SAULIUS ADAMAUSKAS

TECHNOLOGY ADOPTION INVESTMENT TIMING MODEL UNDER MARKET CHANGES

DOCTORAL DISSERTATION

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SAULIUS ADAMAUSKAS

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GLOSSARY OF USED TERMS

ARPU – Average Revenues per Subscriber.
5G – 5G is the coming fifth-generation wireless broadband technology based on the IEEE 802.11ac standard. 5G will provide better speeds and coverage than the current 4G. 5G operates with a 5Ghz signal and is set to offer speeds of up to 1 Gb/s for tens of connections or tens of Mb/s for tens of thousands of connections.
CAPEX – Capital expenditure is used by a company to acquire or upgrade physical assets such as property, industrial buildings or equipment. In accounting, capital expenditure is added to the asset account, thus increasing the asset's basis (the cost or value of an asset adjusted for tax purposes). CAPEX is commonly found on the cash flow statement under "Investment in Plant, Property, and Equipment" or something similar in the Investing subsection.
FCF – Free Cash Flow.
GBM – Geometric Brownian Motion method based on Monte Carlo simulation.
HP – Hodrick-Prescott filter.
IoT – Internet of things refers to the ever-growing network of physical objects that feature an IP address for internet connectivity, and the communication that occurs between these objects and other Internet-enabled devices and systems.
MARPU – Average market Revenues per Subscriber.
Plateau – The highest point of the life cycle in time series.
R&D – Research and development.
Revenues – Surplus revenues of companies in selected geographical area.
ROCE – Return On Capital Employed.
S&T – Science and Technology.
STI – Science, Technology and Innovations.
Subscribers (or Wireless Subscribers) – Surplus subscribers of companies in selected geographical area.
TAW – Measurement in years back from technology cycle plateau moment, which shows the optimal moment for technology adoption.

INTRODUCTION

The relevance of this topic. Revolutionary changes in the market affect economic development and its growth rates. Within stochastic innovation processes uncertainties can be found that encompass generations of new technologies, their development and technological change environment. Over the last few decades academic research and literature were focused on technology development analysis, efficiency of usage, investment timing issues and integration within the business and economic environment. This means that technologies are multidisciplinary based interrelated phenomenon in-between different industries, supply chains, ecosystems and other social factors. Because of this, in the global volatile environment competing companies, where activity is based on technological resources, are forced to make strategic technology management decisions. Thus, innovations and technology development paradigms become inseparable parts of the global economy development process. From this point of view, these paradigms could be considered as a competitive advantage. The variety of technological achievements in different economic sectors, such as information technology, chemistry, energy, medicine, electronics and many other industries, has led to rapid changes, which directly constrain the forecasting and predicting of the previously mentioned developments and the aggregation of those paradigms. For these reasons, companies are faced with having to integrate technology adoption, development and upgrading issues into their strategic decision processes in order to maintain and increase their competitiveness. Due to the volatile environment, companies follow every innovation, and are forced to invest in risky projects in order not to miss out on possible technological leaps in the market, and implement as well as commercialise new technology more rapidly than ever before.

Technology upgrades, turnover or changes are complex processes related with the high risks involved in organisational systems, processes, products and/or services and industry. Consequently, those companies that aim to manage technological risks and in this way keep their competitiveness have to take a variety of factors into consideration, which includes the company’s internal resources and macroeconomic factors, such as demand, production, industry and technology life cycles, social environment, etc. The analysis of academic literature showed technology investment or adoption timing issues as one of the most crucial factors for optimal technological change management when seeking successful products and/or services, staying competitive in the market and financial sustainability at the same time. Certain technological management decisions could be implemented only after some time, because technologies were developing faster than industry.

From a theoretical company’s financial management point of view, each strategic decision must result in an increase of the company’s value. Thus, companies face a problem of adopting new technology at the optimal time so it drives an improvement in competitiveness, the creation of value for the company, investment payback targets planning, building reactivated business models, etc. These issues are more complicated for a mature market, where demand changes can be modelled with uncertain presumptions, because competition is very acute and technology investments are irreversible.

The scientific problem and the level of investigation. Many fundamental works dedicated to solving the problems that are related with the development of technologies at the theoretical level were created. Authors such as Schon (1967), Friar and Horwitch (1985), Bohn (1994), Drejer (2000), Stock and Tatikonda (2000), Perez (2001, 2002, 2009), Jaffe et al. (2002), Rogers (2003, 2010), Ireland and Webb (2007), Rothaermel (2008), Heffner and Sharif (2008), Kaplan and Tripsas (2008) and Tan et al. (2009) made a fundamental background and benchmark for theoretical and practical studies. Well known authors, who continued in the technology change environment analysis are Jones (2005), Mokyr (2005), Crabtree (2006), Grossmann and Steger (2007), Teixeira (2012), Gorodnichenko and Schnitzer (2013) and others. They analysed fundamental sources of economic growth and development emphasising the technological fields and learning technology catch-up opportunities.

In the review of life cycles in economy process academic literature, insights were emphasised by Urban and Hauser (1993), Nito et al. (1998), Aitken et al. (2003), Foxon (2003), Werker (2003), Chang et al. (2006), Murmann and Frenken (2006), Halsnæs et al. (2007), Haupt et al. (2007), Hsueh (2011), Verganti (2011), Taylor and Taylor (2012), Pol (2012), Shahmarichatghieh et. al (2015), Lobel et al. (2015) and others.

Market timing decisions cover multi-disciplinary issues in strategic managerial management processes. Definitions of optimal timing were frequently found, especially in the academic literature of the last few years, involving a variety of underlined elements by Krušinskas and Vasiliauskaitė (2005), Krušinskas (2008), Moon (2010) Wong (2010, 2011), Henderson (2010), Butler et al. (2011), Svensson et al. (2011), Yagi and Takashima (2012), Bolton et al. (2013), Chou et al. (2014) Hagspiel et al. (2015) and others.

In the academic literature, many factors causing technological changes are taking into consideration. These factors are known as drivers, which affect the decision making process, according to Ellis and Shpielberg (2003), Chambers (2004) and Vasauskaite (2013) and are determined as mobile production, rapid technological development, constant search of the optimal price and quality ratio, saturated markets, globalisation of investments and the markets, market fragmentation and shorter life cycles of technological monopolies. Meanwhile, as was pointed out by Chen and Ma (2014), most of the literature on technology adoption is from the perspective of the psychology-based acceptance of new technologies by individual users or organisations.

In today's technology intensive developing economy, companies are challenged to maintain competitiveness and offer customers a continuous line of innovative products and services based on the latest technology; thus, in technology intensive industries, investments in technology adoption are inevitable. Investment timing assessment methods and competitiveness evaluation methods were analysed by such authors as Scarso (1996), David et al. (2001), Krishnan and Loch (2005), Kor (2006), Bouis, Huisman, and Kort (2006), Pertile (2007), Bhaskaran and Ramachandran (2011), Jakšić and Jakšić (2012), Martinez (2013), Hori and Osano

(2013), Biagini et al. (2014) and others. In general, authors focus on the concept of technological innovations, their efficient models in different industries and the aspects of value creation for the company.

From a variety of timing studies, different types of decision support models were investigated by Bar-Han and Maimon (1993), Benaroch and Kauffman (1999), Krušinskas and Vasiliauskaitė (2005), Kamarianakis and Xepapadeas (2006), Mukherji et al. (2006), Ngwenyama et al. (2007), Huang and Da (2007), Wickart and Madlener (2007), Pertile (2007), Wong (2010, 2011), Moon (2010), Henderson (2010), Shibata and Nishihara (2011), Whalley (2011), Yagi and Takashima (2012), Bolton et al. (2013), Wong and Yi (2013), Nishihata and Shibata (2013), Feil and Musshoff (2013), Kim et al. (2014), Jeon and Nishihara (2014) and others.

In general, research and development innovations empower a company to increase productivity by creating new products, improving their quality or reducing existing costs. Even more, science, technology and innovation affect society and its development level by growing GDP, creating and/or optimising new jobs, increasing a countries image in comparison with other countries and create a relevant environment for other businesses, which starts the circle again. Moreover, research and development innovations could produce a positive spillover effects in other companies, sectors, and countries, which could be very significant in a country's economic development. Technological innovation is a result of the interaction of R&D and entrepreneurial dimensions, executed in the network of knowledge creating organisations. Thus, it shows the growing importance of timing, marketing, quality management, investments, etc. Because of this, it is very important to identify such companies and environment issues, which are required to keep and maintain S&T and R&D activities. It is necessary to examine, identify and develop a company's unique set of resources and capacities, to assimilate the opportunities provided by the environment and to avoid the restrictions imposed by the company's internal assets. In general, after the scientific literature analysis, a lack of fundamental and practically implemented studies regarding investment timing valuation models in terms of interfaces between customer behaviour expressed by market demand changes, companies' strategic internal managerial decisions under the influence of technology timing and valuation of technology investment was identified. All these fields are interrelated and interconnected between each other and should be analysed together.

The academic literature review formed a **scientific problem**, which deals with the question of how to make a comprehensive assessment of technology adoption investment timing decision for competing companies under market changes.

The research object is a technology adoption investment timing decision making process.

The aim of the research is to construct a comprehensive technology adoption investment timing valuation support model.

The research tasks. The aim of the dissertation includes the following tasks:

1. To examine different concepts of technologies, emphasising the significance of technologies on the development of economics.

2. To investigate the peculiarities of the optimal investment timing conception in terms of demand uncertainty valuation and the technology life cycle determination.
3. To develop the model of optimal time selection for the adoption of new technology.
4. To perform empirical testing of the model that was developed to select the optimal time for the technology adoption investment on the basis of the results of empirical applications.

The research methods. The following research methods were used in this dissertation:

1. The analysis of the processes for adopting new technologies in the enterprise, and the systemic and comparative analysis of conceptions, methodologies and conclusions, published in scientific literature.
2. The Geometric Brownian Motion method based on the Monte Carlo simulation method was applied for predicting demand fluctuations in projected future periods.
3. The Hodrick-Prescott filter was applied for technology life cycle determination.
4. To conduct the research on the application of the model, mathematical and statistical methods of data processing were used applying STATISTICA, E-views 6 and Microsoft Excel software for the analysis of statistical data.

The research structure. The logical structure of the dissertation research was determined by the sequence of solving tasks intended for achieving the research aim, reflected in the tree main parts of the work:

In the first part of the dissertation the concept of technology investment assessment environment is defined; the changes of technology definitions due time course are distinguished; the main and general concepts of technology, technological change and the effect on economic growth are described as well as definitions and stages of product, industry and technology life cycles. A conceptualisation of technology life cycles and its generation and technology adoption investment timing management are distinguished within the main factors causing technological changes. The importance of the technology adoption investment timing concept is analysed. The economy is expressed as a combination of demand or supply complexity in terms of technological change in order to perceive the best possible time for innovation deployment. Such environment forces companies to exploit demand and the factors under which demand uncertainty can be expressed and described, and even future possible demand changes under the influence of technological change, or in other words historical development analysis of product and/or service with demand paths volatility are analysed. Technology adoption investment timing assessment methods and competitiveness methods are overviewed with a theoretical definition of science and technology based company and its evaluation indicators. Finally, the technology adoption investment decision process is described under the influence of uncertain market changes.

In the second part of the dissertation a comprehensive technology adoption investment timing decision valuation support model is constructed. The models' structure and structural elements are highlighted and analysed in depth. A summary of the results of the academic literature regarding technology adoption investment timing valuation support model parts, variables, methodologies and processes are distinguished. The main stages of the model are: (I) historic demand paths analysis; (II) applying of statistical data validity tests; (III) the forecast of data array using the Geometric Brownian Motion method based on the Monte Carlo simulation; (IV) determination of technology life cycle using the Hodrick-Prescott filter; (V) technology adoption time window determination; and (VI) a company value (NPV) calculation based on free cash flow changes.

In the third part of the dissertation the methodology of the empirical testing of a model for upcoming mobile 5G technology is formulated according to the model constructed in the second part. In the mobile network market, 5G mobile technology generation and it's features are analysed in the period from 2005 Q4 to 2014 Q4; determination of average market revenues and wireless subscribers dynamics statistical validity tests are applied; forecasting of dynamics of market revenues, wireless subscribers and average revenues per subscriber is done using the Geometric Brownian Motion method based on the Monte Carlo simulation for the upcoming 10 years; the determination of mobile technology life cycle using the Hodrick-Prescott filter is implicated and the 5G technology plateau moment determined in Y2024; the technology adoption time window determination for 18 selected competing mobile service providers (all the companies are operating in the European market); the decision value expressed by net present value calculations based on free cash flow changes are analysed; clustering of investors' roles for the companies analysed are done with the expected financial ratios. The selected companies are considered as science and technology based, therefore, after the constructed model has been successfully applied, research results empowered to highlight the investors' strategy roles with the specific financial characteristics and identify the technology adoption time window of 4.3 - 10.5 years before technology plateau moment in Y2024 for particular market players depending on the main resource life cycle expectancy, which was achieved through proportion of calculated companies' value and market capitalisation modelled using 10-years (period) ROCE ratios. According to the results, a technological strategic shift roadmap from mobile 4G to 5G technology was created. The research results also allowed the concluding remarks to be made about the mobile communications company's life cycle, depending on the main resource life cycle expectancy.

The novelty of the research and its practical significance:

1. The importance of the technology adoption investment timing is underlined and described. There is a lack of multidisciplinary based comprehensive optimal technology adoption investment timing models in academic literature.
2. The structure and the factors of technology adoption investment were identified and systematised including both internal company financial indicators and external market environment aspects such as demand expressed by total mobile service subscribers, market revenues and derivative – average market revenues per subscriber. The necessity for such specific indicators are

highlighted by measuring technology adoption investment efficiency evaluation under market changes.

3. A new comprehensive model is constructed, based on the interrelated multidisciplinary parts: strategic decision making process, technology adoption investment valuation and modelling of macro-economic parameters under uncertainty.
4. The constructed model was empirically tested by selecting the optimal time for mobile 5G technology adoption investment in mature markets and evaluating the process, which starts with market analysis, definition of technology life cycle, companies' internal financial factors and strategic investors roles clustering within expected financial ratios. The universality of the model is highlighted for other technologies successful adoption by amending and updating the model's parameters according to the specific financial and market data.

The structure of the dissertation. The dissertation consists of a list of tables and figures presented in the dissertation, the glossary of terms used, introduction, 3 main parts, conclusions, references and annexes. The dissertation contains 126 pages (without 105 annexes) with 23 numerical formulas, 26 figures, 10 tables and 195 references.

1. TECHNOLOGY INVESTMENT ENVIRONMENT THEORETICAL FRAMEWORK AND ITS CHARACTERISTICS

1.1. Definitions of science and technology based companies' strategic management decisions and technological innovation strategy

In the technological revolution analysis, Perez (2009) underlines Schumpeter (1911, 1939) as one of the modern economist to put technical change and entrepreneurship at the root of economic growth. This economist saw technology as exogenous and, together with institutions and social organisations, outside the domain of economic theory, where he focused on explaining the role of innovation in economic growth and the cyclicality of the system. Such tasks were trying to be solved in terms of identifying the common features in the processes of evaluation, in the interrelations and in the breakthroughs that occur in the most diverse technical areas. The variety of minor innovations in the product enhancement and process improvement that follow the introduction of any new product have an important impact on productivity increases and market growth, thus process innovations drive most of scaling up investment.

From the techno-economic point of view, technologies interconnect with each other and tend to appear in other innovations even more, individual innovations are interconnected in technological revolutions, in other words, innovation is an interdisciplinary and constituent of the whole market chain evolution involving suppliers, distributors, customers and many others. Since innovations and technologies are radical, they stimulate whole industries.

According to Perez (2002), there are five successive technological revolutions in the period of the 1700s to the 2000s, which are corresponding big-bangs and the core country where the revolution originally takes shape and from which it spreads across the world: the first – "The Industrial revolution" in Britain in the period of 1771-1829; the second continued in Britain and is called the "Age of Steam and Railways" in the period of 1829-1875; the third known as the "Age of Steel, Electricity and heavy Engineering" began in the USA and Germany forging ahead and overtaking Britain in period of 1875-1908; the fourth revolution developed in the USA again (with Germany at first vying for world leadership), later spreading to Europe in the period of 1908-1971 and is called the "Age of Oil, the Automobile and Mass Production"; the last technological revolution, the "Age of Information and telecommunications" started in the USA (spreading to Europe and Asia) in 1971 with the invention of microprocessors, software, semi-conductors, bio-technologies, microelectronics and other new advanced materials. Thus, the wings of technological revolutions can be considered as a major developer of wealth in terms of establishing new economies, opening innovation opportunity spaces and providing a new set of efficiency and effectiveness of all industries and activities.

Technology and its management are essential for a rapidly changing business environment, thus, the latest academic literature recognises technology as one of the main strategic resources in any enterprise and the technological strategy of an enterprise is considered to be a functional strategy, determining the position of the enterprise in respect of technological changes. Successful development of the activity requires strategic decisions, constant analysis of the business environment and predictions of new technological alternatives. Gaining and sustaining competitive advantage is the defining question of strategy. Rothaermel (2008) states, that a dictum of strategy, that is, the overall firm performance is explained by a firm's strategy "a firm has a competitive advantage when it is able to create more economic value than its rivals". At the same time, reasons for the increasing importance of innovation in many industries include deregulation, globalisation, rapid technological progress (advances in IT, nanotechnology, biotechnology, etc.) and accelerating diffusion rates for technology-based products. Since the only constant in technology intensive industries is change, sustained competitive advantage can only be accomplished through continued innovation. This in turn requires the continuous introduction of new products or services. Meanwhile, according to Ireland and Webb (2007), in today's fast-paced competitive environment, companies face the need to be increasingly nimble and adaptive. While often able to establish a certain level of performance based upon existing technologies, companies are equally as often to be left flat-footed in the face of emerging, novel technologies. The decision to engage in strategic entrepreneurship is a vital but insufficient step to being able to consistently outperform competitors; indeed, firms reach strategic entrepreneurship's potential only by balancing their actions between exploration and exploitation. In slightly different words, the most successful firms balance the efforts they expend to explore for tomorrow's opportunities while exploiting today's competitive advantages. In general, it is agreed, that innovations in technologies are one of the crucial factors in competitiveness, thus technology definition changes are presented in Table 1 below.

Table 1. Technology definition change

Author	Definition
Schon (1967)	Technology is used to extend human capability and can take the form of a tool, technique, product, process, physical equipment or method.
Friar and Horwitch (1985)	Technology is a company's manageable resource.
Bohn (1994)	It is technical knowledge that organisations apply in order to enhance their ability to provide products and services. Emphasising both hard and soft aspects.
Drejer (2000)	The author refers to hardware, human resources and organisational aspects within a firm, thereby acknowledging the role of human skills and experiences.
Stock and Tatikonda (2000)	The variety of forms that technology may take is articulated as a machine, an electrical or mechanical component or assembly, a chemical process, software code, a manual, blueprints, document, operating procedure, a patent, a technique or even a person.
Heffner and Sharif (2008)	Categorise technology into "technoware" or tools, "humanware" or talents, "infoware" or facts, and "orgaware" or methods.
Kaplan and Tripsas (2008).	The authors use the word technology in the tradition of the technology life cycle literature to mean technology as applied in a particular product context and as embodied in a physical artefact. So technology is not just the knowledge from which products are elaborated, but also includes the physical manifestation of that knowledge within a product.

Perez (2001) defined rapidly growing technologies as the abilities to scale-up the business size. Meanwhile, after several years, technologies were associated with the information concept. It is defined by Tan et al. (2009), as an application of communication and information technology tools including a computer network, software and hardware required for internet connection. Thus, according to Onn (2013), the term information technology will cover a wide range of information processing and computer applications in organisations. It will cover systems of information, Internet, information and communication related technologies, and their infrastructure including computer software, networks and hardware, which processes or transmits information to enhance the effectiveness of individuals and organisations.

In the context of the topic, technological change has to be analysed. Technological change, technological development, technological achievement, or technological progress is the overall process of invention, innovation and diffusion of technology or processes (Jaffe et. al 2002). In essence, technological change is the invention of technologies (including processes) and their commercialisation via research and development (producing emerging technologies), the continual improvement of and the diffusion of technologies throughout industry or society. The definition also comprises creation of new products, quality improvements and efficiency gains for existing products. In general, knowledge diffuses across countries and regions, between industries and companies, universities and researchers. According to Teixeira (2012), technological change today is central to the theory of economic growth. It is recognised as an important driver of productivity growth and the emergence of new products from which consumers derive welfare. It depends not only on the work of scientists and engineers, but also on a wider range of economic and societal factors, including institutions such as intellectual property rights and corporate governance, the operation of markets, a range of governmental policies (science and technology policy, innovation policy, macroeconomic policy, competition policy, etc.), historical specificities, etc. Meanwhile, Crabtree (2006), provides a technology space matrix with the same mentioned fundamental outcomes, which can be used as a framework for technology insights analogous to the way an aerial photo provides insights on a geographic area, often showing large-scale relationships that might be missed if viewed close up. The technology space matrix framework can also be used as a starting point from which to identify and to "drill down" to more detailed areas of special interest. Jaffe et al. (2002), underlines the importance of technological change because of two reasons. First, the environmental impact of social and economic activity is profoundly affected by the rate and direction of technological change. Uncertainty about the future rate and direction of technological change is often an important sensitivity in "baseline" forecasts of the severity of environmental problems. Secondly, environmental policy interventions themselves create new constraints and incentives that affect the process of technological change. These induced effects of environmental policy on technology may have substantial implications for the normative analysis of policy decisions. They may have quantitatively important consequences in the context of cost-benefit or cost-effectiveness analyses of such policies.

