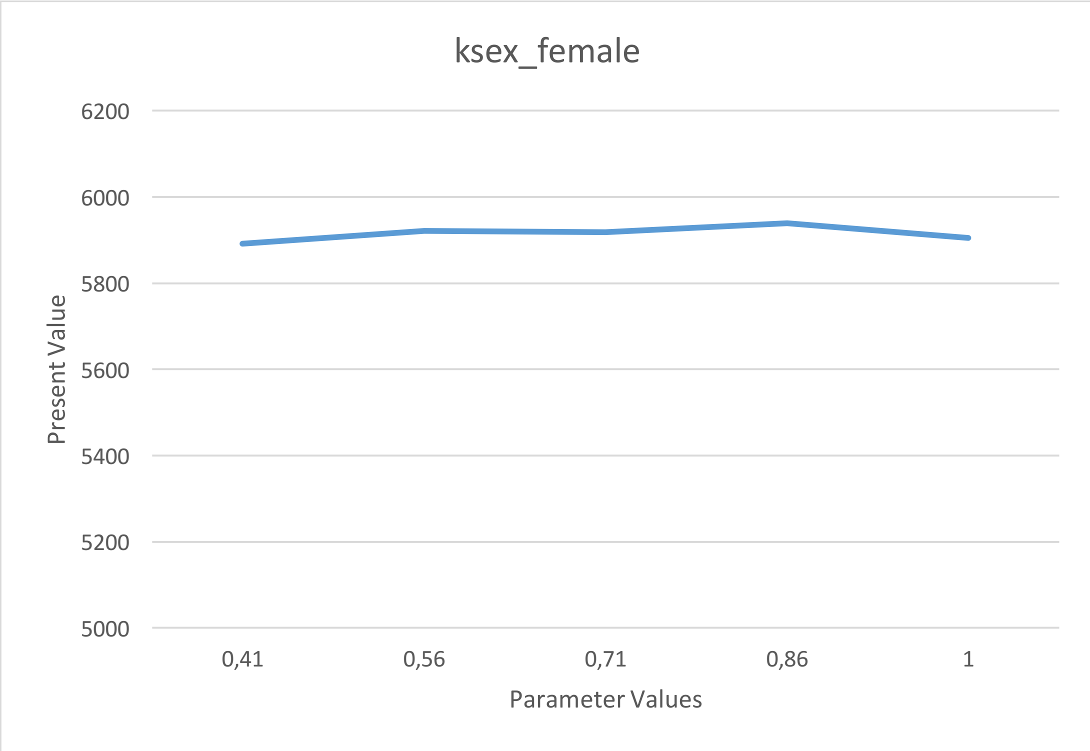


Figure 16.Global sensitivity analysis for ki parameter

Figure 16 shows that present value of Turkcell is not so sensitive to the decay parameter.



a)



b)

Figure 17.Global sensitivity analysis for gender parameter

Figure 17 shows that Turkcell's present value is not sensitive to the adoption rates of males and females.