Sustained and significant growth in average world per capita income started roughly with the first era of the industrial revolution (Jones, 2005). Mokyr (2005), expressed a small doubt that technological process via process innovations played the core role in the starting, accelerating and sustaining of economic growth in the modern era. For this reason, Grossmann and Steger (2007), analysed fundamental sources of economic growth and development in the field by focussing on the basic structure of endogenous growth models with horizontal as well as vertical innovation and emphasising important implications for growth policy. Meanwhile, Perez (2001), presented analysis in technologies, systems and revolutions and paradigms. The author noticed that technologies are interconnected in systems, and these, in turn, are intertwined and interdependent, both with each other and in relation to the physical, social and institutional environment. There is no inevitable progression towards an ever more advanced and always unattainable frontier. There are important discontinuities that become windows through which latecomers can leap forward. These opportunities occur in the form of technological revolutions and involve sharp changes of direction in technological progress. Therefore, new technologies of a revolutionary nature open up new opportunities for learning and catching-up. Gorodnichenko and Schnitzer (2013), examines micro-level channels through financial development and investigate theoretically and empirically how financial constraints affect a companies' innovation activities. The authors identified factors that prevent less developed countries from catching up with developed countries. Stylised facts from OECD countries identify financial frictions as an impediment to investment and to research and development (R&D) spending by companies at the microeconomic level. Even more, foreign-owned companies tend to be more productive than domestically owned firms. The main finding is that domestically owned companies are in fact significantly and robustly less productive than the companies under foreign ownership and that foreign-owned firms innovate more intensively than do domestically owned companies. It means, that domestically owned firms seem to always fall short of the technological frontier that is often embodied by foreign-owned companies.

The technological development impact for the global economy could be easily seen in the research of Collins et al. (2014). The rate of growth of technological progress, income per person and population are presented in Figure 1. It is obviously clear, that technological revolution, research and development in the whole economy, starting from agriculture and ending with economic models, positively affects everything; population increase, the average life maturity, income growth as well as gross domestic product growth all over the world. Thus, in the most fundamental sense, there are only two ways of increasing the output of the economy: (1) business can increase the number of inputs that go into the productive process, or (2) companies can think of new ways in which they can get more output from the same number of inputs. Business success in a time of technological transformation demands innovation. Since the industrial revolution, there have been at least six waves of innovation, which shifted the technologies that underpinned economic prosperity. From this perspective point, business is dependent from technological and innovation processes, its life cycle and ability to change the environment. A multidisciplinary approach, as well as a neurotic network, connects customers, business companies and countries into one ecosystem, which means that each part of it depends on the others. Therefore, there are a variety of academic studies forecasting the nearest future with a huge technological impact for human beings and the future world.

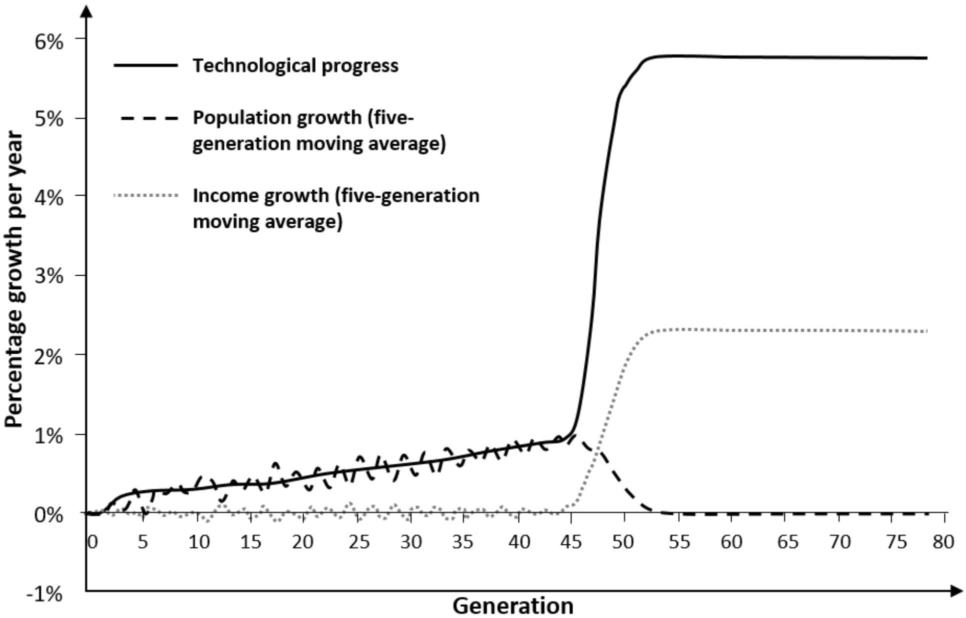


Figure 1. Annual growth rates of technology, population and income by Collins et al. (2014)

After the analysis of academic literature, it could be noticed, that there is a clear direction of technological change in the economic environment. Starting from the early 1900s scientists began to realise that innovations and entrepreneurships are the root and crucial factors of economic growth. It must be underlined, that technologies and innovations in different sectors and areas are interconnected and the technological change or shift is basically affecting the whole economic level not just a single area. Therefore, investment timing decisions are extremely important in today's business development. Moreover, the economy has to be expressed as a combination of demand or supply complexity in terms of technological change in order to perceive the best possible time for innovation deployment. These issues force the exploitation of demand and the factors that can express and describe the demand uncertainty and even future possible demand changes under the influence of technological change, or in other words, historic development analysis of products and/or services with demand path volatility have to be analysed. These insights are one of the main competitive advantage creation methods considering the best possible product and/or service supply for the market. For a deeper understanding, product, industry and technology life cycles must be taken into consideration, which are systemically overviewed in Section 1.2.

1.2. Product, industry and technology life cycle definitions and stages

In the review of life cycles in economy process studies literature, there are several definitions which should be analysed in depth: industry life cycle, product life cycle and technology life cycle. While these concepts are inter-related, it is important to use appropriate terminology in the technology management decision making process.

As was pointed out by Shahmarichatghieh et al. (2015), product life cycle illustrates the fluctuations of the product sales revenue over time, from the beginning of its design to the last phase of its ramp down. While, technology life cycle demonstrates the cumulative product development projects of a technology or technology performance over time, which could represent the technology maturity level in various periods of time. Subsequently, market life cycle represents the appearance and developments of various market segments to the market area of a technology. Apparently, each technology life cycle could contain various product life cycles and each market life cycle could include different technology and product life cycles. Therefore, market life cycle has a more comprehensive view point, and product life cycle is more detailed with specific product centric insight. But, the outcomes of each life cycle concept are different and making decision based on all of them together can lead to more optimised results.

In the studies of Urban and Hauser (1993), Nito et al. (1998), Taylor and Taylor (2012) and Pol (2012), it can be seen that there is a superficial similarity in the structure, shape and terminology between industry life cycle, product life cycle and technology life cycle, mainly because of external structural similarities (see Figure 2).

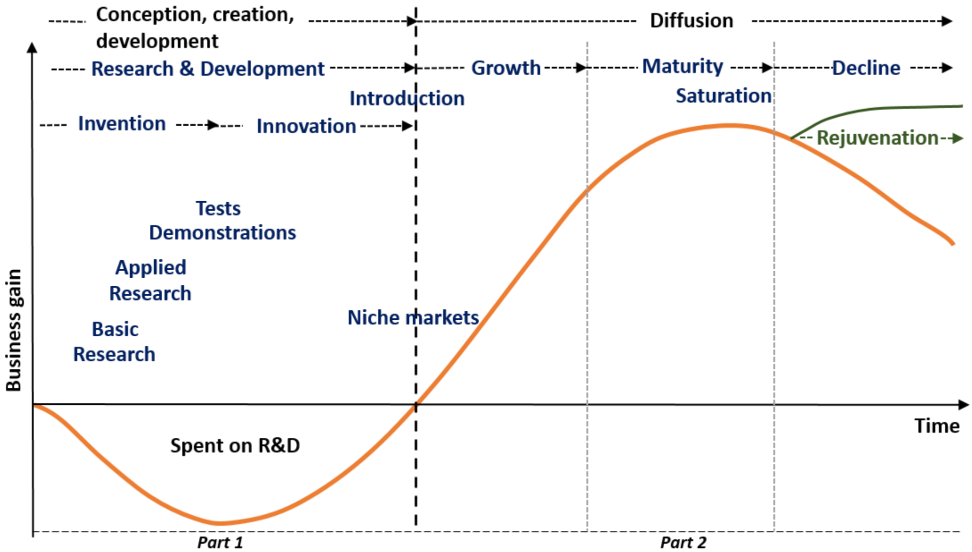


Figure 2. Technology/Product life cycle by Pol (2012)

As was pointed out by Halsnæs et al. (2007), technology/product development, and the rise and fall can be viewed as a two-part process. Part 1 includes conceiving, creating and developing new technologies, meanwhile, Part 2 is the process of diffusing or deploying these technologies. There is a significant gap that must be navigated if an innovation is to reach maturity. According to the authors mentioned previously, in the figure the most generally recognised form of the product life cycle can be found that depicts sales volume or revenue plotted against time as a bell-shaped curve with distinguishable stages representing the introduction, growth, maturity and decline of a product. Such authors as Aitken et al. (2003), Chang et al. (2006) and Hsueh (2011), underline different ways of product life cycle usage, such as marketing decision issues, supply chain management, inventory control and demand forecast models. During the R&D and early introduction innovations will have a period of monopoly where the developers are the sole producers of the product. However, as it enters commercialisation and the growth phase, competitors start to copy and/or improve on the product. Foxon (2003), underlined that the type of innovation also impacts how long it takes the technology to move through the cycle, how it is developed, and its acceptance and adoption by potential users.

Apparently, if the company is forced to invest in any product or project, the technology stage in the life cycle has to be found. Thus, according to Gao et al. (2013) and Shahmarichatghieh et. al. (2015), if the technology is growing or disappearing to other trade-offs in accordance with the technology future, mostly the S-curve of the technology life cycle is based on technology performance over time or cumulative development activities. Technology performance could be measure by various factors and indicators (e.g. Gao et al. (2013) offers a list of technology life cycle indicators, such as the number of patents, corporates, non-corporates, inventors, backward citations, etc. in the Derwent Innovation Index (DII)) but some studies have suggested that different technology indicators should be taken into account and one single factor is not enough to build the S or double-S curve of the technology life cycle. According to Werker (2003), analysis of the three theoretical pillars the product life cycle, technological regimes, and technological paradigms had been put together to model the evolution of markets in time. At first glance, the simulation results seem to show many of the expected patterns of market evolution. The advantage of this is that economic intuition is corroborated by the simulation study.

According to Murmann and Frenken (2006), industry’s life cycle can be represented as an inverted U-shape, which is not dissimilar to the bell-shape of the product life cycle, however, while the product life cycle has four phases, the industry life cycle is typically depicted with three. It is also clear that industry’s life cycle is crucial for supporting management decisions. Meanwhile, according to Shahmarichatghieh et. al (2015), industry’s life cycle could be considered as the market (development) life cycle. As was emphasised by the authors, there are three different markets: growth market (which contains the technology adoption life cycle), the mature market and declining market. The technology adoption life cycle is the first stage in the life cycle. It contains five different important points: Early market (Innovators and Visionaries), the chasm, bowling alley, tornado and main street. Technology adoption life cycle ends by the time that the product goes to the main market area and starts to be commoditised.

According to Lobel et al. (2015), a product launch is an expensive endeavour, involving complex manufacturing, logistics and marketing efforts, and a mistimed product release could have significant consequences on a company's profit stream. Furthermore, companies cannot release new generations of a product in rapid succession and expect consumers to willingly pay to upgrade each time a new version hits the market. In other words, a consumer will purchase the latest version on the market only if it is sufficiently more technologically advanced than the product the person already owns.

The work by Gjerde et al. (2002), considers a company's decision making process regarding the level of innovation to incorporate successive product generations and discusses the framework under which the firm should innovate to the technology frontier compared to adopting incremental improvements. Meanwhile authors Klastorin and Tsai (2004), created a game theoretic model with several firms (profit maximising) that enter a new market with competing products that have finite and known life cycles. In this case, the first entrant sets a price for products in a monopoly situation until the second company enters the market. Eventually, both companies simultaneously set their prices knowing the design and technology sets of both products. The main issue in the analysis is that product differentiation always arises at equilibrium due to the joint effects of resource utilisation, price competition and product life cycle, and this means that such companies would be unwise to arbitrary shorten its product life cycle for the sake of competition.

According to Agarwal et al. (2002), industries, driven by environmental forces and innovation, evolve through prototypical phases of a life cycle and undergo irreversible transformations in their competitive dynamics, organisational diversity and structures. Relaying on life cycle research, the authors identified temporal discontinuities based on the intensification of barriers to entry. Temporal changes in the basis of competitive advantage imply that the type of firm at risk of failure may be closely linked to the life cycle stage of the industry. This notion highlights issues on how life cycle effects may influence failure patterns as they interact with various causal factors. In general, it was proved that the irreversible transformation of the competitive landscape affects not just mortality rates, but also the nature of the relationships between various theorised organisational and industrial characteristics, environmental processes and failure rates. As was pointed put by Bayrus and Agarwal (2007), diversifying entrants have an initial survival advantage over entrepreneurial start-ups. But the reverse for later entrants: start-ups that enter later in the industry have a survival advantage over the later entering diversifying entrants. This research was explained in terms of the companies' product technology strategies, pre-entry experience, and entry timing. Industry time cycle regimes were also analysed in the research of Sarkar el. al. (2006), where the authors investigate how the external knowledge milieu of an entrant, conceptualised as its innovative environment, causes systematic variation in survival patterns. Regardless of different life cycle interrelationships and complexity, it could be said that any product is comprised of technology. Again, since the industry life cycle presents the progress of industries based on particular products, both industry and product life cycles are the best proxies for technology process analysis. Finally, between these definitions lie a number of life cycles for products, thus they are all a function of an enabling technology, which is itself subject to progression via a complex life cycle.

Verganti (2011), made two fields of investigation in his study: the role of design to radically innovate the meaning of products and services, and the interaction of radical design with radical technologies, which he called technology epiphanies (see Figure 3). According to the author, the connection between design and innovation, therefore, is that design is about the innovation of product and service meanings.

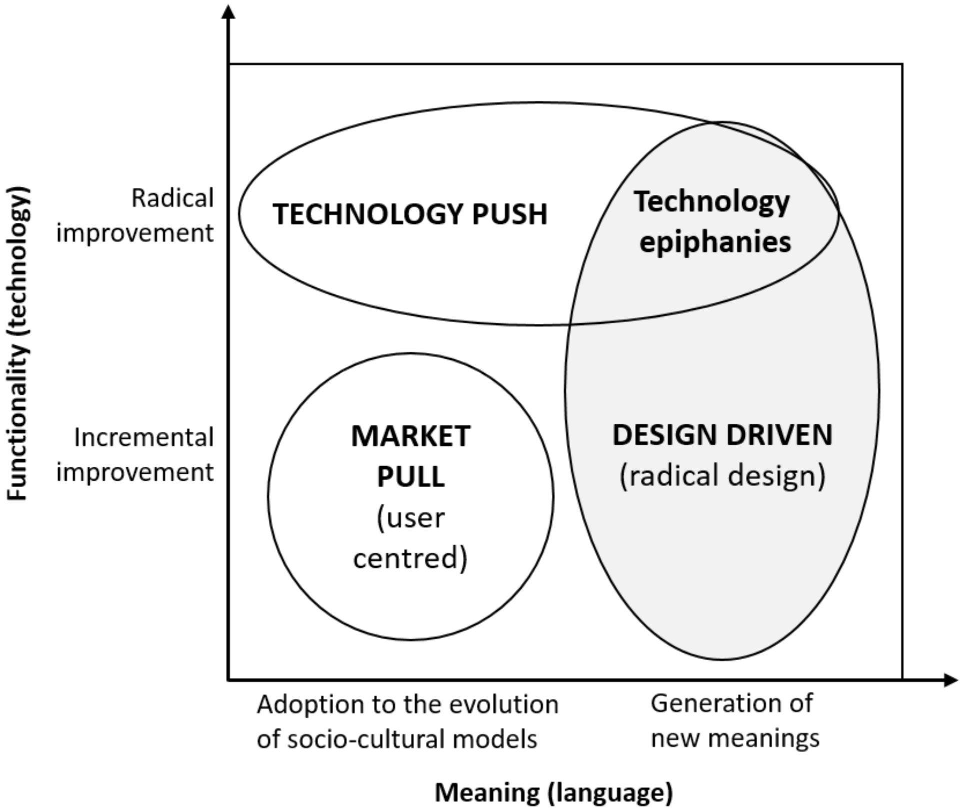


Figure 3. Innovation Strategies and the positioning of the radical design and technology epiphanies by Verganti (2011)

Technological change and the technology life cycle could be considered as an upgrade, meanwhile, in fact there is a new technological deployment, which means that in the short term, business has the ability to manipulate the market. In other words, there is a difference, how technology users understand the technology and its upgrades. These issues are also important from the adopters' point of view, because of two things: firstly, there is a gap of social manipulation presenting an upgrade as a major technology shift; secondly, the costs of adoption are particularly different in comparison with new technology deployment and only technological upgrades.

Verganti (2011), describes three modes of innovation:

- *Design*-driven innovation (radical design), where innovation starts from the comprehension of subtle and unspoken dynamics in sociocultural models and results in proposing radically new meanings and languages that often imply a change in sociocultural regimes;
- *Market*-pull innovation, where innovation starts from the analysis of user needs, and subsequent searches for the technologies and languages that can actually satisfy them. We include user-centred innovation as a declination of market-pull innovation, as they both start from users to directly or indirectly identify directions for innovation. Indeed, user-centred approaches still operate within existing sociocultural regimes, although, being more sophisticated than traditional market-pull processes, they may allow us to better understand how people give meaning to existing things;
- *Technology*-push innovation, that is, the result of dynamics of scientific and technological research. This is where many studies of technology management have been focused in the past.

According to Haupt et al. (2007) and Shahmarichatghieh et al. (2015), patent based Technology Life Cycle stages of the life cycle is the same as Product Life Cycle and the x-axis of the diagram is time as well, but the y-axis is the patent index (see Figure 2). In the introduction (emerging) stage, most of the product developments belong to the fundamental definition of the technology rather than applicable ideas for products in the real market, the R&D teams are trying to find the concept of the technology. Therefore, the application is low and as the risk of investment is apparently high there are not numerous companies who want to be inside the circle. Thus, the competitiveness is low and product integration does not exist. In the growth stage when the concept is discovered, and the tendency of findings went from radicals to applicable market useable products, the applications will increase. The risks of investment decrease and more companies will enter into the completion. Next, in the maturity stage, when the number of patent applications does not change any more, the risk of investment in the stage is low but the number of competitors is at its peak point. The companies are still competing as the previous stage but the technology is completely integrated into new products. Finally, in the decline (Saturation) stage, at the time that the patent applications take a minus trend the technology has left its climax point. The developments belong to minor and major enhancements and the direction of technical improvement, the competitiveness decreases and the "Key Technology" will become "Base Technology".

Taylor and Taylor (2012), stated, that the cyclical model incorporates individual technology cycles, each of which begins with a technological discontinuity, i.e. a breakthrough innovation affecting either processes or products. These discontinuities are followed by a period of ferment[1] during which rivalry and competition among variations of the original breakthrough eventually lead to the selection of a single dominant configuration. Later, such dominant design becomes the industry standard. Following the emergence of the dominant design, an era of incremental evolution of

[1] Definitions of technology life cycle stages (such as era of ferment, era of incremental change, etc.) were found in Anderson and Tushman (1990) research and used in Taylor and Taylor (2012) models.

the selected technology makes up the remaining stage of the cycle. During this period, emergent changes are also known as evolutionary, continuous, incremental or "nuts and bolts" technologies. Once this is over, the cycle of variation, selection and retention begins again with a further technological discontinuity (see Figure 4). The era of ferment is intentionally touching the preceding block to emphasise that it follows immediately from the technological discontinuity. Similarly, the era of incremental change begins without delay following the emergence of the dominant design. The authors Taylor and Taylor (2012), in their research presented a conceptualisation of the technology life cycle (see Figure 4).