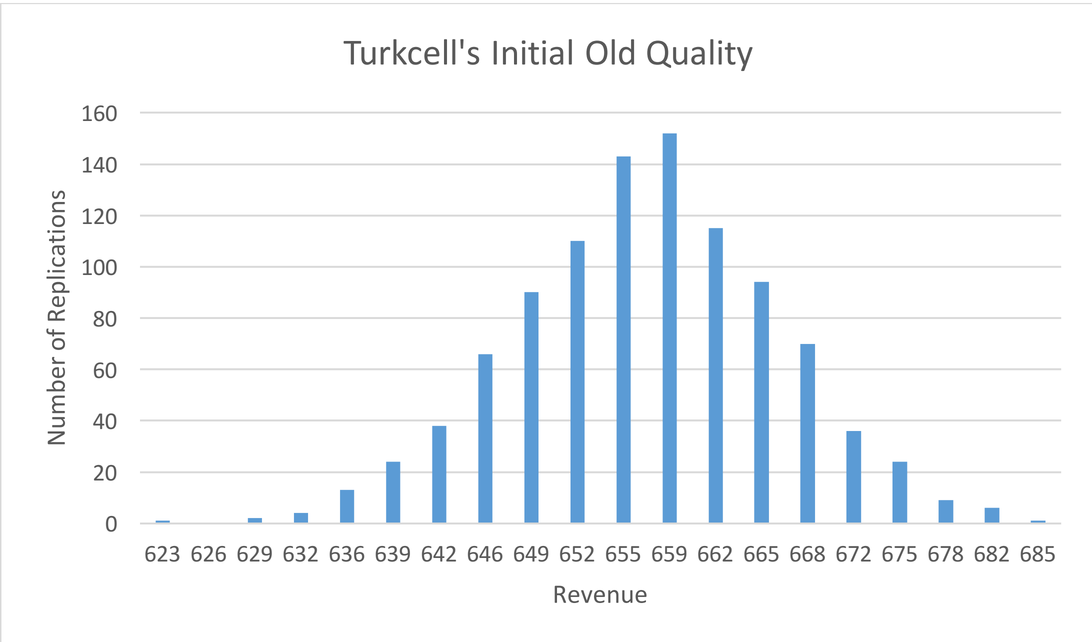
5.2.5 Uncertainty analysis

After sensitivity analysis, uncertainty analysis are performed. The objective of uncertainty analysis is to understand how the uncertainty in parameter values and the model's sensitivity to parameters interact to cause uncertainty in model results. Grimm, (2012)

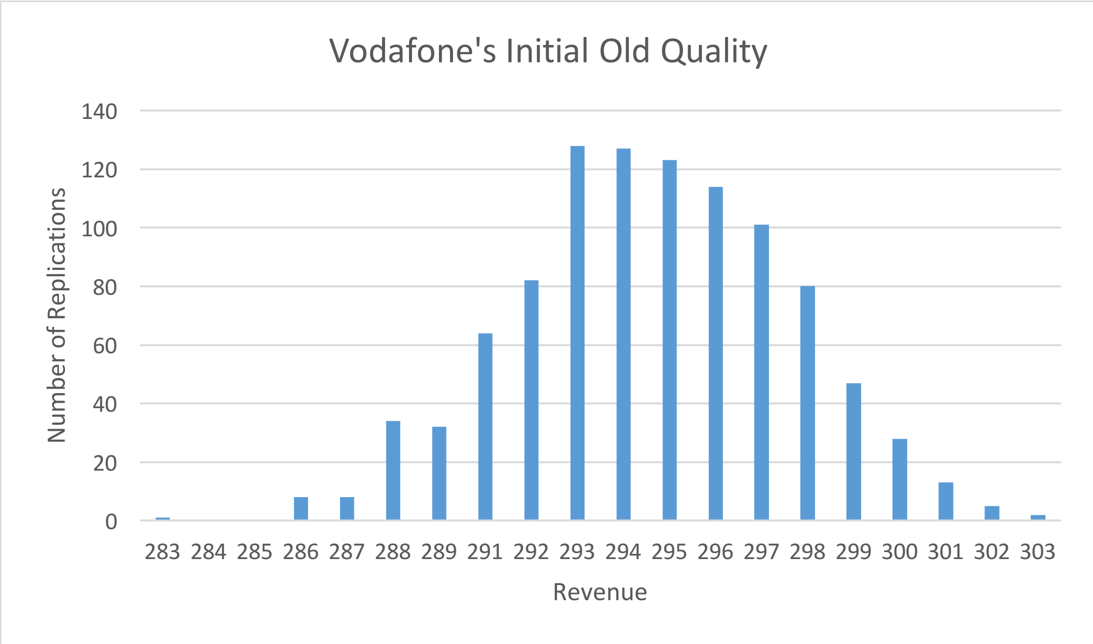
In uncertainty analysis the parameter values are generated from a normal distribution whose mean and standard deviation are shown in table 17. For each parameter 1000 different values are generated. The distribution of the output variable (average revenue) is calculated for each generated value of the parameters. Again $q_{old_{i,0}}$ (i:1,2,3) output is the corresponding operators average revenue for others (ki, ksex_male, ksex_female) output is the average revenue of Turkcell.

Table 17.Uncertainty Analysis

Parameter	Mean	Standard Deviation
$q_{old_{1,0}}$	17	2
$q_{old_{2,0}}$	6	0.6
$q_{old_{3,0}}$	9	0.9
ki	0.95	0.02
$ksex\_male$	0.76	0.08
$ksex\_female$	0.71	0.07



a)