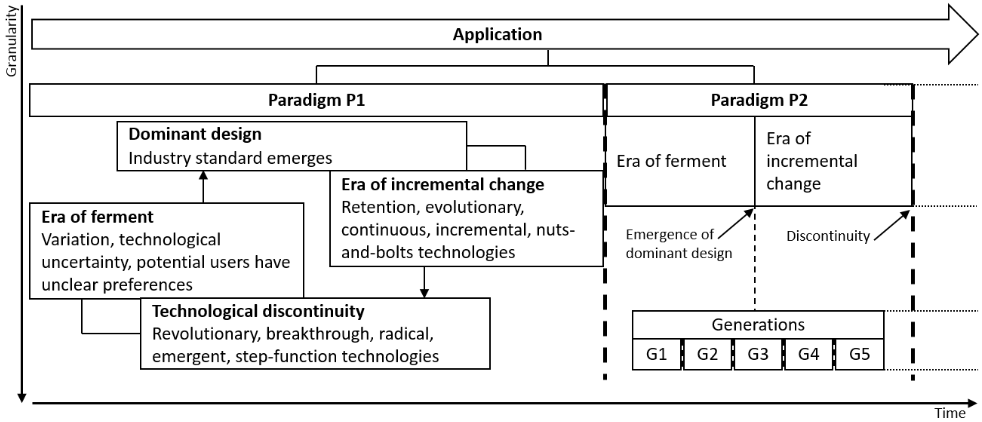


Figure 4. A conceptualisation of the technology life cycle incorporating application, paradigms and generations by Taylor and Taylor (2012) adopted by the author

According to Anderson and Tushman (1990), the era of ferment is characterised by two processes. The first is technological substitution; the innovative product or process replaces the prior technical regime of the industry. The second is design competition. The emergence of a dominant design changes the competitive landscape. After a dominant design emerges, technological progress is driven by numerous incremental innovations. The era of incremental change is characterised by incremental, competence-enhancing, puzzle-solving actions of many organisations.

According to the authors, taking technology as the unit of analysis, and based on the twin dimensions of granularity and time, the model incorporates the three key entities of application, paradigm and generation. The application for a technology forms the highest level of abstraction, and is delivered over time by a number of different paradigms. Within each paradigm, the model differentiates between the eras of ferment and incremental change that are separated by the emergence of a dominant design.

In the academic literature, the phenomenon of the life cycle could be found in terms of product, industry, technology and market development. Each of the cycles have their own determination and development phases. As it was pointed out, investment timing depends on the moment of technology life cycle, considering the general topic it is obviously crucial to understand and define technology life cycle fluctuations as well as the factors, which can describe the cyclicality mentioned previously. Again, technological change and the technology life cycle could be considered as an upgrade, meanwhile, in fact there is a new technological deployment, which means that in the short term business has the ability to manipulate the market. In general, considering technology adoption investment timing decisions, according to the different authors of the academic literature, selected technology life cycle historical paths have to be analysed, also future fluctuation directions have to be defined, or in other words technology life cycle continuity must be integrated beyond actual data sets of current and upcoming paradigms.

1.3. The concept of technology adoption investment timing management solutions

In general, market timing decisions cover multi-disciplinary issues in the strategic managerial management process. Especially frequently definition of optimal timing founded in last years' academic literature involves a variety of elements such as: mathematical technology investment decision model for company value increase (Krušinskas and Vasiliauskaitė (2005) and Krušinskas (2008)); optimal time to outsource under market uncertainty changes (Moon (2010)); how changes in the irreversibility of investment affect the timing and intensity of lumpy investment (Wong (2010)); investment timing by risk averse managers facing incomplete markets and corporate control (Henderson (2010)); financing decisions of debts or equity should predict future stock returns (Butler et al. (2011)); the effect of progressive taxation on a firm's investment intensity and timing decisions using a real options approach (Wong (2011)); energy-related industrial investment projects evaluation under uncertain energy market conditions (Svensson et al. (2011)); examine the timing of investment decisions in relation to the issuance of convertible debt by firms (Yagi and Takashima (2012)); predicting cuts in investment and pay-outs under significant uncertainties in corporate financing conditions (Bolton et al. (2013)); capacity expansion under volatile demand growth and finite equipment lifetime (Chou et al. (2014)); technology adoption intensity rate of new arrivals (Hagspiel et al. (2015)); etc.

In the academic literature, many factors causing technological changes are taken into consideration. These factors are known as drivers, which affect the decision making process, and, according to Ellis and Shpielberg (2003), Chambers (2004) and Vasauskaite (2013), are determined as mobile production, rapid technological development, constant search of the optimal price and quality ratio, saturated markets, globalisation of the investments and the markets, market fragmentation and shorter life cycle of technologic monopolies. Meanwhile, as was pointed out by Chen and Ma (2014), most of the literature of technology adoption is from the perspective of the psychology-based acceptance of new technologies by individual users or organisations. Well-known works from this perspective include the technology adoption lifecycle model, the Bass diffusion model and the technology acceptance model. There are times, when human society as a system needs to consider the adoption of new technologies for the sustainable development of the system. Barreto and Kypreos (2002) and Ma (2010), analysed technology adoption with an operational optimisation framework, which assumes perfect foresight for a long period of time.

However, there are many unpredictable factors by assuming different future scenarios. According to Chen and Ma (2014), in the real world, decision makers commonly adjust technology strategies, based on evaluations of the market and technologies at different stages. In other words, decisions related to technology adoption are commonly made with limited foresight, but adaptively, in reality. In general, it could be said, that technology adoption in the context of innovation processes could be considered as a part of the investment timing process, where a company shifts existing or adopts new technology and afterword commercialise it in the market.

Benaroch and Kauffman (1999) and Huisman (2001), stated that the theory of real options has the potential to play a role in the assessment of business strategies, technology investments and strategic alliances in the highly uncertain and technology driven digital economy. According to Amram and Kulatilaka (1999) and Kauffman and Xiaotong (2005), its advantages over capital budgeting methods have been widely recognised for the analysis of strategic investment decisions under uncertainty. However, the competitive process that occurs around a technology investment have be taken into consideration. As was pointed out by Grenadier and Weiss (1997), there are four potential technology migration strategies:

- *compulsive strategy*: purchasing every innovation;
- *leapfrog strategy*: skipping the earliest version, but adopting the next generation of an innovation;
- *buy-and-hold strategy*: only purchasing the early innovation;
- *laggard strategy*: waiting for the arrival of new innovation and then buying the previous innovation.

In the analysis of real options method usage, Kauffman and Xiaotong (2005), underlined the dynamics of the technology competition process play and purposed a continuous-time approach using the Brownian motion stochastic process to simulate changes over time in a technology adopter's expectations and proved suitability of this method of usage. Therefore, the core of optimal timing, which combines whole elements, is the uncertainty and volatility of the environment. According to Huisman (2001), the technology arrival rates for technological innovations are constant, meanwhile, Hagspiel et al. (2015), relaxed this assumption and assumed that the arrival rate of technological innovation changes with analysis of the electronics industry examples. Thus, it is clear that despite the area in which the industrial company is operating, or what activity the company is providing, if the product and/or service and/or process is technology based, it is only a matter of time before the company will be faced with the necessity to adopt the technology innovation. Moreover, a large fixed cost occurs upon the adoption, which becomes a sunk cost because technology choice is irreversible. Huisman (2001), presented research on technology adoption timing decisions in a real options context and extended the traditional decision of theoretic models on technology adoption with a model in which the technologies arrive according to the Poisson process. The author stated the optimal time to irreversibly switch to a new technology when the value and arrival date of future improvements are uncertain. Authors such as Cho and McCardle (2009), Kwon (2010) and Smith and Ulu (2012), were studying the general model of technology adoption in which time is finite and discrete and at the same time companies are faced with uncertainty on both costs and quality. These authors were using multiple decision, NPV, single adoption investment decision models, where the focus was on deriving the structural properties of the value function and the optimal policies. Meanwhile, Hagspiel et al. (2015), improved the focus and studied the effect on the adoption strategy when the arrival rate of new technology changes over time. Cho and McCardle (2009), exploit the role of stochastic technological and economic dependence on the adoption of multiple types of new technology. The authors proved that this dependence has a material impact on companies' technology adoption decisions and this can either delay or expedite the adoption of technological shift. Kwon (2010), analysed investment and exit decisions of a company facing a declining profit stream, thus there are three options: continue activity, exit or make a onetime investment, which empowers the company to boost the project's profit. Hagspiel et al. (2015), found in some cases that the company optimally adopted a new technology with a time lag after the innovation took place. Results showed that the probability of a time lag between innovation and adoption can be substantially high. Doraszelski (2004), stated that the company may have an incentive to delaying the adoption of new technology until it is sufficiently advanced. However, the results of research by Hagspiel et al. (2015), showed that the probability that a company adopts a new technology with a time lag after its innovation is strictly positive in case the arrival rate would drop after a certain time period without any new arrival. If the firm expects the arrival rate to rise, the time lag effect is not present. Therefore, as Huisman et al. (2003) pointed out, it has been underlined that the optimal investment decision in this perspective may not be dependent only on the characteristics of uncertainty, but also on strategic interactions. This is the case when an option is shared rather than private, so that if the competitor exercises it first the option is no longer available, or its value is reduced.

According to Campbell (2002), there is a growing view that the techniques used to evaluate financial options might be appropriate, in certain circumstances, for evaluating capital investments that have an option like characteristics. These types of investment choices are usually referred to as real options, as the investment opportunities typically involve real assets rather than paper-based assets. The common approach has been to determine the optimal time to begin the development of a project by deriving and analysing the value of waiting to invest. In this case, the evaluation of opportunity costs of waiting has to be taken into consideration.

Thus, in order to understand the conditions and circumstances of entering new technology, companies are forced to solve competition and concentration levels and forms in the industry. Perez (2001), presented a summary of the changing patterns of competition and power structure. The power structure even indicated the size of the window of opportunity in each phase and the conditions that have be fulfilled by aspiring entrants, be they dependent or acting autonomously as direct challengers in the market. It is worth underlining that the scheme does not represent all cases. It was noticed that since there will always be products and industries passing through the different phases, companies are forced to be deliberate about the phase of evaluation and patters of competition in order to make the correct managerial decisions in the context of competition. Even more, companies must identify the current phase of deployment the technological revolution.

Perez (2001), in the analysis of technological and management "common sense", noticed that at the microeconomic level, each radical innovation represents a discontinuity followed by continued evolution until the reduction in the possibilities of increasing productivity and profits gives rise to a search for other radical innovations. Meanwhile, at the macrosystemic level, the successive technological revolutions irrupt in the economic system, bringing whole constellations of new products, technologies and industries. The author analysed periods of change of paradigm, and noticed that during the transition between them, the two main windows of opportunity open simultaneously: phase 1, that of the new technologies and phase 4, that of mature technologies (see Figure 5).

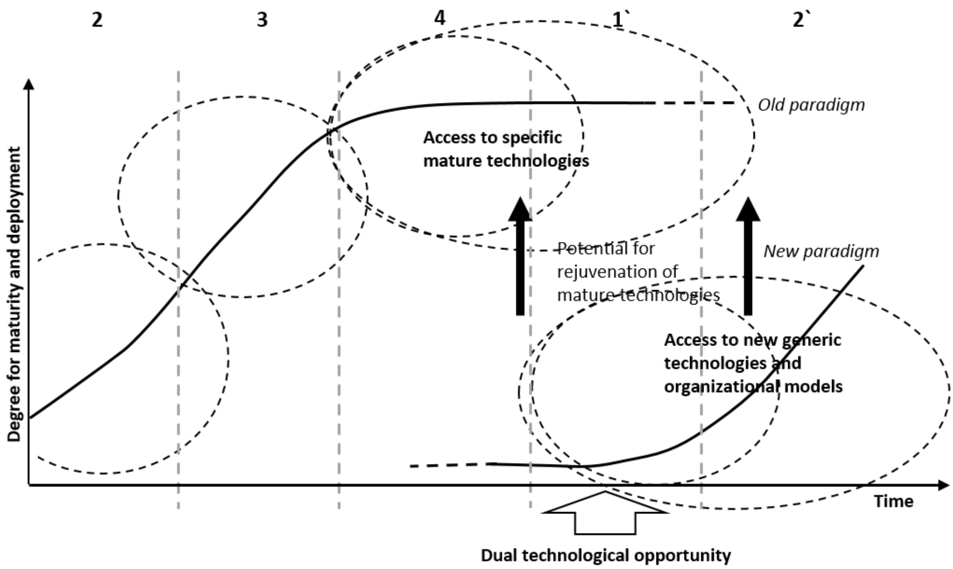


Figure 5. Transition as the best opportunity for making a leap forward by Perez (2001)

According to Perez (2001), although mature products can serve to provide growth for a certain length of time, they are not capable of driving a process of catching up, because their innovation potential is largely exhausted. Therefore, in the period of transition there is an optimal opportunity for making a leap forward, there the new generic technologies and organisational principles can be applied in order to modernise and rejuvenate mature technologies. On the other hand, the problem is then how to pass phases 2 and 3. This requires growing support from the economic environment, constant innovation and capital-intensive investments.

Murto (2007), expanded the investment timing approach by analysing the uncertain technological progress and uncertain revenue stream. When there is only technological uncertainty, the certainty equivalence holds and an estimate on the expected path of future development is sufficient for the optimal decision. However, it was found that when revenue uncertainty is included, then technological uncertainty also starts to matter, making the investor more hesitant to invest. Thus, it is the combination with revenue uncertainty that makes technological uncertainty relevant for the decision maker.

As was pointed out previously, the phenomenon of technology investment is crucial in the adoption time moment, thus the managerial cases in the academic literature were taken into consideration. It was found, that there are a variety of different authors who emphasise the importance of investment timing management in different economic models. In general, after the market of paradigms is analysed and technology life cycle fluctuations are defined, the future technological continuity has to be forecasted. Next, according to the managerial management strategy, demand factors and the technology development phase, managerial decisions can be taken.

1.4. Technology adoption investment timing assessment methods based on company's investment strategy selection

In today's intensive development technological economy, companies are challenged to keep competitiveness and offer customers a continuous line of innovative and latest technology based products and services, thus, in technology intensive industries, investments in technology adoption are inevitable. David et al. (2001), analysed activity in technology based companies and found that this issue is strongly associated with R&D (Research and Development) in a strategic context where R&D investments are likely to enhance the company value, thus, this indicates the strategic importance of innovation, and constitutes an important input for the development of intangible capital, differentiation and product innovation. Kor (2006), developed and tested a theory of direct and interaction effects of the top management team and board outsider composition on R&D investment intensity. The author noticed that both the top management team composition and corporate governance gave direct and additive effects on R&D investment intensity. Even more, monitoring by outsider directors does not constitute a universally effective governance mechanism with regard to a company's R&D investment strategy. And finally, when a company' competitiveness relies on continuous investments in R&D, it is crucial for them to make the necessary adjustments to promote a healthy dialogue between the board and the management team. The solution to the puzzle of why firms differ in R&D investment intensity lies in how they achieve balancing the complex direct and interaction effects of the top management team and board composition on R&D investment intensity.

Biagini et al. (2014), analysed the technology transfer for adoption after it had been deployed. Through the analysis of Global Environment Facility-managed adoption projects, the authors found there is significantly more technology transfer occurring in adoption projects than might be expected given the pessimistic rhetoric surrounding technology transfer for adoption. Most projects focused on demonstration and early deployment/niche formation for existing technologies rather than earlier stages of innovation, which is understandable considering the pilot nature of the projects. Key challenges for the transfer process, including technology selection and appropriateness under climate change, markets and access to technology, and diffusion strategies are presented in Figure 6.

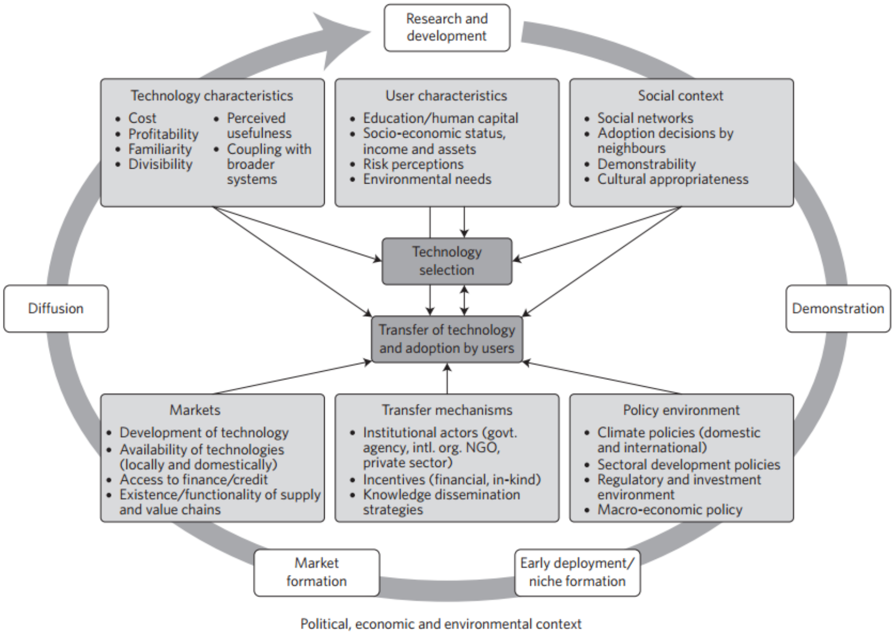


Figure 6. Technology transfer and adoption for climate change adoption by Biagini et al. (2014)

According to Biagini et al. (2014), the model of technology transfer and adoption recognises that many factors are important for technology selection, transfer and, ultimately, adoption of new technologies by users. The factors included here have been identified as the most critical for the climate adoption context, although additional factors may also be influential. This model recognises that technology transfer and innovation are inherently linked and occur simultaneously, with innovation occurring throughout the transfer process, and feedback loops among all the factors. The model is also neutral regarding the source of innovations, both in terms of geographic origin and players. Scarso (1996), formed an option-based approach to technology strategy, which strictly recalls the resource-based theory of competitive advantage (see Figure 7).

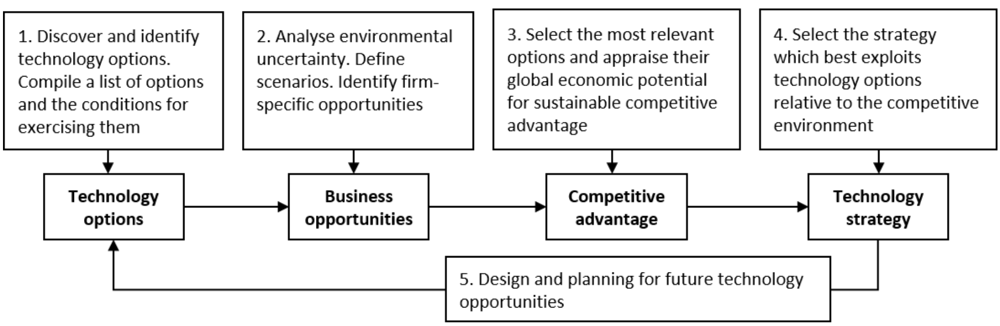


Figure 7. An option-based approach to technology strategy by Scarso (1996)

If technology options are the basis of business opportunities, which constitute the background of the competitive advantage, firms have to follow the innovation strategy that best exploits the available opportunities and poses the premiss for designing and planning new technology options. According to Scarso (1996), the value of this approach is twofold. On the one hand, it stresses the importance of considering all the (present and future) advantages directly and indirectly involved with the new technology; on the other, it highlights the value of persistent information gathering activity. It is exactly the direction of taking explicit advantage and continuously generating new opportunities, thus, providing an option based approach to a technology strategy. As was pointed out by Pertile (2007), it is typical in game theoretical real option models, where the equilibrium is either sequential or simultaneous, depending on the parameter values. In the pre-emption equilibrium, there is an incentive to pre-empt the competitor up to the point where the leader's and follower's values are equalised. In this case, investments are made sequentially in equilibrium. In the second class, besides the pre-emption equilibrium, there is a continuum of Pareto-superior equilibria with simultaneous investments. Assuming that the investment is infinitely divisible, Pertile (2007), underlined that in moving from a monopoly to a perfect competition the optimal timing of irreversible investment is unaffected. A first attempt by Bouis, Huisman and Kort (2006), to extend the analysis with discrete investment to n-players confirms that obtaining general results on the impact of an increase in the number of competitors is complicated. The effects of exogenous changes in the parameters may be asymmetric across the players, meaning that some of them invest earlier, while others invest later.

According to Martinez (2013), the stages of innovation framework depicts three stages: Invention, Innovation, and Adoption are shown in Figure 8.