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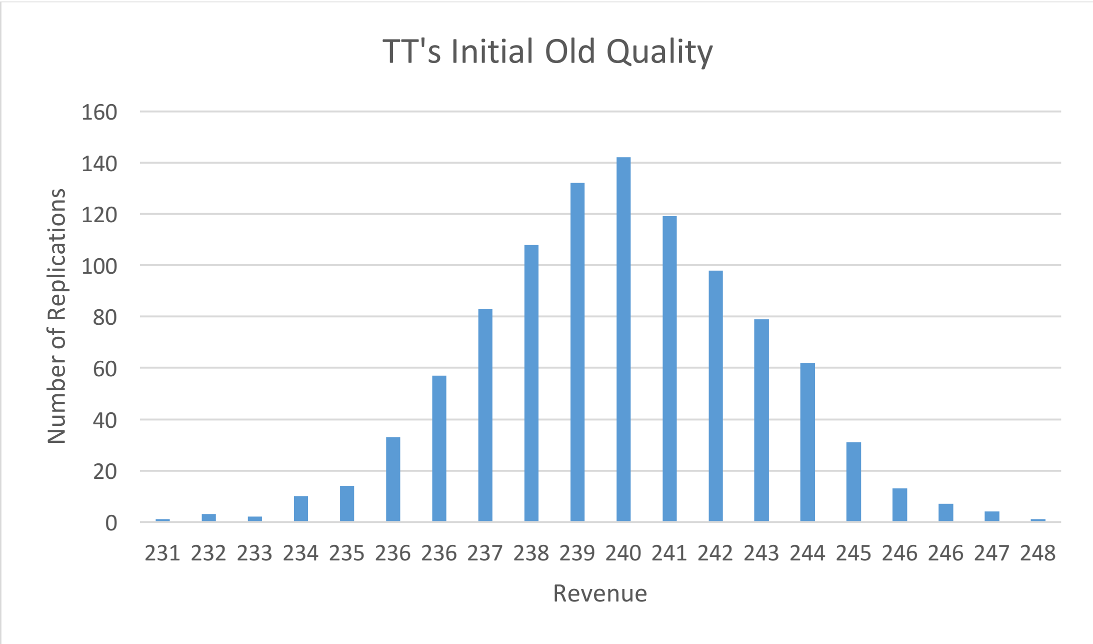

c)

Figure 18.Operators’ revenue distribution for the random variation of old quality parameter

In figure 18 distribution of average revenues for each operator are shown. In figure 19, 20 and 21 distribution of Turkcell's Revenue for the uncertainty of *ki*, *ksex_male* and *ksex_female.*

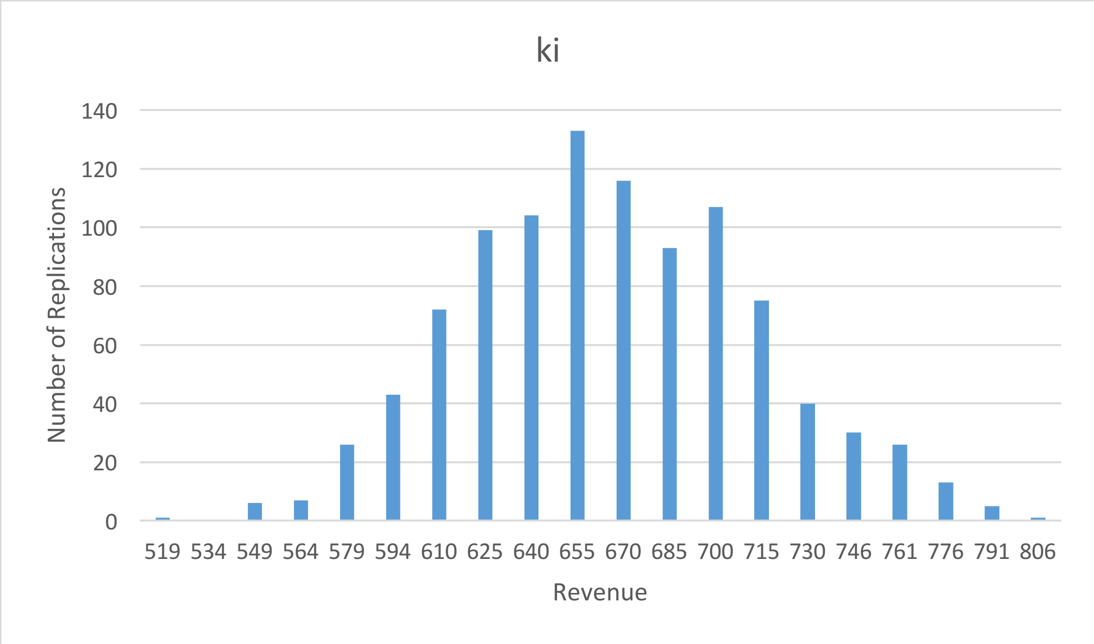

Figure 19.Operators' revenue distribution for the random variation of ki parameter