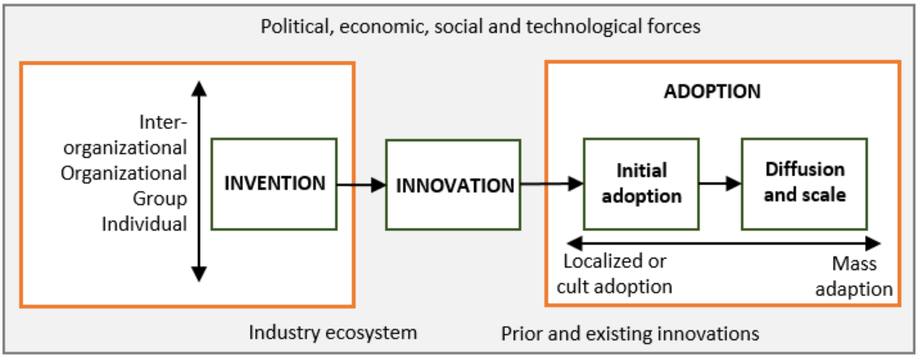


Figure 8. The stages of innovation framework by Martinez (2013)

Meanwhile, according to Rogers (2010), there are four stages of the technology life cycle. In the innovation stage, new products, materials or processes are being presented from R&D activities. The syndication stage represents the demonstration and commercialisation of new technology. Next, the diffusion stage represents the market penetration of a new technology through the acceptance of the innovation by potential users of the technology, however, supply and demand side factors jointly influence the rate of diffusion. Finally, the substitution stage is the last stage and represents the decline in the use and eventual extension of a technology, due to replacement by another technology. Rogers (2003), defined diffusion as “a special type of communication in which the messages are about a new idea”. This gets to the key point that availability of a new idea is not enough; rather, diffusion is more dependent on the communication and decision-process about whether and how to adopt the new idea. This process is shown in Figure 9 below.

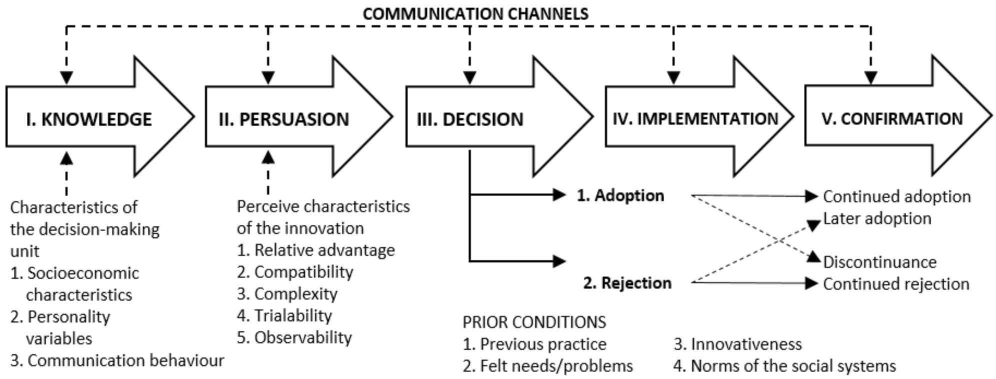


Figure 9. A Model of the Five Stages in the Innovation-Decision Process by Rogers (2003)

There is knowledge and application amongst some early adopters in small-scale pilots, but a majority of faculty members either have no knowledge of the pilot or are not persuaded that the idea is to their advantage, and there is little support or structure to get the organisation at large (i.e. the majority of the faculty for a traditional institution, or perhaps for a central academic technology organisation) to make a considered decision. It’s important to note that in many cases, the innovation should not be spread to the majority, either due to being a poor solution or even due to organisational dynamics based on how the innovation is introduced.

According to Hori and Osano (2013), irreversibility creates an option value in waiting to launch a risky but value-increasing investment project and strongly affects the decision maker’s incentives in undertaking the project. Managing development decisions for new products and/or services based on dynamically evolving technologies is a comprehensive and complex challenge, especially in highly competitive industries. Authors such as Bhaskaran and Ramachandran (2011), presented an analysis of how a firm could incorporate the presence of a strategic competitor in making technology selection and investment decisions regarding new products. In the research, the innovative firm and its rival can introduce a new product immediately or pursue a more advanced product for a later launch. Bhaskaran and Ramachandran (2011), underlined that in highly competitive industries, firms can adopt different technologies and effectively use introduction timing to mitigate the effects of price competition. More importantly, the firm could strategically invest in the advanced product to influence its rival’s technology choice. Krishnan and Loch (2005), stated that the selection of new product and risk management in the development process are the most critical challenges. Huchzermeier and Loch (2001), underline the uncertainty of new product development in terms of numerous reasons that range from unreliability of the market forecasts to the creative and unpredictable nature of the process itself.

In the academic literature a variety of models could be found that are used to manage new product development under the technology change pressure. Loch and Terwiesch (2005), created a model of real-time decision making in projects where collaborating stakeholders adapt to the stream of information they retrieved from the partner's side. Bhaskaran and Ramachandran (2011), modelled resource allocation decisions as a higher level variable that affects the outcome of a project without modelling the details of this process in a competitive environment. Basically, product development management challenges companies to make technology adoption decisions because of increasing competitive pressures. Thus, the authors found that competing firms often have the incentive to choose different roles as market pioneers or technology leaders by making significantly different product development and introduction decisions. Even companies that have similar technological options have strong incentives to stagger the order in which they enter the market. This situation enables the company to use introduction timing as a mode to further differentiate its product in competitive environments. Secondly, a firm can use investments in advanced development not just to improve the outcome of that project, but also as a strategic tool to control the introduction strategy of a competitor. A conceptual framework that can assist managers in the development and commercialisation of new products is presented in Figure 10 below.

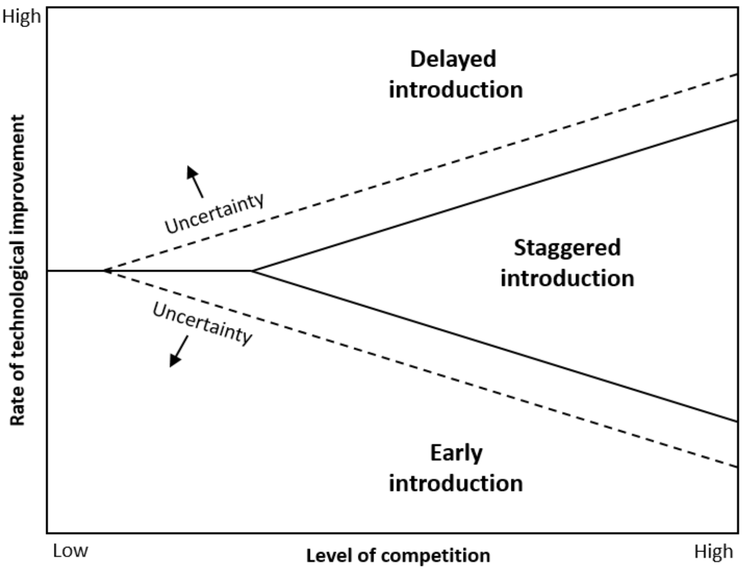


Figure 10. Entry strategies for various market and technological conditions by Bhaskaran and Ramachandran (2011)

According to the authors, when the level of competition is low, a firm's launch decisions can be fairly independent of its rival's entry decisions. In addition, if the technology is expected to improve at a very limited (or significant) rate, the firm should still act unilaterally and introduce a product early (or later). However, as the level of competition increases, the firm should move away from unilateral decision making; instead it should incorporate the competitor's product attributes and introduction decisions in determining its strategy. Furthermore, when the risks involved in developing the advanced version is high, the management of uncertainty, in conjunction with staggered product introduction, becomes critical to the success of a company.

In the alternative research, Vasauskaite (2010), seeks for the time selection for the implementation of new technology on the basis of technology efficiency parameters. In this case the author forms a set of factors for time selection, next technology efficiency parameters are calculated, in the third part technology life cycle identification is done, next the time of technology implementation is defined and finally, qualitative evaluation of the time selection for implementation of new technology is done.

Nowadays, the emergence of knowledge as one of the factors of production is creating a great impact on internal organisation resources and is leading to competitive advantages among companies. Perhaps the most important feature of knowledge is it being non-exclusive public goods, in fact, employing knowledge does not stop other people from using it. But what is rare is the ability to use knowledge in ways that ensure growth and economic development. The authors Jakšić and Jakšić (2012), stated that economic growth and development are strongly related to technological change, and the character of new technologies is radically changing the focus of key development factors. The growth of the knowledge economy is primarily based on the creation and effective utilisation of knowledge. Developing countries have raised their expectations high in terms of the development of the knowledge economy (Kriaucioniene, 2009). Hall et al. (2009) and Hall and Jaffe (2012), analysed the importance of science, technology and innovation level measurement and presented a systemised list of indicators that could be used to measure technology, innovation level or how much a company is science based and/or environment friendly. However, these indicators are more applicable for S&T environment assessment, than for an S&T based company. Haq (2012), analysed how integrative knowledge-based development can contribute to economic growth and social development as an important field of research. The author showed how it would be useful for country-specific demands and issues, and the significance of investment in knowledge-based research and the importance of universities in the practice and advancement of integrative approaches of knowledge-based development. Adamauskas and Krusinskas (2013), presented a list of indicators (see Table 2), that could be used for S&T based company identification.

Table 2. STI indicators

Indicator	Meaning/importance
R&D spending / Net sales	Amount of net sales, which equals to R&D spending. Basically, it is useful to measure the impact of R&D expenditure on net sales.
R&D spending / EBITDA	The efficiency of R&D products.
R&D spending / Employees	Amount of R&D spending for one company's employee.
Net sales / S&T degree holder	Amount of net sales for one science and engineer degree holder.
Net sales / PhD's	Amount of net sales for one PhD degree holder
Education spending / Spending	The level of education spending in comparison to all spending.
Innovation revenues / Revenues	The level of innovation revenues in comparison to all revenues.

Source: Adamauskas & Krusinskas (2013)

These ratios were created in accordance with S&T based company features, R&D environment and other key issues, which are important in the research of such company. Also it must be underlined that after the academic literature review, where the main focus is on the science and technology interrelationship, this list of indicators shall be used to analyse these kinds of companies, nevertheless these indicators are exclusively dedicated for R&D based companies and their application success mainly depends on data validity.

Also the condition of the availability data was taken in consideration, thus, all quantitative ratios are easily computed. According to Adamauskas and Krusinskas (2013), during the analysis of S&T based company interactions with the industry's environment, the strategic management problem appeared, and then the incentives of firms to invest in research and development were analysed. Vandekerckhove and Bondt (2007, 2008), took into account this problem and analysed it through the sequential moves of the companies. According to the authors, there may be spillovers between leaders and followers, and also between these two groups of players. Critical spillover values are identified that drive the effects of cooperation in R&D as is the case in simpler settings. These S&T company strategic moves could be considered both as a feature of such kind of company and as a result when the company is operating in an S&T based environment. The nature of strategic investments is to maintain a sustainable competitive advantage.

After the analysis of the academic literature, it could be declared that the optimal technology adoption investment timing decision making process should include historical development analysis of the product and/or service with demand path volatility as well as technology life cycle analysis. Furthermore, the uncertainty of demand in the future has been projected and the technology life cycle continuity has been integrated beyond actual data sets. Through the data arrays in the analysis, crucial and the most important for the technology development, demand volatility and behaviour investment parameters must be taken into consideration. Combined together they empower the decision maker to take the optimal technology adoption investment timing decision for competing companies in the market. According to the purpose of this thesis, in Section No. 2, the comprehensive technology adoption investment timing valuation support model is constructed.

2. COMPREHENSIVE TECHNOLOGY ADOPTION INVESTMENT TIMING VALUATION SUPPORT MODEL CONSTRUCTION

It is practically impossible to determine new future technology demands, or even its success in adoption due to the time consuming technology adoption decision process, thus investment timing decision management is considered as the comprehensive model, based on mathematical calculations, business understanding and parameters, which can reveal and prove the validity of the models' results for companies' strategic managerial decisions. In general, the aim of this thesis has several threads. Firstly, continuing mobile technology changes, and benefits of high-speed (mobile wireless) internet (even with low energetic costs) force telecommunication companies to compete and satisfy demand for network implications. On the other hand, investment returns must be sufficient in the high-tech mobile technology industry.

Next, all the models' stages are explained in more detail in terms of necessity, calculation sequence and formulas required to reach the goal presented in the introduction.

2.1. Historical demand paths analysis and statistical data validity tests

Historical demand paths analysis

The historical demand paths of mobile service market revenues, which are directly associated with mobile technology generation, defined in the maturity of at least 30 quarters. In this thesis, it is assumed that demand volatility depends on two parameters; average market revenue and quantity of subscribers. After the historical analysis of parameters, dynamics and growth rates, extraordinary events take place (if there are any) in understanding unusual changes. Penetration rates will be analysed in order to understand permeability of wireless services in selected markets. It must be underlined that in the wireless service market Revenues and Wireless Subscribers are considered as a framework ratio and will be used in forecasting and understanding demand uncertainty, thus, in the next stage the statistical data validity test shall be applied.

Statistical data validity tests

As was mentioned previously, statistical data validity tests of wireless market Revenues and Wireless market subscriber's data are applied. Brockwell and Davis (2002), Liang (2003), Watteel-Sprague (2000), Maratha and Sarah (2005), Hui (2012) and Chou et al. (2014), offer these statistical analyses methods for the appropriate geometrical Brownian model: Dickey-Fuller test, Q-Q plots, autocorrelation test and Kolmogorov-Smirnov test, which are briefly summarised below.

Augmented Dickey-Fuller test

According to Green (2002), the implications of unit roots in macroeconomic data are potentially profound. If the variable is truly *I*, then the shocks will have a permanent effect. It is noticed, that if it was confirmed, then the observation would mandate a major reconsideration of the analysis of macroeconomic policy. Consider the simple AR (1) model with zero-mean, white noise innovations,

$$y_t = \gamma y_{t-1} + \varepsilon_t. \quad (1)$$

At this stage Dickey and Fuller proved that if γ equals one, then

$$T(c - \gamma) \xrightarrow{d} v, \quad (2)$$

where v is a random variable with finite and positive variance.

Green (2002), underlines two important implications in the Dickey-Fuller study results: The first is that the estimator of γ is biased downward if γ equals one, and the second – the OLS estimator of γ converges to its probability limit more rapidly than the estimators. An extension that will accommodate some forms of serial correlation is the augmented Dickey-Fuller test (see Formula 3 below):

$$\Delta y_t = \mu + \gamma^* y_{t-1} + \sum_{j=1}^{p-1} \phi_j \Delta y_{t-j} + \varepsilon_t, \quad (3)$$

$$where\ \phi_j = -\sum_{k=j+1}^{p} \gamma k\ and\ \gamma^* = \left(\sum_{i=1}^{p} \gamma_i\right) - 1.$$

In other words, this test is created to define whether the time series has a unit root or not. Unit root is an auto-regression parameter equal to one. If the time series has a unit root, then it is not stationary. According to Green (2002), the unit root test is carried out as before by testing null hypothesis $\gamma^* = 0$ against $\gamma^* < 0$. The test statistics formula is presented below:

$$DF_t = \frac{\hat{\gamma}}{SE(\hat{\gamma})} \quad (4)$$

Dickey-Fuller present counterparts to the critical *F* statistics for testing the hypothesis (Banerjee et al. (1993)). To ensure the time series stationarity verified by the Dickey-Fuller test with a significance level of 0.05, the obtained *p*-value shall be greater than 0.05.

Q-Q plots

According to Thode (2002), probability plots are plots of sample order statistics against some "expected" values of the order statistics (Q-Q plots), or against some uniform order statistic (P-P plots). Regression tests are measures of the linearity in probability plots. The selection of a value for the abscissa of the plot is (or is dependent upon) an estimate of the empirical cumulative distribution function of the hypothesised null distribution.

The quantile-quantile (Q-Q) plot is a graphical technique for determining if two data sets come from populations with a common distribution. A Q-Q plot is a plot of the quantiles of the first data set against the quantiles of the second data set. By a quantile, it means the fraction of points below the given value. That is, the 0.3 quantile is the point at which 30% percent of the data fall below and 70% fall above that value. Motulsky (2013), is declaring that if the data are truly sampled from a Gaussian distribution, the Q-Q plot will be linear. If the X and Y values are comparable, then the points are expected to line up on the line of identity. Systematic deviation from this ideal is evidence that the data are not sampled from a Gaussian distribution. In other words, if the two distributions being compared are similar, the points in the Q-Q plot will approximately lie on the line y = x. If the distributions are linearly related, the points in the Q-Q plot will approximately lie on a line, but not necessarily on the line y = x. Q-Q plots can also be used as a graphical means of estimating parameters in a location-scale family of distributions.

The main step in constructing a Q-Q plot is estimating the quantiles to be plotted. If one or both of the axes in a Q-Q plot is based on a theoretical distribution with a continuous cumulative distribution function (cumulative distribution function, CDF), all quantiles are uniquely defined and can be obtained by inverting the CDF. If a theoretical probability distribution with a discontinuous CDF is one of the two distributions being compared, some of the quantiles may not be defined, so an interpolated quantile may be plotted. If the Q-Q plot is based on data, there are multiple quantile estimators in use. Rules for forming Q-Q plots when quantiles have been estimated or interpolated are called plotting positions.

Autocorrelation test

Green (2002), noticed that the autocorrelation tests are based on the principal that if the true disturbances are autocorrelated, then this fact can be detected through the autocorrelations of the least squares residuals. The simplest indicator is the slope in the artificial regression

$$e_t = re_{t-1} + v_t,$$
$$e_t = y_t - x_t'b.$$
$$r = \frac{\sum_{t=2}^{T} e_t e_{t-1}}{\sum_{t=1}^{T} e_t^2} \quad (5)$$

If there is autocorrelation, then the slope in this regression will be an estimator of $\rho = Corr[\varepsilon_t, \varepsilon_{t-1}]$. According to Verbeek (2008), the autocorrelation function describes the correlation between Y_t and its lag Y_{y-k} as a function of *k*. Recall that the *k*-th order autocorrelation coefficient is defined as

$$\rho_k = \frac{cov\{Y_t, Y_{t-k}\}}{V\{Y_t\}} = \frac{\gamma_k}{\gamma_0}. \quad (6)$$

According to the graphs of autocorrelation it is possible to determine stationarity of the process. The values of the stationary process are close to zero. Finally, given measurements, $Y_1, Y_2, \ldots, Y_N$ at time $X_1, X_2, \ldots, X_N$, the lag *k* autocorrelation function is defined as

$$r_k = \frac{\sum_{i=1}^{N-k}(Y_i - \bar{Y})(Y_{i+k} - \bar{Y})}{\sum_{i=1}^{N}(Y_i - \bar{Y})^2} \quad (7)$$

Autocorrelation is a correlation coefficient. However, instead of correlation between two different variables, the correlation is between two values of the same variable at times X_i and X_{i+k}.

Kolmogorov-Smirnov test.

According to Motulsky (2003), prism tests for deviations from Gaussian distribution using the Kolmogorov-Smirnov (KS) test. Since the Gaussian distribution is also called the "normal" distribution, the test is called a normality test. The KS statistic quantifies the discrepancy between the distribution of your data and an ideal Gaussian distribution, larger values denoting larger discrepancies.

Meanwhile Bolen et al. (2014) noted, the Kolmogorov-Smirnov test is a nonparametric procedure used to test for the equality of continuous, one-dimensional probability distributions that can be extended for the comparison of two independent samples. The Kolmogorov-Smirnov statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution. The Kolmogorov-Smirnov test statistic is defined as

$$D = \max_{1 \le i \le N} \left(F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right) \quad (8)$$

where F is the theoretical cumulative distribution of the distribution being tested, which must be a continuous distribution, and it has to be fully specified.

Finally, the Kolmogorov-Smirnov test for normality of the distribution can be proved than time series obtained *p*-value is greater than 0.05.

Summing up, the aim of this section is to clarify whether the historical data, which are taken into consideration, could be used for Geometric Brownian Motion methodology (next section). As mentioned before, academic literature authors are offering these four statistical data validity tests that shall prove the option for further calculations.

2.2. The forecast of data array using Geometric Brownian Motion method based on the Monte Carlo simulation

In the environment of continuous technological change, companies are usually facing the challenge of technology update and/or adoption decisions, whether to invest in new generation technology or not. Even more, companies need to understand when the optimal time is for such decision making in order to keep competitive, create the maximum possible value for the company and reach the shortest investment payback term. According to Mukherji et al. (2006), who analysed information technology upgrade timing issues, typically a few companies would upgrade or adopt a new version or new generation every time a release is announced; instead they would leapfrog to adopting a subsequent release. However, making such technology adoption investments continuously can be very expensive. The authors noticed that investing frequently is costly and at the same time risky, however, waiting to long can put the organisation at risk of losing the first mover advantage associated with introducing competitive products and services. According to Lee et al. (2009), by using numerical analysis to explore the sensitive analysis of optimal IT investments, the results of the simulation are as follows: the larger (smaller) the IT investments, the higher (lower) the threshold of IT investments, and the greater (smaller) a firm's value will be; increasing (decreasing) price volatility will increase (decrease) the threshold and delay (advance) the timing of investing in IT, which is consistent with the results of real option theorem; and depreciation of IT investments will decrease a firm's value, increase the threshold, and delay the timing of IT investments.