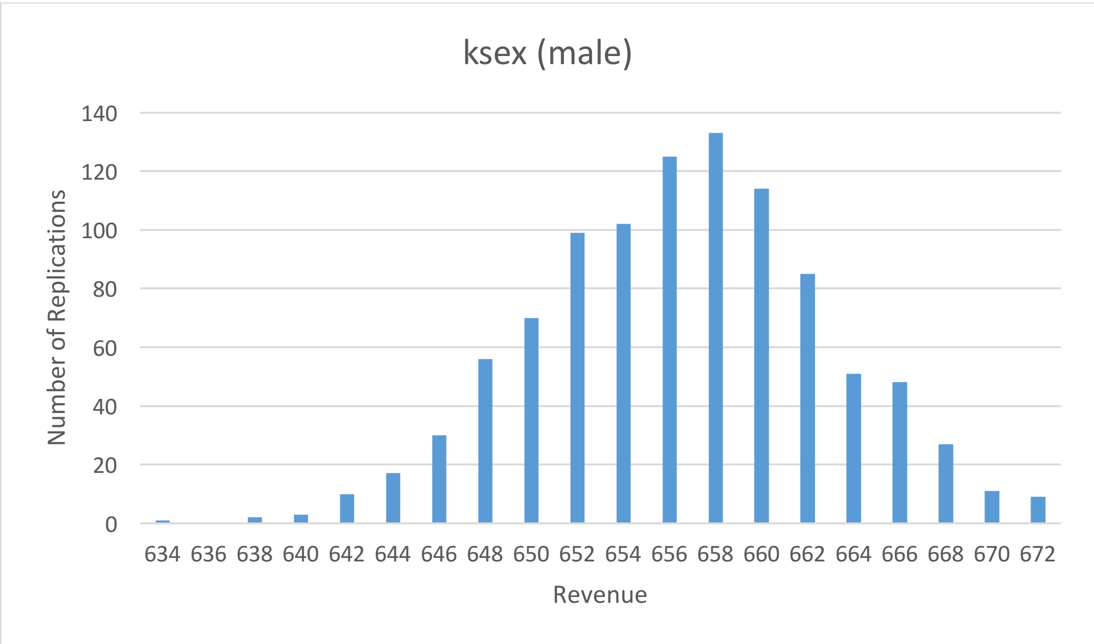

Figure 20.Operators' revenue distribution for the random variation of ksex(male) parameter

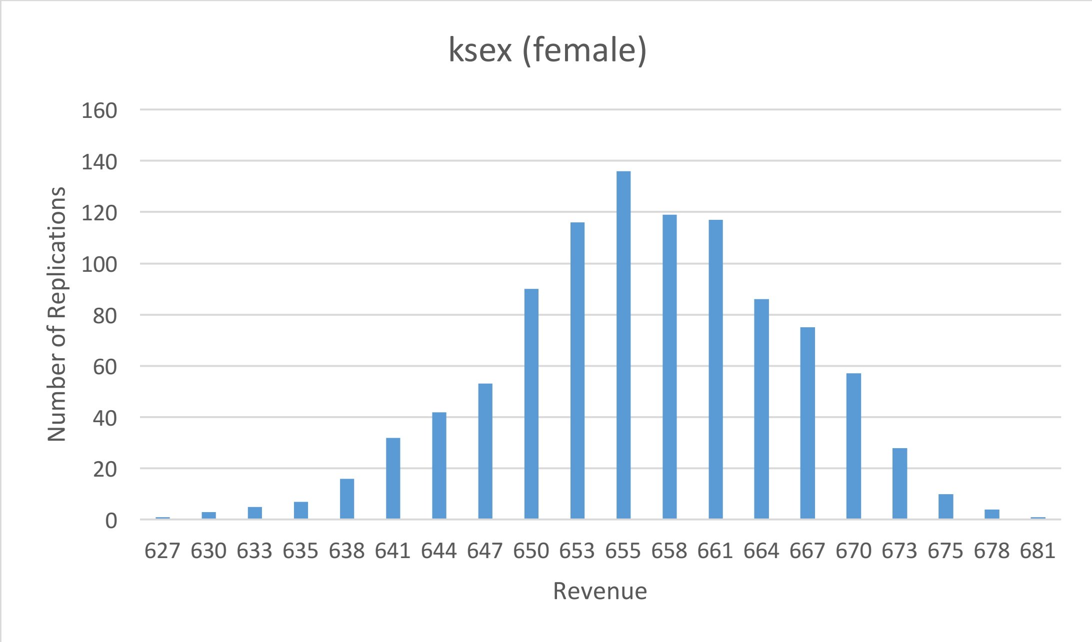

Figure 21.Operators' revenue distribution for the random variation of ksex(female) parameter

Jarqua-bera normality test are applied for the outputs of uncertainty analysis. The test statistics are shown in table 18.

Table 18.Uncertainty Analysis

Parameter	Output	JB Statistics
$q_{old_{1,0}}$	Turkcell_revenue	0.9
$q_{old_{2,0}}$	Vodafone_revenue	0.21
$q_{old_{3,0}}$	TT_revenue	0.16
ki	Turkcell_revenue	9.19
$ksex\_male$	Turkcell_revenue	0.27
$ksex\_female$	Turkcell_revenue	4.17

When the uncertainty in $q_{old_{1,0}}$, $q_{old_{2,0,}} q_{old_{3,0}}$, $ksex\_male$ and $ksex\_female$ parameters are normally distributed. There corresponding outputs are found to be normally distributed at significance level of 5%. When uncertainty in the decay factor of quality is normally distributed. Turkcell's average revenue is found to be not normally distributed at a significance level of 5%. The critical value of the jarqua-bera test significance level of 5% is 5,99.

CHAPTER 6

CONCLUSION

This study investigates the effects of investment strategies of mobile operators to new and old technologies on the average revenue and present value of profits. Agent-based modeling and simulation methodology is being used as it is appropriate to model the behavior of agents in changing technology by their using habits and the outputs of these habits to the operator's revenues.

Main finding of this study can be summarized as follows: For each operator the revenues from the old technology declines when the new technology is in operation. The expected revenue from the new technologies is lower than old technology revenues. This is due to high competition in the mobile phone industry. Percentage of investment made to the new technology directly effects to operator's present value. As the percentage of the investments made to new technology increases present value of the operators' increases. Based on this finding, it can be suggested that all operators should increase their investments to the new technology.

This study can be extended in a few directions as a future work. One direction is to add additional characteristics of the subscribers such as education level, living area, operator service rate and mobile phone use type effecting the usage behavior. Another direction to include positional information about the subscribers using geographical information systems. These additions are expected to increase the accuracy of the model. The adaption parameters of the subscribers can be obtained empirically from conjoint analysis. In case investment strategy of one of these operators' effects adaption behavior of subscribers of other operators there is some interdependence between operators' strategies. In such cases the agent based model can be formulated as a game theoretic simulation model.

All the codes which written in this thesis can be found on appendix.

REFERENCES

Baerenklau, K., & Knapp, K. (2007). Dynamics of Agricultural Technology Adoption: Age Structure, Reversibility, and Uncertainty. *American Journal of Agricultural Economics, 89*(1), 190-201.

Bass, F. (1969). A New Product Growth for Model Consumer Durables. *Management Science, 15*(5), 215-227.

Brown, D., Page, S. E., Riolo, R. & Rand, W. (2004). Agent-based and analytical modeling to evaluate the effectiveness of greenbelts. *Environmental Modelling & Software,* 19, 1097-1109.

Casti, J. L. (1996), Seeing the light at El Farol: *A look at the most important problem in complex systems theory*. Complexity, 1: 7-10. doi:10.1002/cplx.6130010503

Davis, F. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly,13*(3), 319-340. doi:10.2307/249008

Duffy, J. 2006. Agent-based models and human subject experiments. In: *Handbook of Computational Economics,* vol. 2: *Agent-Based Computational Economics* (ed. L. Tesfatsion & K. Judd). Elsevier, Amsterdam, pp. 949-1011.

Forrester, J. W. (1968). *Principles of Systems*. Norwalk, CT: Productivity Press.

N. S. A. Karim, R. A. Alias, S. A. Mokhtar and N. Z. A. Rahim, "Mobile Phone Adoption and Appropriation in Malaysia and the Contribution of Age and Gender," *2009 International Conference on Information and Multimedia Technology*, Jeju Island, 2009, pp. 485-490. doi: 10.1109/ICIMT.2009.87

Lai PC. (2017) The literature review of technology adoption models and theories for the novelty technology. *Journal of Information Systems and Technology Management* Vol. 14, No. 1, Jan/Apr., 2017 pp. 21-38

LeBaron, B. 2001. Empirical regularities from interacting long-and short-memory investors in an agent-based stock market. *IEEE Transactions on Evolutionary Computation*, 442-55.

Lotka, A. (1926). Elements of physical biology. *Science Progress in the Twentieth Century (1919-1933), 21*(82), 341-343.

Miranda L., & Lima C. (2013). Technology substitution and innovation adoption: The cases of imaging and mobile communication markets. *Technological Forecasting & Social Change* 80 (2013) 1179–1193

Morris M., & Venkatesh V. (2000). Age differences in technology adoption decisions: implications for a changing work force. *Personnel Psychology*.

Opper, M., & Saad, D. (Eds.). (2001). *Advanced Mean Field Methods: Theory and Practice—Neural Information Processing*. Cambridge, MA: MIT Press.

Parker, D., Manson, S., Janssen, M., Hoffmann, M., & Deadman, P. (2003). Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review. *Annals of the Association of American Geographers, 93*(2), 314-337.

Parunak, H. V. D., Savit, R., & Riolo, R. (1998). Agent-based modeling vs. equation-based modeling: A case study and users' guide. Workshop on Multi-Agent Systems and Agent-Based Simulation (MABS '98). Springer.