From a variety of timing studies, several types of decision support models could be taken. Bar-Han and Maimon (1993), Kamarianakis and Xepapadeas (2006) and Mukherji et al. (2006) offered the application of dynamic impulse-control methods (such as Black–Scholes) to determine the intervals at which decisions are made; Benaroch and Kauffman (1999), applied an option-pricing model in which the company achieves the information necessary for decision making, however, they do not consider the values and costs that the company will be faced with. Krušinskas and Vasiliauskaitė (2005), analysed the mathematical technology adoption investment decision model for company value increases through technology efficiency parameters although the authors did not measure macroeconomic impact. Ngwenyama et al. (2007), offered to use the learning curve method, which could maximise productivity. As Feil and Musshoff (2013), noticed in analysing the flexibility of the net present value (NPV), extended by the real options approach, irreversible investment should only be realised if the NPV of its expected returns exceeds the investment costs (in this case, the investment threshold is shifted upwards). While Wong (2010), analysed both options, investment and disinvestment, at the same time (investment threshold if the firm is not invested and disinvestment if the firm is invested). Meanwhile Jeon and Nishihara (2014), proposed the reversible investment decision support model with macroeconomic conditions based on optimal switching of a diffusion regime. The authors used Markov chain methodology and considered business cycle fluctuations with additional triggers of investment and disinvestment determined endogenously in each state. Huang and Da (2007) and Wickart and Madlener (2007), used the Geometric Brownian Motion process for the timing decision support model to determine energy price volatility. Pertile (2007), adopted a real options approach through GBM to study the optimal timing of investment in new technologies by health care providers competing for patients and the role of alternative payment systems in the adoption decision. Modelling companies' future profit flow Moon (2010), used GBM, because the future value of profits is difficult to observe and it has an uncertainty. Wong (2010, 2011), Shibata and Nishihara (2011), Whalley (2011), Wong and Yi (2013) and Kim et al. (2014), used GBM for random cash flow under the intensity of investment projection and project value projection. Henderson (2010), used GBM for investment payoff projection in the context of investment timing. Yagi and Takashima (2012), made a demand shock uncertainty evaluation using GBM tools. Meanwhile Bolton et al. (2013), used standard Brownian motion for price of capital and gross of investment analysis for firms facing stochastic financing conditions in the context of market timing as well as Nishihata and Shibata (2013), who used GBM for the price of the project output calculations.

From another perspective, Huisman and Kort (2004), inspired by Fudenberg and Tirole (1985), researched and analysed the scenario of duopoly with identical firms, which both have the option to adopt new technology. According to the model, the later company acquires the technology, the less it costs, however, investing earlier implies that the firm can produce more efficiently from an early point in time. The authors found that since probability, which is expressed by the Poisson parameter, is increasing, the pre-emption game turns into an attrition game. From this perspective and other mentioned technology adoption decision support models, it is clear, that based on the type of technology under consideration, there can be substantial differences in factors that drive adoption decisions. In the real world it is usually difficult to leapfrog new technology and wait for another one, because of losing first mover advantage, have some monopoly profit, even more, the technology adoption decision could be a crucial factor for a sustainable business and inevitable for company survival. Theoretically, adopting new technology or upgrading it every time a new version is released should keep the firms at the cutting edge, thus, the necessity of behavioural investment timing decision support models is becoming increasingly important in real world business. The literature overview shows that previously a lot of models were created, which consider a company's internal capacity expansion (e.g. Abel and Eberly (1996), Dangl (1999), Bøckman et al. (2008) and Chou et al. (2014)) and capabilities to adopt new technology (e.g. sizing models). Later, the authors started to combine macroeconomic factors and associate them together in the context of the decision process. As Jeon and Nishihara (2014), noticed, the investment environment changes frequently by exogenous shocks such as business cycle, and the exercise of the firm's option is affected by them.

Basically, according to Qin (2007), the real options are used to support managerial decisions in an uncertain environment either on a strategic level or on an operational level, moreover, as mentioned above, McDonald and Siegel (1986), showed that demand follows a Wiener process. As was pointed out by Billington et al. (2002), a growing trend is noticed in high-tech companies for determining the optimal timing and scaling using real options. Meanwhile Benavides et al. (1999) and Liang (2003), observed that demand is moving stochastically over time as the Geometric Brownian Motion process. This assumption was used for optimising capacity expansion in terms of timing and scaling. This methodology was also used as the central object of probability theory in the research of Mörters and Peres (2010), at the same time Lawler and Limic (2010), analysed this approximation of random walk by Brownian motion in the context of the stochastic process formed by successive summation of independent, identically distributed random variables. Garvin and Cheah (2004), underlined that a property inherent within Geometric Brownian Motion is log-normally distributed, that is the reason of necessity of statistical data validity tests presented above. Maratha and Ryan (2005) states that many recent examples of Geometric Brownian Motion models have arisen in real option analysis, in which the value of some "underlying asset" is assumed to evolve to the stock price, moreover, the method has also been assumed in problems related to natural resources in terms of forecasting future net prices, even more, for present value cash flows can be modelled as a GBM process. The GBM model has also been used to represent future demand in capacity studies, also Dias et al. (2004), used geometrical Brownian motion for solving and modelling timing issues. Hori and Osano (2013), used the geometrical Brownian motion method in optimal timing of investment when the decision to invest is being taken by a manger under uncertainty.

In general, the Geometric Brownian Motion process can be comprehended as shocked drift value change in a time series, as it is shown in Formula 9 and Figure 11 below. The first term in a Formula 9 is a "drift" and the second term is called "shock". For each time period, the model presumes the value will "drift" up by the expected volatility, however the drift will be shocked (added or subtracted) by a random shock. The random shock will be the standard deviation σ multiplied by a random number - ε. This is simply a way of scaling the standard deviation. That is the essence of the Geometric Brownian Motion process, as illustrated in Annex 9. The created values follow a series of steps, where each step is a drift plus/minus a random shock (itself a function of the stock's standard deviation):

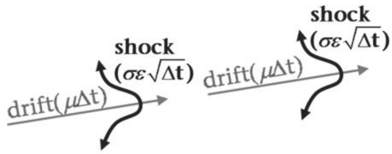


Figure 11. General random walk graphical process

The sample Geometric Brownian Motion trials are shown in Annex 9 using 50 and 100 possible paths. According to Yang (2011), in the modelling of the financial market Brownian Motion plays a significant role in building a statistical model. In general, the process above is of solving a stochastic differential equation, and in fact, Geometric Brownian Motion is defined as a stochastic differential equation.

The scientific novelty, or in other words originality, in this thesis is the methodology of demand dynamics forecast and its determination. After the academic literature review, it was found that there is a variety of methods that consider demand path uncertainty and its forecasts, however, in this thesis it is decided to use the Geometric Brownian Motion process based on the Monte Carlo simulation for defining demand paths in terms of both subscribers and market average revenue per user shall be forecasted. In this model two parameters will be used to describe the wireless market – ARPU and MARPU. According to Osweiler (2013), the Average Revenue Per User (ARPU) has long been the benchmark metric in the wireless industry. This parameter is a measure used primarily by consumer communications and networking companies, defined as the total revenue divided by the number of subscribers. In general, this term is used by companies that offer subscription services to clients (e.g. telephone carriers, ISP, hosts, etc.) and shows the revenue generated by one customer for each time period. This provides a granular view at per user basis and allows the tracking of revenue growth and compares this parameter with market competitors. In this research, all ARPU ratios have been calculated for the same time period for all companies in order to retain the ability of objective comparison. Meanwhile, Market Average Revenue Per User (MARPU) means the same, however, it is calculated as an average ratio for selected regions and/or list of companies and means the market average revenue for one user.

According to Kroese et al. (2014), the Monte Carlo simulation is the generation of random objects or processes by means of a computer. In many cases the random objects in the simulation are introduced "artificially" in order to solve purely deterministic problems, thus, the simulation simply involves random sampling from certain probability distributions. In both way, either the natural or artificial setting of the Monte Carlo technique, the idea is to repeat the experiment many times to obtain many quantities of interest using the Law of Large numbers and other methods of statistical inference. In general, the Monte Carlo method is a broad class of computational algorithms that rely on repeated random sampling to obtain numerical results. They are often used in physical and mathematical problems and are most useful when it is difficult or impossible to use other mathematical methods. Monte Carlo methods are mainly used in three distinct problem classes: optimisation, numerical integration and generating draws from a probability distribution. Blayo et al. (2014), presents a definition of what constitutes a Monte Carlo method:

1. Define a domain of possible inputs.
2. Generate inputs randomly from a probability distribution over the domain.
3. Perform a deterministic computation on the inputs.
4. Aggregate the results.

Blayo et al. (2014), underlines that a standard hypothesis in data assimilation is that errors come from observations only, thus in step No. 1, the uncertainty in the observational network shall be defined. It is assumed that the observations have independent errors with Gaussian distributions. In step No. 2, for each number a corresponding set of random perturbations is obtained. Step No. 3 is a data assimilation cycle where the input is a long sequence of observation values. In the last step, statistics over the ensemble of outputs are computed.

Farahmand et al (2001), used the Monte Carlo simulation for transport dynamics of electrons in the ternary compounds, meanwhile Nylund et al. (2007), used this technique for mixture modelling to identify unobserved heterogeneity in a population, Vrugt et al. (2008), used this method for estimating the posterior probability density function of hydrologic model parameters in complex, high-dimensional sampling problems. In the context of real options and/or decision making, Herath and Park (2002), made a theoretical framework for estimating the volatility parameter of an underlying variable using the Monte Carlo simulation technique in multi-stage capital investment opportunities; Zhao et al. (2004), researched highway development decision-making under uncertainty used this simulation including multiple uncertainties due to changes in political, social, and environmental contexts and presented a multistage stochastic model for decision making in highway development, operation, expansion, and rehabilitation; Cheah and Liu (2006), evaluated governmental support in infrastructure projects as real options used the Monte Carlo simulation. Also Tran et al. (2013), created a probabilistic Monte Carlo simulation model and used to assess consumer heterogeneity for early and mass market adopters. The authors have found that the Monte Carlo simulations combined with scenarios can give insight into diffusion dynamics for other energy demand-side technologies. From this point of view, it could be said that the methodology is widely used in different science areas starting from medicine and ending in social science, including economics and finance.

Assuming that Geometrical Brownian Motion is an appropriate model for MARPU calculation, obtained by selected geographical segment total wireless revenues divided by total wireless subscribers, the next parameters of the GBM based on the Monte Carlo simulation process are defined.

By the common GBM definition, a stochastic process x_t follows Geometric Brownian Motion if it satisfies the following stochastic differential equation:

$$dx_t = \mu x_t dt + \sigma x_t dz_t \quad (9)$$

where $dz_t = \varepsilon_t \sqrt{dt}$ is the Wiener process and ε_t is the standard Normal distribution.

Pacati (2011), underlines the GBM definition as follows: A Geometric Brownian Motion is the solution of a stochastic differential equation with linear drift and diffusion coefficients.

According to Lieberman (1989) and Chou et al. (2015), logarithmic growth rate r_t will follow a Normal distribution, thus

$$r_t \sim N(\left(\mu - \frac{\delta^2}{2}\right)\Delta t, \delta^2 \Delta t) \text{ or, for brevity of notion, } r_t \sim N(m, s^2) \quad (10)$$

where Δt is the time interval. The drift parameter μ and the volatility parameter σ can be estimated by using formulas below:

$$\hat{\mu} = \frac{\bar{r}}{\Delta t} + \frac{\hat{\sigma}^2}{2} = |\frac{\bar{r}}{\Delta t} + \frac{S_r^2}{2\Delta t}, \hat{\sigma} = \frac{S_r}{\sqrt{\Delta t}}, \quad (11)$$

$$\text{where } \bar{r} = \frac{1}{n}\sum_{t=1}^{n} r_t, S_r^2 = \frac{1}{n-1}\sum_{t=1}^{n}(r_t - \bar{r})^2.$$

Forecasted parameter growth is presented as a logarithmic or arithmetic growth rate. The arithmetic growth rate R_t is the ratio of the increment over the base value:

$$R_t = \frac{x_t - x_{t-1}}{x_{t-1}} = \frac{x_t}{x_{t-1}} - 1 \quad (12)$$

The relationship between r_t and R_t are:

$$r_t = ln(1 + R_t) \text{ or } R_t = e^{r_t} - 1 \quad (13)$$

If the considered parameters follow a Geometric Brownian Motion process, then the arithmetic growth rate follows a log-normal distribution. Its variance and expected value can be expressed as:

$$Var(R_t) = exp(2\mu \cdot \Delta t)\,[exp(\sigma^2 \Delta t) - 1] =$$
$$= exp(2m + s^2)\,[exp(s^2) - 1] \quad (14)$$

$$E(R_t) = exp[\mu\Delta t] - 1 = exp\left(m - \frac{s^2}{2}\right) - 1 \quad (15)$$

In Annex 10, Geometric Brownian Motion is presented ($\mu = 0.15$; $\sigma = 0.2$; $x_0 = 1$; $\hat{\mu} = 0.11$) according to Pacati (2011), where the mean path (red), 20 sample paths for t ∈[0.5] (green), 1%, 5%, 10%, 90%, 95% and 99% percentile (red dashed).

According to the Formulas 9-15, GBM process based on the Monte Carlo simulation empower us to determine future values of Wireless market Revenues and Subscribers. Using these data values, it should be able to calculate ARPU and MARPU parameters, even more so considering actual historical data and forecasted values, the mobile (wireless) technology life cycle shall be calculated in determining the end of 4G and the life cycle stages of upcoming 5G mobile technology.

2.3. Determination of technology life cycle using Hodrick-Prescott filter

Sorensen (2011) presented a technology adoption life-cycle and the innovation hype cycle (see Figure 12). In the Figure the author presented the well-known Rogers (2003), *S*-curve diffusion of innovation and investment strategies. According to the author, investors tend to adopt new technologies at varying rates. Their relative speed of adoption can be plotted as a normal distribution, with primary differentiation being the individuals' psychological disposition to new ideas. Each of five possible investors strategy types have their definition presented in the table below:

- **Innovators** (2.5% of total companies) are risk takers who have the resources and desire to try new things even if they fail.
- **Early adopters** (13.5% of total companies) are selective about which technologies they start using. They are considered the "one to check in with" for new information and reduce others' uncertainty by adopting it.
- **Early Majority** (34% of total companies) take their time before adopting a new idea. They are willing to embrace a new technology as long as they understand how it fits with their lives.
- **Late Majority** (34% of total companies) adopt in reaction to peer pressure, emerging norms, or economic necessity. Most of the uncertainty around an idea must be resolved before they adopt.
- **Laggards** (16% of total companies; according to Sorensen (2011) this category can be split with an additional type known as vigorous resistors) are traditional and make decisions based on past experience. They are often economically unable to take risks on new ideas.

In accordance with technology adoption decision taking time moment, the company can be considered as a member of one of the categories mentioned. However, from this thesis point of view, the comprehensive model does not take into account such categories for the decision making process, therefore, after the decision has been made, companies could be assigned to different categories with its specific characteristics.

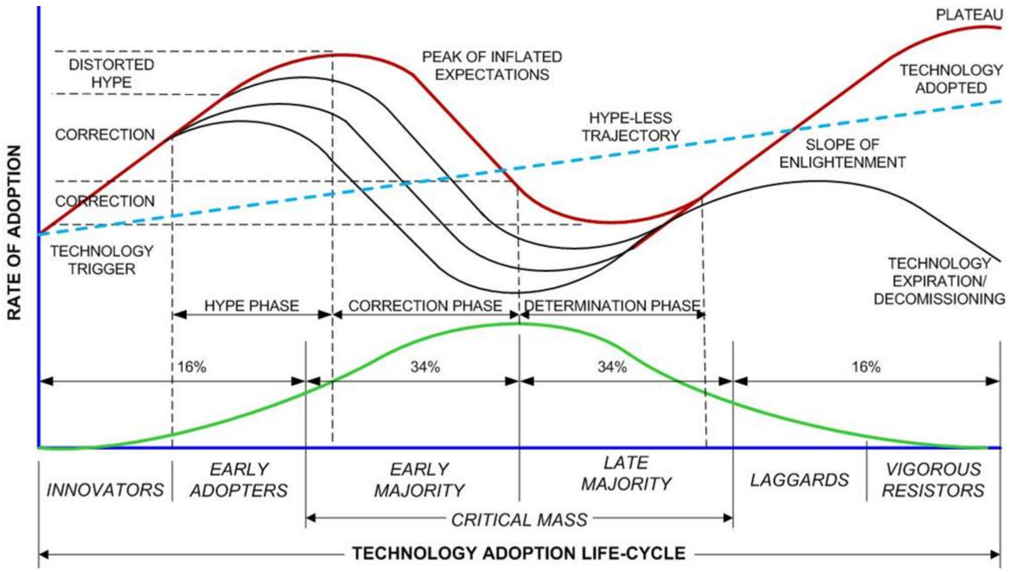


Figure 12. Technology adoption life-cycle and the innovation hype cycle by Jon Sorensen (2011)

In the context of the comprehensive technology adoption investment timing valuation support model, the aim is to find the technology adoption investment time window, which can empower a company to reach its highest possible value and competitive advantage, or in other words, because of the different and continuously changing technology life cycle environment, the product and/or service, which is based on this technology, has a separate life cycle. Thus, in the time frame these two life cycles are desolating among each other, and force different managerial decisions in the context of technology adoption, capital expenditure, additional revenues in terms of new or technology updated product and/or services and whole (additional) company value creation. After the massive mathematical calculation methodologies used, in order to determine an investment time window in the time scale, it was decided to evaluate the technology life cycle and determine the concept of technology adoption time window as follows:

- Technology adoption time window; this is a moment in the time scale, when a company is starting the adoption of new technology or its update. It means that starting from this moment the company shall face additional capital expenditure in terms of hardware, software acquisition, licensing issues, information requiring collection, competence for employee amplification and all other expenditure, which are required to adopt new technology.
- Revenues from new products and/or services created based on new (or updated) technology; this is a moment in the time scale, when a company's investments began to generate revenues, after new products and/or services and/or processes have being created (updated). Until this moment, the company is only suffering from financial costs. This time point is important in the project or company

value creation process, because the amount of revenue depends on whether it will be profitable or not.

- Technology life cycle Plateau; is the moment in the time scale, when the technology life cycle reaches its highest position. In general, companies that have already implemented new (or updated) technology shall generate higher than average revenues from product and/or service. Those companies, which have adopted the technology earlier, shall have a constantly higher competitive advantage in comparison with those that are leapfrogging new technology (or its update) or still waiting (late majority and laggard category). From the financial perspective, the profitability generated by technology based products and/or services shall be evaluated as the difference for investment accepted risk. At this time moment the leader, in its economic sector, shall be determined, as well as followers, and furthermore, all investment timing solutions will not create additional value for the company, because new (or upgraded) technology is already on the market and companies cannot collect early adopter's investment risk premiums. After this time moment profitability from the product and/or service becomes close to the average market level or even less than average market level. It is obviously clear that after this time moment new upgrades or new technology shall be planned to be implemented.

Taking into account these time steps or time moments, the technology adoption time moment shall be calculated back starting from the technology Plateau moment. From this point of view, all competing companies shall be assessed as equal market players with the same technology cycle environment. This approach empowers the comparison of different market players, which have the same technology implementation information. Even more, it is possible to scale up the market players as the leaders or followers in the context of investment timing. Moreover, this approach allows company value changes to be calculated. Thus, the created comprehensive model is not considering the market players as a members of the decision making categories with its specific characteristics according to which investment timing decisions shall be taken, but assessing the competing company's investment timing managerial decisions with the same constructed technology life cycle, or in other words constantly fixed demand uncertainty. That is the reason *GBM* is suitable for this research for technology life cycle data creations according to the historical fluctuations. In this thesis, it is assumed, that the technology life cycle shall be evaluated according to the market Revenues growth rates. According to the model sequence, technology life cycle shall be determined using the Hodrick-Prescott filter. As was pointed out by Flaig (2012) and Jong and Sakarya (2015), the HP filter is a commonly used tool in macroeconomics, and is used to extract a trend component from a time series. According to Harvey and Trimbur (2003), the Hodrick-Prescott filter, which is a mathematical tool, can be used in macroeconomics to define real economic cycle components' fluctuations in the particular time series. According to Weron and Zator (2014), in macroeconomics the smooth part corresponds to the long-term growth and the volatile part to the business. In previous research, the authors noticed (Adamauskas and Krusinskas (2012a, 2012b)), that this tool helps to create "gentle" non-linear graphical sequences in the analyse of the sensibility of periodical fluctuations in the short and long term. According to Flaig (2012), the sensibility of trend is obtained under the modification of multiplayer λ (the frequency of period) in the short term. The larger the value of λ, the higher is the latter penalty. Recent applications of the HP filter to high frequency data include Harris et al. (2011), Chen and Reeves (2012) and Lisi and Nan (2014), among others. The filter is readily available in many econometric and statistical software environments. Hodrick and Prescott recommend the use of the λ=1600 value in the analyses of quarterly steps of fluctuations. In this study case, let say y_t (when t = 1, 2, ..., T) is a logarithm of total wireless Revenues time series. Considering the relevant and positive values of λ, there is a component of trend, which minimises (Flaig (2012), Weron and Zator (2014) and Jong and Sakarya (2015)):

$$min \sum_{t=1}^{T}(y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1}[(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2 \qquad (16)$$

The first part of the equation is the sum of the squared deviations $d_t = y_t - \tau_t$ which penalises the cyclical component. The second term is a multiple λ of the sum of the squares of the trend component's second differences. This second term penalises variations in the growth rate of the trend component. The larger the value of λ, the higher is the penalty.