Rogers, Everet M. (1995), *A Diffusion of Innovations,* The Free Press, 79-81

Venkatesh, V., & Davis, F. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science, 46*(2), 186-204.

Venkatesh, V. (2000). Determinants of Perceived Ease of Use: Integrating Control, Intrinsic Motivation, and Emotion into the Technology Acceptance Model. *Information Systems Research,11*(4), 342-365.

Venkatesh, V., Morris, M., Davis, G., & Davis, F. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly, 27*(3), 425-478. doi:10.2307/30036540

Venkatesh, V.; Bala, H. (2008), Technology Acceptance Model 3 and a Research Agenda on Interventions, *Decision Sciences*, 39 (2): 273–315, doi:10.1111/j.1540-5915.2008.00192.x

Volterra, V. (1926). Fluctuations in the abundance of a species considered mathematically. *Nature*, 188, 558–560.

Wilensky, U., & Resnick, M. (1999). Thinking in Levels: A Dynamic Systems Approach to Making Sense of the World. *Journal of Science Education and Technology, 8*(1), 3-19.

Wilensky, U., & Reisman, K. (2006). Thinking like a Wolf, a Sheep, or a Firefly: Learning Biology through Constructing and Testing Computational

Theories-An Embodied Modeling Approach. *Cognition and Instruction, 24*(2), 171-209.

Wilkerson-Jerde, M., & Wilensky, U. (in press). From probabilistic birth to exponential population: Making sense of the calculus of complex systems. *Journal of the Learning Sciences*.

Wilson, W. (1998). Resolving Discrepancies between Deterministic Population Models and Individual-Based Simulations. *The American Naturalist, 151*(2), 116-134. doi:10.1086/286106

Ying Su. (2010a). Culture and Technology Adoption (CTA) Framework: *Analyzing Mobile Phone Users in China (Beijing).*

Ying Su. (2010b). Age/Gender/Occupation and Mobile Phone Technology Adoption: *A Cross-cultural Study in China (Beijing)and the UK (Portsmouth)*

APPENDIX

CODE WHICH USED IN THIS THESIS

```
globals
[
  ki
  kt
  ku
  kun
  r
  data
  filelist
  kqual
  shf
  male
  female

  n-people
  age
  sex
  kage
  ksex


  Turkcell_Market_Share
  Turkcell_new_Inv
  Turkcell_new_present_value
  Turkcell_new_quality
  Turkcell_new_revenue
  Turkcell_old_Inv
  Turkcell_old_present_value
  Turkcell_old_quality
  Turkcell_old_revenue
  Turkcell_present_value
  Turkcell_total_new_revenue
  Turkcell_total_old_revenue
  Turkcell_total_present_value
  Turkcell_total_revenue
  Turkcell_Color
  Turkcell_Color_New
  Turkcell_Inv
  Turkcell_Rev
  Turkcell_old_user
  Turkcell_new_user

  TT_Market_Share
  TT_new_Inv
  TT_new_present_value
```

```
  TT_new_quality
  TT_new_revenue
  TT_old_Inv
  TT_old_present_value
  TT_old_quality
  TT_old_revenue
  TT_present_value
  TT_total_new_revenue
  TT_total_old_revenue
  TT_total_present_value
  TT_total_revenue
  TT_Color
  TT_Color_New
  TT_Inv
  TT_Rev
  TT_old_user
  TT_new_user

  Vodafone_Market_Share
  Vodafone_new_Inv
  Vodafone_new_present_value
  Vodafone_new_quality
  Vodafone_new_revenue
  Vodafone_old_Inv
  Vodafone_old_present_value
  Vodafone_old_quality
  Vodafone_old_revenue
  Vodafone_present_value
  Vodafone_total_new_revenue
  Vodafone_total_old_revenue
  Vodafone_total_present_value
  Vodafone_total_revenue
  Vodafone_Color
  Vodafone_Color_New
  Vodafone_Inv
  Vodafone_Rev
  Vodafone_old_user
  Vodafone_new_user

]

extensions [csv]

turtles-own
[
  operator
]

to setup
```

```
ca
reset-ticks
file-close-all

  set ki 0.95
  set kt 0.007
  set ku 0.3
  set kun 0.4
  set r 0.025
  set kqual -0.01
  set shf 25
  set female 0.71
  set male 0.76

set TT_Color yellow
set Turkcell_Color blue
set Vodafone_Color red

set TT_Color_New orange
set Turkcell_Color_New green
set Vodafone_Color_New white

set TT_Market_Share 22.7
set Turkcell_Market_Share 48.2
set Vodafone_Market_Share 29.1

set TT_old_quality 9
set Turkcell_old_quality 17
set Vodafone_old_quality 6

set TT_new_quality 0
set Turkcell_new_quality 0
set Vodafone_new_quality 0

set n-people 720

crt n-people
[
setxy random-xcor random-ycor
set shape "person"
set color gray
]

;; Set 10-17 as 1, 18-29 as 2, 30-49 as 3, 50-64 as 4, 65+ as 5

ask n-of (n-people * 13 / 100 ) turtles
[
  set age 1
]
ask n-of (n-people * 20 / 100 ) turtles
```

```
[
  set age 2
]
ask n-of (n-people * 29 / 100 ) turtles
[
  set age 3
]
ask n-of (n-people * 14 / 100 ) turtles
[
  set age 4
]
ask n-of (n-people * 8 / 100 ) turtles
[
  set age 5
]

;; Set male as 1, female as 2

ask n-of (n-people * 51 / 100 ) turtles
[
  set sex 1
]
ask n-of (n-people * 49 / 100 ) turtles
[
  set sex 2
]

if age = 1
[
  set kage 0.98
]
if age = 2
[
  set kage 0.94
]
if age = 3
[
  set kage 0.88
]
if age = 4
[
  set kage 0.7
]
if age = 5
[
  set kage 0.5
]

if sex = 1
[
```

```
  set ksex male
]
if sex = 2
[
  set ksex female
]



  ;; Set some of the agents to use TT as their mobile operator considering TT's market
share
ask n-of ( n-people * TT_Market_Share / 100 ) turtles
[
  set color TT_Color
  set operator "TT"
]

;; Set some of the agents to use Vodafone as their mobile operator considering
Vodafone's market share
ask n-of ( n-people * Vodafone_Market_Share / 100 ) turtles with [color = gray]
[
  set color Vodafone_Color
  set operator "Vodafone"
]

;; Set the rest of the agents to use Turkcell as their mobile operator
ask turtles with [color = gray]
[
  set color Turkcell_Color
  set operator "Turkcell"
]

file-open "data.csv"
set data csv:from-file "data.csv"




end

to go

  tick

  set Turkcell_new_present_value Turkcell_new_present_value + (
Turkcell_total_new_revenue - Turkcell_new_Inv ) / ( 1 + r ) ^ ticks
  set Turkcell_old_present_value Turkcell_old_present_value + (
Turkcell_total_old_revenue - Turkcell_old_Inv ) / ( 1 + r ) ^ ticks
```

```
  set Turkcell_present_value Turkcell_new_present_value +
Turkcell_old_present_value
  output-print Turkcell_present_value


  if file-at-end? [stop]
;;extract value from the list, using item 0 to remove the list, and just keep the value
  set Turkcell_Inv item 0 item ticks data
  set Turkcell_Rev item 1 item ticks data
  set Vodafone_Inv item 2 item ticks data
  set Vodafone_Rev item 3 item ticks data
  set TT_Inv item 4 item ticks data
  set TT_Rev item 5 item ticks data
  set Turkcell_old_user item 6 item ticks data
  set Vodafone_old_user item 7 item ticks data
  set TT_old_user item 8 item ticks data
  set Turkcell_new_user item 9 item ticks data
  set Vodafone_new_user item 10 item ticks data
  set TT_new_user item 11 item ticks data
  if ticks = length data [stop]


if ticks < 8

[
  set Turkcell_old_Inv Turkcell_Inv
    Turkcell

  set Vodafone_old_Inv Turkcell_Inv
    Vodafone

  set TT_old_Inv Turkcell_Inv
    TT

]

if ticks = 8