As was mentioned before, the Hodrick-Prescott filter shall create a non-linear graphical sequence using historical and forecasted market Revenues. It is expected to define the cyclicality, which shall be used to determine the technology adoption investment time window. From the Plateau (or the boom stage in the cycle), time shall be calculated back for each company to determine the precise adoption time moment. It must be underlined that the additional profitability or revenues are expected for the company just because the capital expenditure company are faced to, thus, in the next models' stage the market player's financial situation shall be analysed. Summing up, financial efficiency can be found analysing the first half of the technology life cycle, which shall be expressed as the time period in years and months for each market player.

2.4. Technology adoption investment time window determination

In order to evaluate the company's ability to realise new products in the market, understand it's financial situation and economic sustainability in terms of technology based products and/or services selling, several financial ratios shall be calculated for each market player (see Annex 1). Nevertheless, Adamauskas and Krusinskas (2013) analysed science and technology based companies assessment issues and described indicators under which such companies shall be described, and additional financial factors are already added in the table.

For the ability to understand these ratios (and other parameters in this thesis) interdependency between each other in the future, statistical mathematical tool can be applied, such as correlation. According to Cohen et al. (2003), correlation is a statistical measure that indicates the extent to which two or more variables fluctuate together. A positive correlation indicates the extent to which those variables increase or decrease in parallel; a negative correlation indicates the extent to which one variable increases as the other decreases. This tool can be used to model tendencies in the forecasting stage. The main advantage of this tool in comparison with covariation, is the independency of measuring units for the variables selected. One of the most commonly used formulas in stats is Pearson's correlation coefficient formula.

$$R = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{(n\sum x^2 - (\sum x)^2)(n\sum y^2 - (\sum y)^2)}} \tag{17}$$

The correlation coefficient always takes a value between -1 and 1, with 1 or -1 indicating perfect correlation (all points would lie along a straight line in this case). A positive correlation indicates a positive association between the variables (increasing values in one variable correspond to increasing values in the other variable), while a negative correlation indicates a negative association between the variables (increasing values in one variable correspond to decreasing values in the other variable). A correlation value close to 0 indicates no association between the variables. According to Boguslauskas et al. (2010), Pearson's coefficient value is changing between -1 and 1 and shall be interpreted as follows: at a coefficient value from 0.3 to -0.3 the relationship between variables is considered as a very week or no correlation at all; starting from 0.3 to 0.5 (and from -0.3 to -0.5 respectively) it is considered as a poor positive (negative) correlation; starting from 0.5 to 0.7 (and from -0.5 to -0.7 respectively) it is considered as a medium positive (negative) correlation; starting from 0.7 to 0.9 (and from -0.9 to -0.9 respectively) it is considered as a strong positive (negative) correlation; and starting from 0.9 to 1 (and from -0.9 to -1 respectively) it is considered as a very strong positive (negative) correlation. This coefficient does not incorporate causation, however it can empower a company's managers to make insights between several parameters and simply support managerial decisions.

After the technology life cycle time frame parameters are clear, the optimal investment timing window for each service provider (market player; according to financial data availability) is calculated. Considering the demand paths and technology life cycle fluctuations, the technology adoption investment time window shall be calculated for market members in terms of CAPEX payback terms (time to cover capital expenditure). In this section, two methods were taken in consideration (see Figure 13).

One of the most crucial insights that shall be underlined, is that both methods are designed to find the technology adoption time windows for each company. At the same time, the academic literature underlines investment strategy roles according to the time moment selection in accordance with other companies. This means that the most important factor for strategy selection is the time variable. If the results of the calculation show (whatever method is used), that the investment time window has a relatively small scatter between the first and last decision maker, this means, that all the companies should invest in new technology at the same time. Such phenomena shall be rejected considering the fact that the same technology investment time for all companies are against all theoretical theories. In other words, such situation contradicts the conception of investment timing and investment strategy selection.

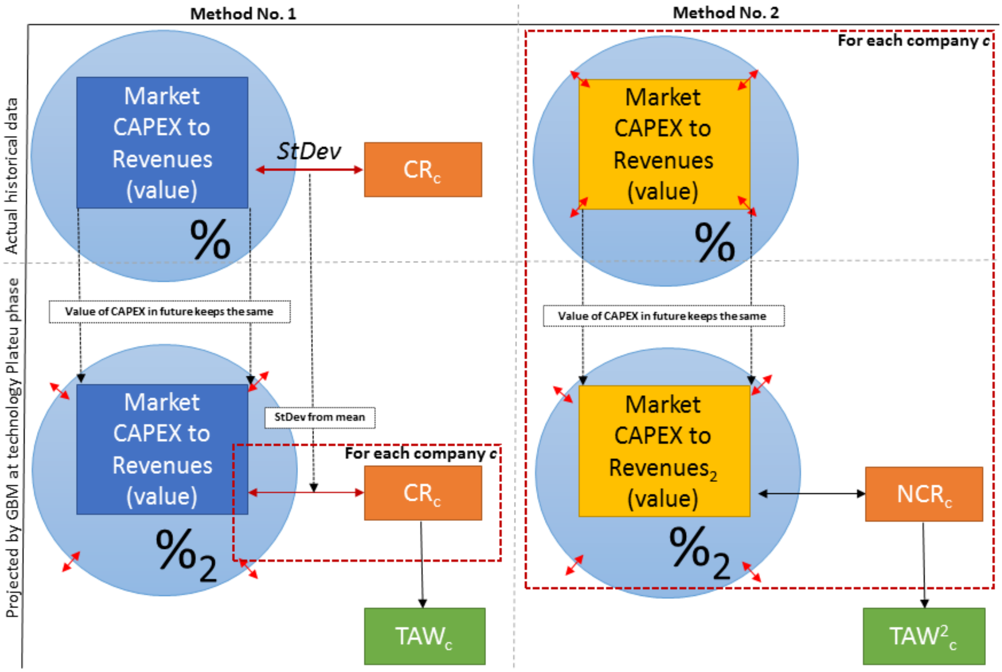


Figure 13. Technology adoption time window determination methods graphical view

***Method No. 1*.**

The average market CAPEX to Revenues ratio shall be calculated assuming the fact that market data shall be equal to the averaged selected company's ratios. Secondly, deviations from market average (deviation from mean) for each company were calculated. Next, it is important to understand the absolute value of market CAPEX, which shall be achieved by expressing the average market CAPEX to Revenues ratio to euros. At this stage it is assumed that market players will not increase their current CAPEX level at the time of the mature technology life cycle period, thus, it is possible to calculate the absolute CAPEX value in the Plateau time moment. Here the calculation results of previous models' parts shall include, market Revenues (calculated by Geometrical Brownian Motion based on Monte Carlo simulation results) in the Plateau of technology life cycle determined by previous mobile generation life cycle data and Hodrick-Prescott filter results. Finally, the forecasted market CAPEX to Revenues ratio becomes a "fixed component", meanwhile, deviations from mean for each company is a "variable component" (it is assumed that market players shall have the same deviation from market ratio in the future as it is now). Summing up, fixed and variable components *CR* (CR_c is the CAPEX to Revenues ratio) for each company are calculated, and afterwards, the adjusted CAPEX to Revenues ratios were achieved for each service provider with payback terms calculated using the formula:

$$TAW_c^1 = \frac{1}{CR_c}, \quad (18)$$

where TAW_c (Technology Adoption Window) is the number of years for technology investment payback (well known in mathematics, considered as the multiplicative inverse for number *x*, denoted by *1/x* is the number which when multiplied by *x* yields the multiplicative identity).

***Method No. 2*.**

In this method absolute market $CAPEX_2$ values are calculated according to different actual companies' CAPEX to Revenues ratios (different forecasted market $CAPEX_2$ values achieved). Secondly, new CAPEX to Revenues were calculated NCR_c (NCR_c is the CAPEX to Revenues ratio for each company analysed) considering market Revenues in the Plateau time moment defined and CAPEX level calculated. Finally, using previous formula (see Formula No. 9), TAW^2_c for each service provider is achieved.

2.5. Company value (NPV) calculation based on Free Cash Flow changes

According to Fernández (2007), the methods for valuating companies are classified in several groups (see Table 3), however, the methods that are becoming increasingly used and popular are those based on cash flow discounting. The main idea is that these methods asses the company as a cash flow generator because of any changes.

Table 3. Main valuation methods

Balance sheet	Income statement	Mixed (Goodwill)	Cash Flow Discounting	Value Creation	Options
- **Book value** - **Adjusted book value** - **Liquidation value** - **Substantial value**	- Multiples - PER[2] - Sales - P/EBITDA - Others	- Classic - Union of European Accounting Experts - Abbreviated income - Others	- Equity cash flow - Dividends - Free Cash Flow - Capital Cash Flow - APV	- EVA - Economic profit - Cash value added - CFROI	- Black and Scholes - Investment option - Expand the project - Delay the investment - Alternative uses

Source: Fernández (2007)

Using balance sheet methods, the estimated value is based on company assets, thus, these methods are not suitable for this study, because they determine the value from the static viewpoint, which does not take into account future demand paths and/or technology life cycle, subscribers' behaviour changes or the industry situation. Meanwhile, income statement methods are based on the profit (loss) statement structural statements values. These methods have similar constrains as balance sheet valuation group methods. The same situation is with Goodwill based methods, which basically shows the companies intangible assets value. Zhou (2013), used NPV in the

[2] According to Fernández (2007), the PER (price earnings ratio) of shares indicates the multiple of the earnings per share that is paid on the stock market.

evaluation of investments in the logistics industry, which, according to the author, has uncertainty, irreversibility and fuzziness; giving full consideration to market volatility, uncertainty, irreversibility and real options. Fernández (2013), offered around 10 different company valuation methods, from which the cash flow discounting methods seek to determine the company's value by estimating the cash flow it will generate in the future and then discounting them at a discount rate matched to the flows' risk. In this study, the net present value (NPV_c) approach is the most intuitive and accurate valuation approach in order to understand the *FCF* impact on the company's net present value. Steiger (2010), analysed the validity of the company valuation using discounted cash flow methods and presented classical NPV calculation formula where future cash flows are discounted by an appropriate discount rate (see Formula 10). The author offer divides the process of valuing a company with the discounted cash flow method into different stages (Steiger (2010) and Damodaran (2010)). Garvin and Cheah (2004), observed that NPV analysis works quite well when the risks across the lifespan and assets remain relatively stable. Since such authors as Damodaran (2010), Dehning et al. (2005), Fernández (2013) and Steiger (2010), declare that one of the crucial parameter for determining a company's (or investment project's) value change is Free Cash Flow, the first state includes prediction of future Free Cash Flow (FCF) for the next five to ten years. Meanwhile, Damodaran (2010), offered to calculate company value in accordance with the business life cycle. The FCF is the operating cash flow, that is the cash flow generated by operations, without taking into account borrowing (financial debt), after tax, thus, the company value is obtained by calculating these cash flows' present value using a suitable discount rate. In this research, ROCE is used as a discount rate. FCF, the free cash flow generated by the company at year *t*, thus, *NPV* is expressed as:

$$NPV_c = \sum_{t=1}^{n} \frac{FCF_t}{(1+ROCE)^t} \qquad (19)$$

where t – Cash Flow period; *n* – last period.

Net present values (NPV) for each company *c* is calculated based on FCF changes. Appreciating the impact of decision timing, relationship with Market Capitalisation is determined. It is important to underline assumptions and links between these methods and calculations. As it was mentioned previously, market Revenues and Wireless Subscribers was forecasted with the GBM process using market data received from Bloomberg, meanwhile selected companies were presented as significant market players. To avoid the same Revenues growth for each company, *MARPU* was selected as the ratio associated with Subscribers growth rates. Determining the mobile service technology life cycle total Wireless Revenues was selected, the same value was used to calculate CR_c *and* NCR_c. Furthermore, despite the fact that *TAW*s are calculated, the most interesting and valuable issues are each company NPV at the time of the Plateau (the same time moment as was used to calculate *TAW*s). In this study it is assumed, that the major factor in the companies' financial statements, which represents core activity success, is Free Cash Flow.

The next stage according to Steiger (2010), is an appropriate discount rate selection. In traditional NPV calculation it is assumed that the discount rate must be selected as the minimum acceptable rate of return on the money invested. According to Fernández (2007), Weighted Average Cost of Capital (WACC) is an appropriate discount rate using FCF. Since Return On Capital Employed (ROCE) is a return earned and WACC is a return required, the target rate to use as the basis for Net Present Value calculations may be at or above the Return On Capital Employed (ROCE). The return on capital employed measures the proportion of adjusted earnings to the amount of capital and debt required for a business to function. For a company to remain in business over the long term, its return on capital employed should be higher than its cost of capital; otherwise, continuing operations gradually reduces the earnings available to shareholders. To have comparable data (few companies provide ROCE ratios in their financial prospects, because of internal company reasons and/or calculation methodology, some differences could arise), ROCE is calculated under the formula:

$$ROCE_c = \frac{EBIT_c}{Total\ assets_c - Current\ liabilities_c} \tag{20}$$

Average $ROCE_{avg.}$ is calculated averaging the actual $ROCE_c$ of each selected company.

FCF_c in the forecasted periods is calculated according to the annual MARPU growth rates (achieved from previous calculations and are similar for all companies) starting from the last financial period FCF amount for each company. Meanwhile, continuous value ($ConV_c$) is calculated using the formula (see Formula 21). The necessity of continues value is important, because companies are willing to continue their activity and evaluation period for the companies that are not finite.

$$ConV_c = \frac{FCF_{last}}{ROCE_c} \tag{21}$$

In the final NPV calculation step according to Steiger (2010), the company's continuous value has to be identified and added to NPV. The company value (CV_c) based on NPV is calculated under the formula:

$$CV_c = NPV_c + \frac{ConV_c}{(1+ROCE_c)^{t_{last}}} \tag{22}$$

In the end, the share of the company's market capitalisation[3], which was affected by the FCF based on the investment timing decision, is known as TF_c and calculated using formula:

$$TF_c = \frac{NPV_c}{MCap_c} \quad (23)$$

TF_c shows the share of value, which was generated by the *FCF* changes with current Market Capitalisation as of the last financial period, or in other words TF_c is the NVP_c to $MCap_c$ ratio as a proportion of the value created after the period analysed and the current market value is calculated.

The remainder of this paper is organised as follows. In Section 3 the mobile network market, 5G mobile technology generation and its features are described. Next, an empirical analysis, simulation and its results are explained. Managerial implication of the finding and conclusions can be found in the Conclusions section.

2.6. The structure of comprehensive technology adoption investment timing valuation support model

This model is focused on mobile service providers and the new technologies these companies are faced with. In the real world market players are currently competing by attracting potential customers not only with ordinary products and/or services, but even doing it by "looking out of the box". In other words, in this rapidly growing technology era all science and technology based companies sooner or later comprehend that the number of customers is not growing as fast as was experienced before the 21st century, this means that a successful business stands on the business life platform, which has a business life platform. This so called platform has (according to the companies and industry) its own technologies with technology and even the product and/or service life cycle working against it. Thus the expected results of the thesis and this comprehensive model are twofold: firstly, to prove the fact, that the technology adoption decision is dependent on each market player, despite the fact that all market and technology evolution information is reachable by everyone, even more, market demand uncertainty can be solved by chaos (GBM) theory. Secondly, the research shall empower them to determine the life cycle of the business platform, in other words, the business life cycle, which means that this company's existence period is a crucial time scale for the company value assessment. Such period shall show investors the real companies' value calculation time frame and create opportunity to compare discounted value with current company value. This information is also extremely important because of upcoming mergers and acquisitions, which shall be expected because of the retreating number of users. Finally, companies shall be able to determine the proportion of value created after the

[3] Market Capitalization ($MCap_c$) is the market value of a company's outstanding shares. This figure is found by taking the stock price and multiplying it by the total number of shares outstanding as of the last financial period for all market players.

analysed period to the current market value, and even to identify the optimal investment timing moment for upcoming new technology adoption, where optimal investment is considered as the time moment, which shall create the highest possible value and competitive advantage for the company in terms of each managerial decision making process.

All of this impacts on the optimal investment timing in technology adoption necessity and importance, thus this comprehensive model shall be practically implicated and empower companies to determine the optimal investment timing moment for adopting new technology in terms of company value. Moreover, this model is based on the same market ratios, although at the same time a different company has their own different financial rate, this model is based on the same market ratios, thus empirical models' results shall present mobile (wireless) based companies business cyclical nature as well as a proportion in the company value generated by Free Cash Flow according to market uncertainty and technology life cycle.

The detailed expected models structure and results is presented in Table 4.

Table 4. The structure of comprehensive technology adoption investment timing valuation support model

Instruments/Measures	Stage	Expected results
Actual historical data: market data, previous academic research data, statistical analysis and synthesis of fragmentary knowledge on the subject.	**I. Historical demand paths analysis**	1. In this thesis, it is assumed that demand volatility depends on two parameters: - *Average market revenues (Revenues)* - *Quantity of subscribers (Subscribers).* 2. Determination of mentioned parameters dynamics and growth rates in terms of selected geographical area as well as the penetration rates changes. 3. Current and previous mobile technology generation development features.
Determination of average market revenues (Revenues) and Subscribers dynamics statistical validity tests.	**II. Statistical data validity tests**	Statistical validity test shall be applied: 1. Dickey-Fuller test (for stationarity of both time series). 2. Q-Q plots (ascertain Normal distribution). 3. Autocorrelation test 4. Kolmogorov-Smirnov test (ascertain Normal distribution)
1. Determination of demand paths – 40 iterations of both Revenues and Subscribers shall be forecasted. **2. Determination of MARPU (Market Average Revenue Per User)** **3. Dynamics and statistical analysis and**	**III. The forecast of data array using Geometric Brownian Motion method based on Monte Carlo simulation**	Geometric Brownian Motion (GBM) process based on Monte Carlo simulation used to define forecasted parameters below[4]: *1. 40 iterations of market Revenues.* *2. 40 iterations of Subscribers.* *3. 40 values of MARPU rate.* For both (1 and 2) GBM process based on Monte Carlo simulation additional parameters for drifts and random shocks) defined: - *Drift* (μ) *value;* - *Volatility* (σ) *value;* - *Time Step* (Δt)*;*

[4] The amount of 40 iterations is used to calculate the 10-year period, while each iteration is quarterly based.

Instruments/Measures	Stage	Expected results
synthesis of fragmentary knowledge on the subject.		- *Wiener process (dz_t);* - *Standard Normal distribution (ε_t);* - *Variance value (Var(R_r)).*
Determination of mobile technology life cycle in accordance with historical (stage I) and forecasted data (stage III).	**IV. Determination of technology life cycle using Hodrick-Prescott filter**	Hodrick-Prescott filter shall be used to define the stages and maturity of upcoming new 5G mobile technology. Additional parameters defined: - *Frequency of period (λ);* - *Trend component (τ_t);* - *Cyclical component (deviation from the trend) (d_t).*
Optimal investment timing window for each service provider (market player; according to financial data availability) shall be calculated based on separate market player financial data and previous model stages results in terms of CAPEX payback terms. These parameters shall present the time moment according to technology life cycle (considered as optimal investment timing moment), when the market player shall start investing in new mobile technology adoption.	**V. Technology adoption time window determination**	Technology Adoption Window ratios shall be determined for each market player in selected geographical area based on two different methods: ***Method No. 1*** Parameters defined: - *Actual CAPEX to Revenues ratios for each player;* - *Stand dev. from mean rates for each player;* - *Forecasted CAPEX to Revenues ratios for each company (CR_c);* - *Technology Adoption Window (TAW_c^1).* ***Method No. 2*** Parameters defined: - *Market CAPEX values (Market $CAPEX_2$);* - *Forecasted CAPEX to Revenues ratios for each company (NCR_c);* - *Technology Adoption Window (TAW_c^2).*
Net present values (*NPV*) for each market player shall be calculated as well as company values based on Free Cash Flow changes. On purpose to appreciate the impact of decision timing, relationship determined with Market Capitalisation. Two scenarios shall be applied in terms of individual ROCE or average ROCE selection.	**VI. Company value (NPV) calculation based on Free Cash Flow changes**	Net Present Values shall be determined in the Plateau of upcoming technology life cycle. NPV to Market Capitalisation ratio shall be determined as a proportion of value created after period analysed to the current market value. Additional parameters defined: - *Forecasted Free Cash Flows values for each player (FCF_c);* - *Return on Capital Employed ($ROCE_c$);* - *Average Market Return On Capital Employed ($ROCE_{avg}$);* - *Continuous value for each player ($ConV_c$);* - *Proportion of value created after period analysed to the current market value (TF_c).*

This technology adoption timing model is triggered by some threshold values. Chou et al. (2014), in the study of sizing and timing models comparison, the capacity expansion can be triggered when the demand catches up with the installed capacity or when the backlog reaches a threshold value. This research has several issues: (1) the mobile service industry has its own characteristics in demand, technology fluctuations and evolution aspects, capital expenditure (CAPEX) intensity, etc. It is assumed that the technology adoption decision is irreversible and needs time to be fixed. Also, the lifetime of engineering network equipment and even planning horizon is finite. (2) The second issue is considering technology adoption decision criteria, which are based on profitability and demand-satisfying issues. Even if technology adoption is feasible, it is not an optimal strategy if the adoption costs are significantly high, or in other words, irreversible investment shall only be realised if the net present value of its expected returns exceeds the investment costs by a considerable amount. (3) Thirdly, fluctuations of mobile network technology generations are taken into account. (4) Dixit (1989), noted hysteresis of investment is affected by macroeconomic conditions. As was pointed out by McDonald and Siegel (1986) and Jeon and Nishihara (2014), investment costs follow a Geometric Brownian Motion. Elliott, Miao and Yu (2007), underlined that a diffusion process of Geometric Brownian Motion is not suitable for modelling investment costs unless expected costs follow a controlled diffusion process. As was mentioned previously Huang and Da (2007), successfully used the Geometric Brownian Motion process for the timing decision support model in determining the energy price for Chinas' electricity industry. According to the results of the literature review, the Brownian Motion process can be used as a tool for volatility forecasting as a part of the investment timing valuation support model in the context of macroeconomic environment changes. Therefore, the model in this study is based on the Monte Carlo simulation of the Geometric Brownian Motion process for mobile service demand paths forecast calculations. Even more, the model has additional limitations: (I) forecasted FCF growth rates are equal to forecasted MARPU changes; it is assumed (II), that historical (previous) technology development statistical parameters will be analogical for upcoming technology shifts in terms of demand determination; it is assumed (III), that upcoming technology generation will have the same technology development life cycle as it was in previous generations in terms of the time for the stages of life cycle, and finally (IV), this model is constructed under mature market changes.

After the academic literature review, the optimal technology adoption investment timing valuation support model is constructed from the six stages (see Figure 14). It should be noted that the model constructed shall not be used for technology adoption timing valuation for technology, which is inherent for a separate company as a technological solution for e.g. efficiency management; this model shall be used in markets where technology is used. Or, in other words, for technologies, which are affecting the whole market, even mature markets.

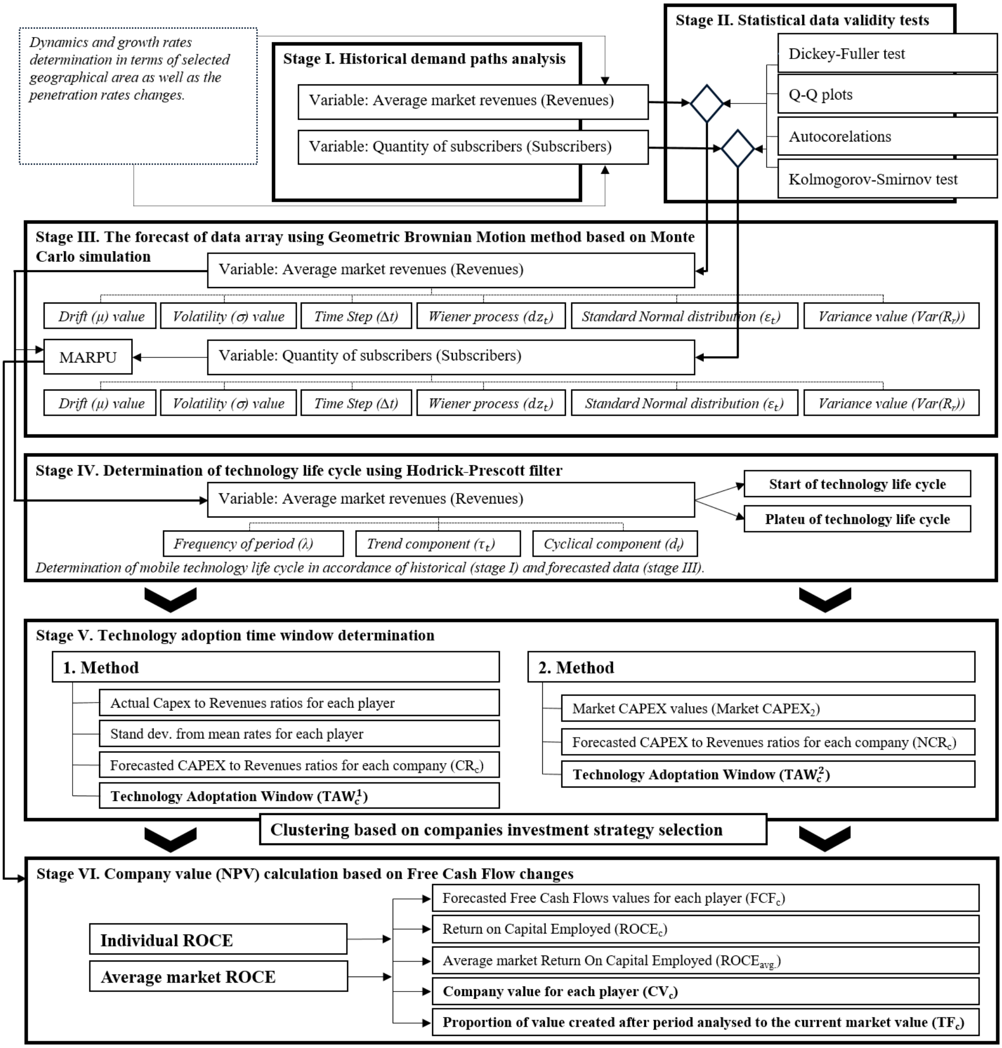


Figure 14. Comprehensive technology adoption investment timing valuation support model schematic view

Thus, in Section 3, empirical analysis of mobile technology life cycle changes and technology adoption issues shall be analysed. In this case, exponential growth in demand requires investments in new technology adoption. The second reason is that technology adoption's investment time window is a crucial factor for mobile service industry members. Investment timing decisions directly faces the company's value and ability to attract additional subscribers. Finally, mobile technology adoption investment timing valuation support models have not been given sufficient attention in the academic literature.

3. COMPREHENSIVE TECHNOLOGY ADOPTION INVESTMENT TIMING VALUATION SUPPORT MODEL APPLICABILITY RESEARCH

Companies face a problem of caching the optimal timing of new technology adoption that drives a loss or gain of competitiveness, value creation or disruption for the company, investment payback target setting, building reactivated business models, etc. These issues are more complicated for mature markets, where demand changes can be modelled with uncertainty presumptions, because competition is very acute and technology investments are irreversible. The constructed model in the research presented is focused on analysis of historical mobile network technologies and demand parameters of mobile service market revenues. It is expected to project upcoming mobile service technology (5G) evaluation life-cycle under volatile demand changes in which selected companies shall take technology adoption decisions. Even more, according to the results, it is expected to assign companies to different strategical management decision making roles in the context of technology adoption with their own characteristics. In general, optimal investment time frames shall be defined and the value for companies shall be retrieved.

The decision to select this industry is twofold – firstly, there is a lack of academic research on real-option investment timing models in the telecommunication service sector. Secondly, this industry has a huge demand of investment timing decision support models, because of the development of network technology generations, updating network infrastructure, keeping up-to-date with mobile device manufactures and keeping competitiveness with very tough demand requirements, ensuring network externality options and price changes for the customer.

3.1. Technology selection change environment

Currently new 4G (LTE networks) are becoming more and more available in the world. Meanwhile mobile service providers are forecasting that 5G shall be available in 2020+, with more than 1,000-time higher traffic capacity limits, ultra-reliable, and with low energy consumption. This type of network shall correspond and satisfy the technical requirements for M2M industry (Machines to Machines) and the IoT industry (Internet of Things). Even more, this shall change the income structure of service providers, because high speed internet connection occupies cellular connections.

According to the OVUM (2015), the Internet of Things (IoT) is expected to encompass billions of devices by 2020, with a market set to be worth trillions of dollars in revenue, but for the moment, take-up remains limited. Operators, chipset makers, and home-appliance and electronics retailers are beginning to offer products and services that enable users to control a number of devices from a single hub or app, with a view to making IoT easier to install, operate, and understand. The Internet of Things has been the object of much discussion for years, but it remains a fragmented set of verticals rather than a true market. It can be divided into two main segments, consumer and industrial, which are for the most part exclusive and which each encompass a variety of activities (see Figure 15).

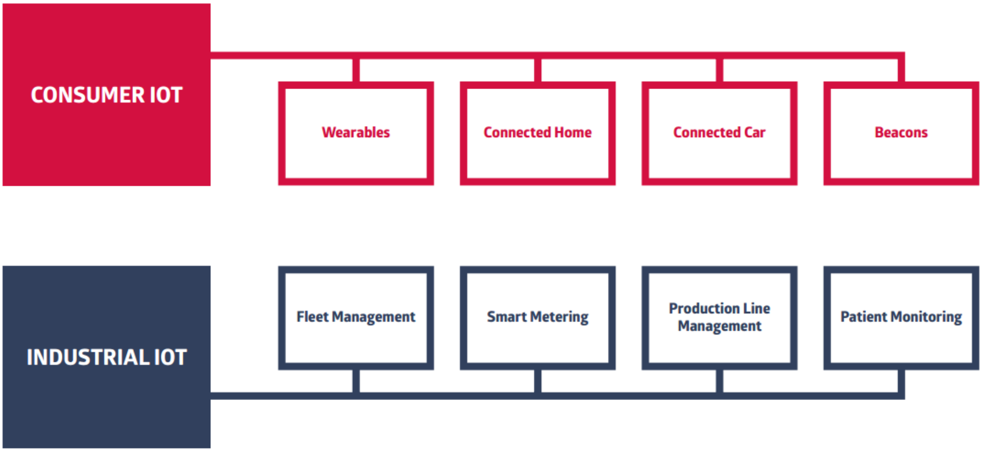


Figure 15. Consumer and industrial IoT verticals by OVUM (2015)

The consumer side has received the most interest from operators and customers, relating as it does to the connected home, connected car, and wearable devices. The challenge for stakeholders, whether they are operators, OEMs, standards bodies, or retailers, is to bring each strand together, using the technology that consumers already own. The popularity of smartphones has done much to enable that process, by bringing connectivity to widespread standards and by bringing technologies such as cellular, Wi-Fi, and Bluetooth into a single device. According to OVUM (2015) forecasts, the number of M2M connections in North America is expected to exceed 77 million at the end of 2019, when it will be worth USD 11.9 billion in annual revenue. These figures do not include devices that connect via other technologies (Bluetooth, Wi-Fi). Estimates of the future annual revenue of the Internet of Things are in the trillions of dollars, with billions of connected devices expected by 2020.

The deployment of well-known mobile network generation LTE, or in other words, the 4G network, is in full progress and it could be expected that a majority of the operators will have this technology running in the next few years. It could be noticed that some operators stopped develop 3G and started investing only in 4G deployment. Such countries as Japan, Korea and the USA are far away from Europe in developing the new generation of mobile technology and intends to adopt it as soon as it has approved standards. Taking a deeper look to the mobile service generations, it is found that the previous aim of technology (1G) was to provide voice services, and meanwhile, the next generation (2G) was upgraded with basic messaging and data services. Further mobile service technology (3G) was orientated to higher data transmission service. Finally, current (4G) and upcoming (5G) technologies are built on a data-led basis and orientated to high data capacity infrastructure, where the voice service is just an app running on it. According to the Bloomberg statistics, the majority of revenue now comes from data services. In more technology orientated countries like Japan and the USA the level of revenues from data service is around 60-80% and these facts again prove the necessity of technology adoption timing decision importance.

As with 3G and 4G mobile network technologies, 5G will be standardised through the 3rd Generation Partnership Project (3GPP), the cellular communications standards organisation. Along with the telecommunications vendor community, many other leading industry bodies are supporting the development of 5G technology. These include the European Commission via the 5G Private Public Partnership (5G PPP), the University of Surrey 5G Innovation Centre, EU project METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society) and 4G Americas. According to the European Commission, with mobile traffic expected to grow by a factor of 1,000 by 2020, and the number of connected users to multiply 10 to 100-fold, the world clearly needs new communication infrastructure the like of which will be the very backbone of the new digital economy. All this is why the EU is already committed to investing EUR 700 million in a 5G Public-Private Partnership for research, development and innovation in this field. Unlike other industries, these companies do not have the ability to leapfrog new technology release. As it was found by Adlyte et al. (2015), Sweden as a country and companies operating inside this country are considered as a leader with the highest ITT (Investment to technologies) indexes. Since several companies are operating in Sweden, technology adoption managerial solutions are extremely important for them and has a crucial impact for the whole mobile service industry. On the other hand, from today's point of view, it does not matter in which country the mobile service operators is located in, because 5G technology is currently under development. Next, in this research selected companies will be evaluated in the context of technology adoption investment timing.

In this section, comprehensive technology adoption investment timing valuation support model applicability research is presented applying the model for mobile service providers.

3.2. Models applicability research process parametrisation and characteristics

As it was mentioned previously, the technology adoption investment timing valuation support model shall be practically implicated for mobile service providers as a real world technology adoption investment timing solution for competing companies, as well as substantiating the impact of models components' and necessity in the whole comprehensive model and final results. It is very important to underline, that the aim of the applicability research is to identify information for the models' practical implication process and the calculation of companies' present values of cash flows according to the strategic managerial decisions, or forecast accurate and precise value changes for each company. The applicability research shall be implicated based on the theoretical model presented in Section 2 and expected results are presented in the table below (see Table 5).

Table 5. Comprehensive models' structure and expected results

Step	Expected results
1. Mobile network market, 5G mobile technology generation and its features	Actual historical data shall be analysed within market data, previous academic research data, statistical analysis and synthesis of fragmentary knowledge on the subject for selected geographical region. Determination of average market Revenues, quantity of Subscribers and penetration rates.
2. Determination of average market revenues (Revenues) and wireless Subscribers dynamics statistical validity tests.	After applying statistical validity tests, it is expected to clarify that both time series are not stationary and normal distributed.
3. Forecasted dynamics of market Revenues, wireless Subscribers and MARPU using Geometric Brownian Motion method based on Monte Carlo simulation	According to the method, in maturity of 10 years (40 quarterly based iterations) forecasted dynamics of average market Revenues and market Subscribers shall be calculated as well as MARPU for the same period. For both, average market Revenues and wireless Subscribers, parameters shall be defined: - *Drift (μ) value;* - *Volatility (σ) value;* - *Time Step (Δt);* - *Wiener process (dz_t);* - *Standard Normal distribution (ε_t);* - *Variance value ($Var(R_r)$).*
4. Determination of mobile technology life cycle	In accordance with actual historical data, fluctuations of previous mobile technology evaluation (1G, 2G, 3G, 4G) and forecasted dynamics of Revenues for upcoming 10 years new 5G mobile technology life cycle, in terms of time frame, shall be determined using Hodrick-Prescott filter. Parameters shall be defined: - *Frequency of period (λ);* - *Trend component (τ_t);* - *Cyclical component (deviation from the trend) (d_t).* It is expected to define time moments of 5G mobile technology life cycle structure, or in other words, to determine at least beginning of the cycle and boom phase.
5. Selection of companies operating in the selected geographical territory	Financial parameters shall be defined as was previously presented in Annex 1.
6. Technology adoption time window determination	Optimal investment timing window for each mobile service provider (market player; according to financial data availability) shall be calculated based on separate market player financial data and previous model stages results in terms of CAPEX payback terms. These parameters shall present the time moment according to technology life cycle (considered as optimal investment timing moment), when the market player shall start investing into new mobile technology adoption. Two methods shall be used with different parameters: ***Method No. 1*** Parameters defined: - *Actual CAPEX to Revenues ratios for each player;* - *Stand dev. from mean rates for each player;* - *Forecasted CAPEX to Revenues ratios for each company (CR_c);* - *Technology Adoption Window (TAW_c^1).*

Step	Expected results
	Method No. 2 Parameters defined: - *Market CAPEX values (Market $CAPEX_2$);* - *Forecasted CAPEX to Revenues ratios for each company (NCR_c);* - *Technology Adoption Window (TAW_c^2).*
7. Decision value (NPV) calculation based on Free Cash Flow changes	Net present values for each market player shall be calculated as well as companies' values based on Free Cash Flow changes. NPV to Market Capitalisation ratio shall be determined as a proportion of value created after period analysed to the current market value. Additional parameters defined: - *Forecasted Free Cash Flows values for each player (FCF_c);* - *Return on Capital Employed ($ROCE_c$);* - *Average Market Return On Capital Employed ($ROCE_{avg.}$);* - *Continuous value for each player ($ConV_c$);* - *Proportion of value created after period analysed to the current market value (TF_c).*

The summary of the practical models' implication results and interpretation shall present the relevance and suitability for the real world decision making process, crucial modelling constraints and further model expansion framework.

3.3. Models applicability research

1. Mobile network market, 5G mobile technology generation and its features

According to Roberts (2015), many operators are already experiencing capacity issues in the populated areas where traffic density is at its highest. Operators struggle to meet demand with the required quality of service that can only be alleviated through the provision of additional spectrum or building additional capacity sites to soak up traffic. The key drivers behind 5G are outlined below:

- *High Throughput* – The average throughput achieved by users is a better indicator of quality than the headline peak data rate offered by a technology and its allocated spectrum. However, the combination of increasing the peak data rates and deploying small cells will provide higher average throughputs resulting in a far better user experience. 5G could potentially deliver data rates up to 10 Gbps with typical user data rates of around 1 Gbps.
- *Low Latency* – Latency is the round trip delay experienced by the user whilst accessing/using an application or service on their mobile device. Whilst LTE 4G provides much improved latency compared to 3G technology, the delays are still too high for many real time applications. The aim with 5G is to reduce latency to less than 1 ms. A latency of 1 ms and lower will be required for "tactile internet" applications where perceived instant response time is achieved when interacting with virtual reality and augmented reality software systems. Also, mission critical machine to machine real time control systems will require very low round trip delays in order to operate effectively and safely.
- *High Quality* – 5G radio access and core systems will need to be engineered to provide the appropriate levels of service quality and availability. 5G

will also need to ensure that a seamless user experience is achieved when moving across different areas and technology segments within the network.

- *High Capacity* – Operators are already experiencing a “capacity crunch” and are alleviating this through acquisition of new spectrum, re-framing of existing spectrum used for previous mobile generations, and where possible, installation of new macro and small cell sites.
- *High Throughput* – The average throughput achieved by users is a better indicator of quality than the headline peak data rate offered by a technology and its allocated spectrum. However, the combination of increasing the peak data rates and deploying small cells will provide higher average throughputs resulting in a far better user experience. 5G could potentially deliver data rates up to 10 Gbps with typical user data rates of around 1 Gbps.
- *Long Battery Life* – Energy efficiency becomes very important for devices that require a long battery life. These could include sensors and meters requiring a battery life of up to 10 years. Battery life is therefore extremely important if the vision of the “Internet of Things” is to be realised.
- *Efficiency* – 5G will need to enable cost efficient high density small cell capacity solutions. The total CAPEX and OPEX required to install and operate 5G small cell systems will need to be lower than current 4G small cell solutions so that network operators adopt 5G as their priority capacity solution. Provision of backhaul to high numbers of small cells is often a cost issue for network operators.

Mobile traffic is expected to grow by up to 1,000 times over the next decade, and this will have a tremendous impact on the underlying network infrastructure. The immediate challenge of 5G networks will be to scale up traffic requirements to serve new kinds of elaborate machine-to-machine systems and applications. Industry and academia experts from Net World 2020, the European Technology Platform that laid the foundation of the 5G Public-Private Partnership, explained in a recent white paper that 5G will provide a universal communication environment that enables the wider societal challenges, such as transport, automotive, safety, employment, health, environment, energy, manufacturing and food production to be addressed. In other words, it will deliver a business-critical infrastructure, fully integrated with the business value chain of vertical usage segments and able to adapt to their requirements in real time. It has been estimated that private companies will spend over EUR 234 billion in the network infrastructure and technology over the coming decade, with competition to take 5G Worldwide likely to be fierce.

As was mentioned before, two main parameters are selected to describe mobile service and technology markets, total wireless Revenues and total wireless Subscribers. The analysed time periods consist of 37 quarters starting from 2005 Q4 and ending in 2014 Q4. The selected market involves such countries as Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine and United Kingdom (market data selection was limited to data availability, thus, in this research it is assumed that these countries, and the companies operating in them, are the mobile network market; see Figure 16).