[

  set Turkcell_new_quality kt * Turkcell_Inv
  set Vodafone_new_quality kt * Vodafone_Inv
  set TT_new_quality kt * TT_Inv



]

if ticks > 8
[
```

```
  set Turkcell_new_Inv Turkcell_Inv * Turkcell_Str
  set Turkcell_old_Inv Turkcell_Inv * (1 - Turkcell_Str)

  Turkcell_new


  set Vodafone_new_Inv Vodafone_Inv * Vodafone_Str
  set Vodafone_old_Inv Vodafone_Inv * (1 - Vodafone_Str)

  Vodafone_new


  set TT_new_Inv TT_Inv * TT_Str
  set TT_old_Inv TT_Inv * (1 - TT_Str)

  TT_new

]

if ticks = 28 [stop]

end

to Turkcell

  set Turkcell_old_quality ki * Turkcell_old_quality + kt * Turkcell_old_Inv
  let kq random-normal 1 0.05
  set Turkcell_old_Revenue ku * kq * sqrt Turkcell_old_quality

  set Turkcell_total_old_revenue Turkcell_old_revenue * (count turtles with
[operator = "Turkcell"])
  set Turkcell_total_revenue  Turkcell_total_old_revenue

end


to Turkcell_new


if count turtles with [operator = "Turkcell"] > 0
[
if Turkcell_new_quality > Turkcell_old_quality + 2
[
  let switcher floor (count turtles with [operator = "Turkcell"] * 1 * kage * ksex / (1 +
exp (kqual * ((Turkcell_new_quality - Turkcell_old_quality) + shf))))

  if switcher > count turtles with [operator = "Turkcell"]
  [
    set switcher count turtles with [operator = "Turkcell"]
  ]
```

```
  ask n-of (switcher) turtles with [operator = "Turkcell"]
  [
    set color Turkcell_Color_New
    set operator "TurkcellNew"
  ]
]
]
set Turkcell_old_quality ki * Turkcell_old_quality + kt * Turkcell_old_Inv

let kq random-normal 1 0.05

set Turkcell_old_Revenue ku * kq * sqrt Turkcell_old_quality

set Turkcell_total_old_revenue Turkcell_old_revenue * (count turtles with [operator
= "Turkcell"] )

set Turkcell_new_quality ki * Turkcell_new_quality + kt * Turkcell_new_Inv

set Turkcell_new_Revenue kun * kq * sqrt Turkcell_new_quality

set Turkcell_total_new_revenue Turkcell_new_revenue * (count turtles with
[operator = "TurkcellNew"])

set Turkcell_total_revenue  Turkcell_total_old_revenue +
Turkcell_total_new_revenue

end


to Vodafone

  set Vodafone_old_quality ki * Vodafone_old_quality + kt * Vodafone_old_Inv
  let kq random-normal 1 0.05
  set Vodafone_old_Revenue ku * kq * sqrt Vodafone_old_quality

  set Vodafone_total_old_revenue Vodafone_old_revenue * (count turtles with
[operator = "Vodafone"])
  set Vodafone_total_revenue  Vodafone_total_old_revenue

end


to Vodafone_new


if count turtles with [operator = "Vodafone"] > 0
[
if Vodafone_new_quality > Vodafone_old_quality + 2
[
```

```
  let switcher floor (count turtles with [operator = "Vodafone"] * 1 * kage * ksex / (1
+ exp (kqual * ((Vodafone_new_quality - Vodafone_old_quality) + shf))))

  if switcher > count turtles with [operator = "Vodafone"]
  [
    set switcher count turtles with [operator = "Vodafone"]
  ]

  ask n-of (switcher) turtles with [operator = "Vodafone"]
  [
    set color Vodafone_Color_New
    set operator "VodafoneNew"
  ]
]
]
set Vodafone_old_quality ki * Vodafone_old_quality + kt * Vodafone_old_Inv

let kq random-normal 1 0.05

set Vodafone_old_Revenue ku * kq * sqrt Vodafone_old_quality

set Vodafone_total_old_revenue Vodafone_old_revenue * (count turtles with
[operator = "Vodafone"] )

set Vodafone_new_quality ki * Vodafone_new_quality + kt * Vodafone_new_Inv

set Vodafone_new_Revenue kun * kq * sqrt Vodafone_new_quality

set Vodafone_total_new_revenue Vodafone_new_revenue * (count turtles with
[operator = "VodafoneNew"])

set Vodafone_total_revenue  Vodafone_total_old_revenue +
Vodafone_total_new_revenue

end


to TT

  set TT_old_quality ki * TT_old_quality + kt * TT_old_Inv
  let kq random-normal 1 0.05
  set TT_old_Revenue ku * kq * sqrt TT_old_quality

  set TT_total_old_revenue TT_old_revenue * (count turtles with [operator = "TT"])
  set TT_total_revenue  TT_total_old_revenue

end


to TT_new
```

```
if count turtles with [operator = "TT"] > 0
[
if TT_new_quality > TT_old_quality + 2
[
  let switcher floor (count turtles with [operator = "TT"] * 1 * kage * ksex / (1 + exp
(kqual * ((TT_new_quality - TT_old_quality) + shf))))

  if switcher > count turtles with [operator = "TT"]
  [
    set switcher count turtles with [operator = "TT"]
  ]

  ask n-of (switcher) turtles with [operator = "TT"]
  [
    set color TT_Color_New
    set operator "TTNew"
  ]
]
]
set TT_old_quality ki * TT_old_quality + kt * TT_old_Inv

let kq random-normal 1 0.05

set TT_old_Revenue ku * kq * sqrt TT_old_quality

set TT_total_old_revenue TT_old_revenue * (count turtles with [operator = "TT"] )

set TT_new_quality ki * TT_new_quality + kt * TT_new_Inv

set TT_new_Revenue kun * kq * sqrt TT_new_quality

set TT_total_new_revenue TT_new_revenue * (count turtles with [operator =
"TTNew"])

set TT_total_revenue  TT_total_old_revenue + TT_total_new_revenue

end
```