Figure 16. Selected geographical region where mobile service providers are operating

All of them are graphically presented in Figure 17 and Figure 18 with additional growth rate (%) parameters for each. It can be seen that the number of subscribers has a relatively positive growth trend, however growth rates are decreasing. Meanwhile, total wireless revenue has a negative growth trend starting from 2012. Even more, the global financial crises aftereffects could be easily found in the figures.

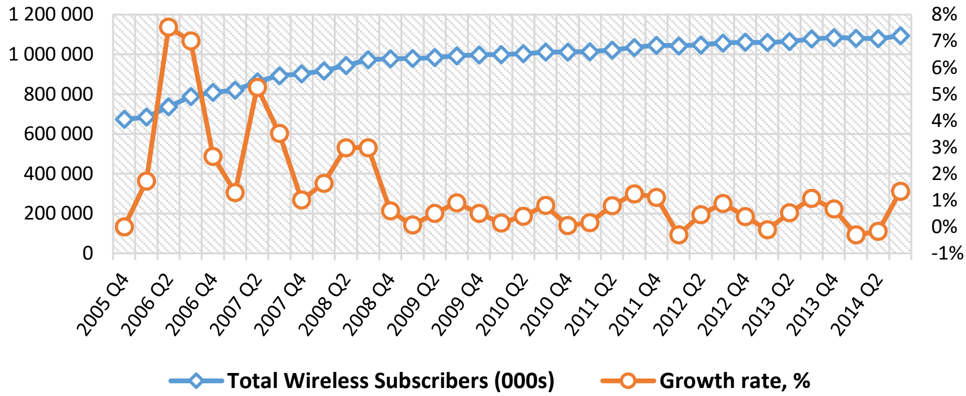


Figure 17. Total Wireless subscribers' dynamics and growth rates. Source: Bloomberg

The analysis of actual historical data of wireless market Subscribers showed (see Figure 17), that the average growth rate of Total Wireless Subscribers is around 1.41%, however the pace of growth is slowing, in the period of 2005 Q4 to 2008 Q4, the average growth rate was around 3.19%, meanwhile, in the period of 2008 Q4 to 2014 Q3 it was 0.49%. The identified reduced growth rate could be easily explained as an aftereffect of the Global financial crisis. On the other hand, the highest penetration jump (see Figure 20) was noticed in Finland, Russia, Sweden and Ukraine, where the major parts of the countries have a higher penetration rate of 100% as of 2014 Q4. Thus it could be assumed that the number of subscribers will not grow at the same paces as it was before Y2008. Therefore, M2M and other technologies, which are based on wireless communication will increase the demand of growing users of mobile wireless service, or in other words, one subscriber may have several devices connected, for this reason wireless market Revenues is analysed.

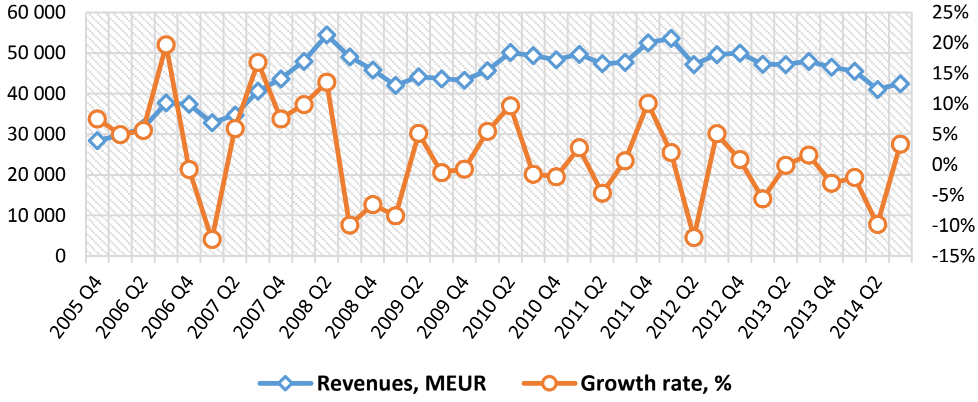


Figure 18. Selected market Wireless revenues dynamics and growth rate. Source: Bloomberg

In the maturity of the analysed period, the average growth rate of wireless Revenues is around 1.60%. Meanwhile, in the period of 2005 Q4 to 2008 Q4 the average growth rate was around 4.77% and in the period of 2008 Q4 to 2014 Q3 it is negative and reached -0.18%. The reasons for the decrease in market Revenues is several fold: firstly, it could be assumed that in the period before the Global financial crisis mobile service users used to have higher expenses as a share of household income (or at a company level as well). At this time competing companies were forced to revise pricing structures in order to survive and keep the number of subscribers. Providers reconsidered pricing plans and started offering personal solutions for their customers. Secondly, in the same period technology expansion waves increased the ability to use more wireless based connections in comparison to GSM, moreover, smartphones started to replace mobile phone with a higher intensity. This situation forced mobile service providers to offer more attractive cellular data services. The era of mobile applications increased consumption of data transfer in mobile networks and replace the structure of Revenues for mobile service providers (see Figure 19).

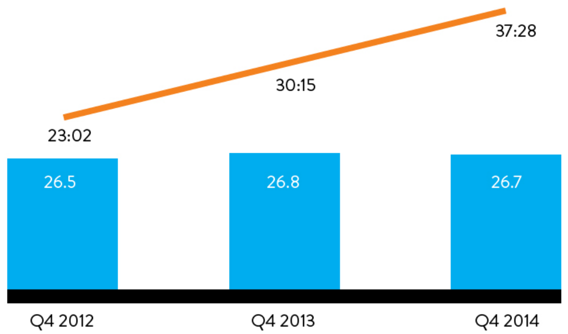


Figure 19. Average number of applications used and time duration per person per month. Source: Nielsen, (2015)

According to the Nielsen research (2015), in 2014 Q4 smartphone users accessed 26.7 applications per month on average and spent 37 hours 28 minutes per month on them. Also, it is worth noting that smartphone users mostly use their mobile phone on games and social networking (49% and 30% respectively). Considering that has been mentioned, it is clear that mobile service providers shall change the structure of Revenues and reconsider CAPEX levels. Even more, technology adoption strategic managerial decisions shall be crucial in upcoming future events because of infrastructure costs, which could rise because of the new concept of technology. It must be underlined that a comprehensive model should be widely and easily implemented into the science and technology based companies' strategic financial management decision making process. Indeed, motivation is focused on principals, which are inevitable in volatile markets for active market players in terms of competitiveness. The development of mobile technology generation was analysed by Patil et. al (2012), where differences between specific generation could be found. Considering mobile technologies, subsequent generations and sub-generations have their own technical environment and different network infrastructure technical parameters, which in turn, are important in technological change and the context of investment timing. Which means, that investments into infrastructure could be meaningless due to customer's behaver and value perception because of especially rapidly changing technologies under the influence of competitiveness.

Naturally, after the Subscribers and Revenues analysis it is important to revise wireless penetration rates in different countries (see Figure 20). Here, penetration rates dynamics comparison between 2011 Q1 and 2014 Q4 time periods is presented. It was noticed, that the highest jumps were made in Finland, Russia, Sweden and Ukraine.

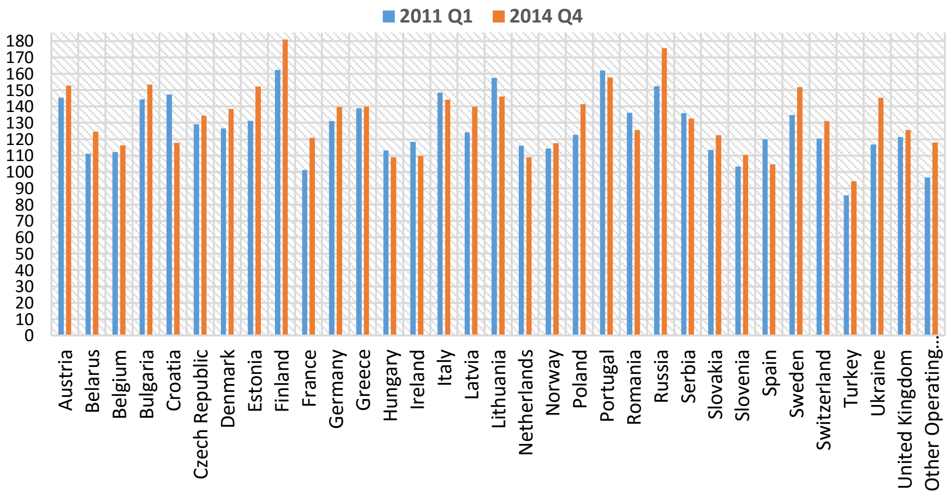


Figure 20. Wireless Penetration Rate (%) dynamics 2011 Q1 vs. 2014 Q4. Source: Bloomberg

Furthermore, there are countries where penetration rates do not exceed 100 p.p. such as Turkey. From the penetration rates point of view as of 2014 Q4, Austria, Bulgaria, Estonia, Finland, Russia and Sweden are found to exceed 150%. According to Statista[5] the mobile wireless penetration ratio worldwide in 2011 Q4 was up to 87%, meanwhile, at the end of 2014 it was 93%. It is forecasted to reach 99% at the end of Y2020. For a comparison basis, at the end of 2014 Q4 the penetration rate for the Americas was 63.1%, CIS – 57.4%, Arab States – 34.7%, Asia Pacific 33.8% and Africa had only 18.9%. In this context it could be underlined that the penetration rate in Europe is the highest worldwide.

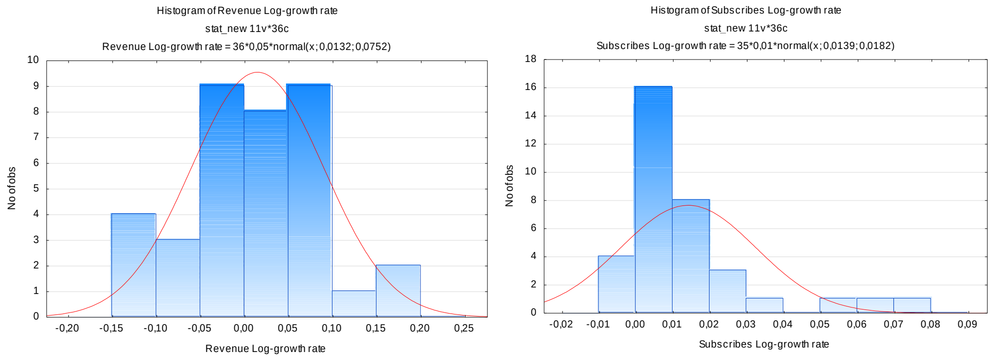
According to Chetan (2015), mobile network technologies evolve over a 20-year technology life cycle. On average, the time-to-peak has been 12 years, meanwhile the time from peak-to-sunset is around 7 years. For each technology the cycle standardisation time period is around 7-8 years. METIS, Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society stated, that 5G technology deployment started in 2012, thus, statistically, it is expected to have standards running on 2019-2020 and peak period at 2024. For this reason, mobile generation demand paths defining parameters analysed in the Models' Part 1, such as wireless market Revenues, Subscribers and their derivative MARPU (Market Average Revenues per User), have to be projected into a maturity of 10 years starting from Y2014 until the peak (Plateau) period of technology life cycle as of Y2024, on a quarterly basis. This time frame will be crucial in the Models' Part 3 establishing both forecasting tool and the time frame for parameters forecasting.

2. Determination of average market revenues (Revenues) and wireless Subscribers dynamics statistical validity tests

Statistical analysis presented in Section 2.2. was successfully implemented in this study:

1. Both time series are not stationary and verified by applying Dickey-Fuller test. With a significance level at 0.05, the obtained *p*-value of 0.0910 for wireless revenues and 0.6371 for subscribers are greater than 0.05.
2. That the time series of the logarithmic growth rate are stationary and cannot be rejected with a confidence level of 0.05. Let the original time series be represented as x_t. The logarithmic growth rate is defined as $r_t = ln(x_t/x_{t-1})$. The Dickey-Fuller test yields *p*-values of 0.0103 and 0.0003.
3. The Q-Q plots resemble those of the Normal distribution. Distribution of growth rates for wireless subscribers and total revenues is presented in Figure 21.
4. Autocorrelation test: There is no significant autocorrelation.
5. The Kolmogorov-Smirnov test for normality of the distribution was used and *p*-value of 0.14114 was retrieved for revenues, and 0.2123 for wireless subscribers. Both of them are greater than 0.05.

[5] Statista - The Statistics Portal 2015. http://www.statista.com/statistics/232594/mobile-wireless-penetration-worldwide/



a) Region wireless Revenues b) Region wireless Subscribers

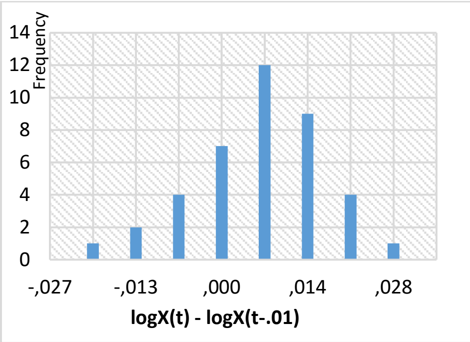
Figure 21. The histogram of logarithmic growth rates.

It was noticed that one extraordinary event took place in 2008, the selected market mobile service revenues, and the global economy as well, was devastated by a global financial market crisis. The effect can be seen in Figure 18 and the flattened growth rate that started in 2008 of Total Wireless subscribers can be seen in Figure 17.

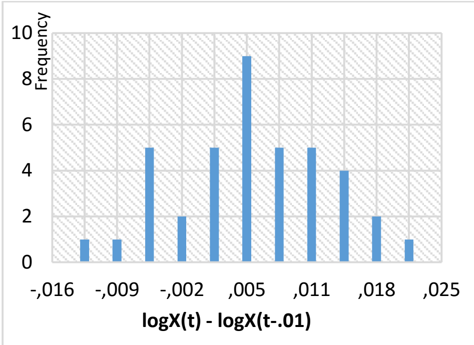
Summing up, the results of the statistical validity tests show that time series are appropriate in terms of statistics for further analysis and data usage in the Geometric Brownian Motion method based on the Monte Carlo simulation.

3. Forecasted dynamics of market Revenues, wireless Subscribers and MARPU using Geometric Brownian Motion method based on Monte Carlo simulation

The calculation results, generated by the Geometric Brownian Motion based on the Monte Carlo simulation (as was defined as models part No. 2), of selected geographical region total wireless Revenues and total Subscribers can be seen in Annex 3 and Annex 4. In defining parameters, the Drift (μ) value for Total wireless service revenues is 1.15% and Volatility (σ) parameter reaches 7.55%, meanwhile, considering the total wireless subscribers it is 1.39% and 1.82% respectively. As it was mentioned previously, MARPU is calculated (total revenue divided by the number of subscribers) for each iteration of 40 time steps (see Figure 23) and the frequency of all iterations can be found in Figure 22. The frequency dispersion presented in the figures also proves the fact of Gaussian dispersion of time series, in other words, both time series are normality distributed considering forecasted market Revenues and Subscribers in maturity of 10-years. It is very important to underline, that the methodology selected (GBM based on Monte Carlo simulation) is not used to forecast neither marker Revenues, nor market Subscribers. The aim of this method is to simulate the dynamics of selected time series in accordance with historical statistical dynamics parameters based on the chaos uncertainty process. It should be disclaimed that historical data array dispersion and volatility parameters could be very different in comparison to the way it was used in this thesis, however, since there are no significant clues of unfamiliar dynamics and/or shocks, it is assumed that the Geometrical Brownian Motion chaos theory is the appropriate method to construct dynamics simulation for the aim of this thesis.



a) Region wireless revenues



b) Region wireless subscribers

Figure 22. Frequency of logarithmic growth change of forecasted parameters using GBM based on the Monte Carlo simulation

As it was mentioned, in the figure below (see Figure 23) actual and projected dynamics of the wireless market Revenues and Subscribers are presented. It is clearly noticeable that the growth rate of Subscribers is positively increasing starting from the Y2005 until the end of Y2024. The pace of growth of Subscribers is increasing starting from Y2017. This could be explained by mobile technology adaptation to the M2M concept based equipment of the Internet of Things (IoT) becoming more and more popular. On the other hand one Subscriber shall have several devices on the same subscription account. In the analysis of relationships between variables, it was found that the correlation between Subscribers and marker Revenues (see Annex 6) in the actual historical period is significantly high and is up to 78.4%, meanwhile, between Subscribers and MARPU reaches only 1.7%. Therefore, correlation between market Revenues and MARPU is around 63.7%. This means that MARPU scaling is affected by Revenues and by the number of Subscribers.

On the other hand, analysing the relationships between Subscribers and market Revenues in the whole period (using actual historical data and projected simulation, which is considered as the future values of these time series), the correlation is found to be lower, at 52.0%. This could be explained in the behaviour change as it was projected, because the correlation between Subscribers and MARPU increased up to 63.3%, whereas between Revenues and MARPU decreased down to 32.8%. These insights show the future importance of Subscribers and Revenues dynamics, therefore mobile service companies shall be forced into an acquisition process in order to keep competitive and providing the newest technology based service for the customers. Since the market penetration was relatively small, the amounts of Revenues were the crucial business model for such kind of companies, meanwhile, penetration rates increased more than 100%, the average return on a subscriber is affected by the number of Subscribers. Thus, it could be concluded with the insight of importance of market share size of the biggest market players and the number of devices per account, for future MARPU structure analysis. However, from this research point of view, the methodology is orientated into technology adoption time window determination not Revenues structure dynamics change.

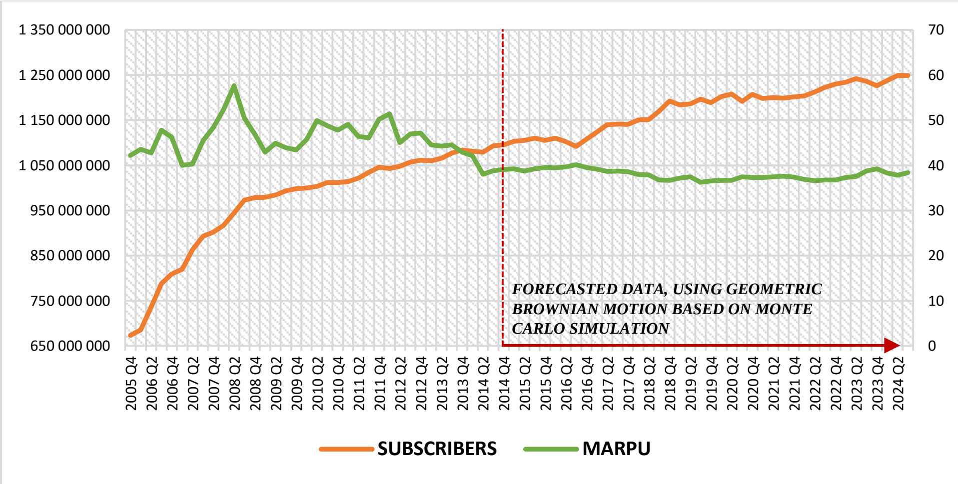


Figure 23. Dynamics of subscribers and MARPU (Actual historical data source: Bloomberg)

According to the results of analysis, the actual quarterly based MARPU of selected geographical area is EUR 45.62, meanwhile it is projected that the value of MARPU shall decrease down to EUR 37.94, thus, the average whole period analysed MARPU value is EUR 41.68. For comparison basis average MARPU values are presented in Table 6 below.

Table 6. Average quarterly based MARPU in EUR[6]

North America	Japan	Western Europe	Middle East	Latin America	Eastern Europe	Africa	Asia-Pacific (ex Japan)	Global
121.74	110.28	78.82	31.66	23.96	19.60	17.89	14.77	30.40

Source: Statistica 2015

It is obviously noticeable, that the higher average return per Subscriber is defined in North America (EUR 121.74), meanwhile the Global level is around EUR 30.40. Since there is a promiscuity of countries selected in the analysis, is not appropriate to compare the MARPU values, however, the actual and projected value is between Western Europe and Middle East levels and far higher that the Global level.

In summary, the Geometrical Brownian Motion method based on the Monte Carlo simulation was used for determining future wireless market Revenues and Subscribers in maturity of 10-years, starting from Y2014. MARPU dynamics and values were calculated. These variables shall be used in further model steps – determining the technology life cycle and its structure, defining the investment time window and forecasting the future selected companies free cash flow changes.

[6] Statista - The Statistics Portal 2015. http://www.statista.com/statistics/203642/forecast-for-the-global-average-revenue-per-mobile-user-in-2015-by-region/; The Dollar to Euro conversion rate was taken as of 2014.12.31 and equal to 1 USD = 0.8262 EUR

4. Determination of mobile technology life cycle

According to the comprehensive model structure defined previously, in this step the upcoming mobile technology life cycle shall be determined using the Hodrick-Prescott filter using Formula 16. Empirical implication is showed below in Figure 26.

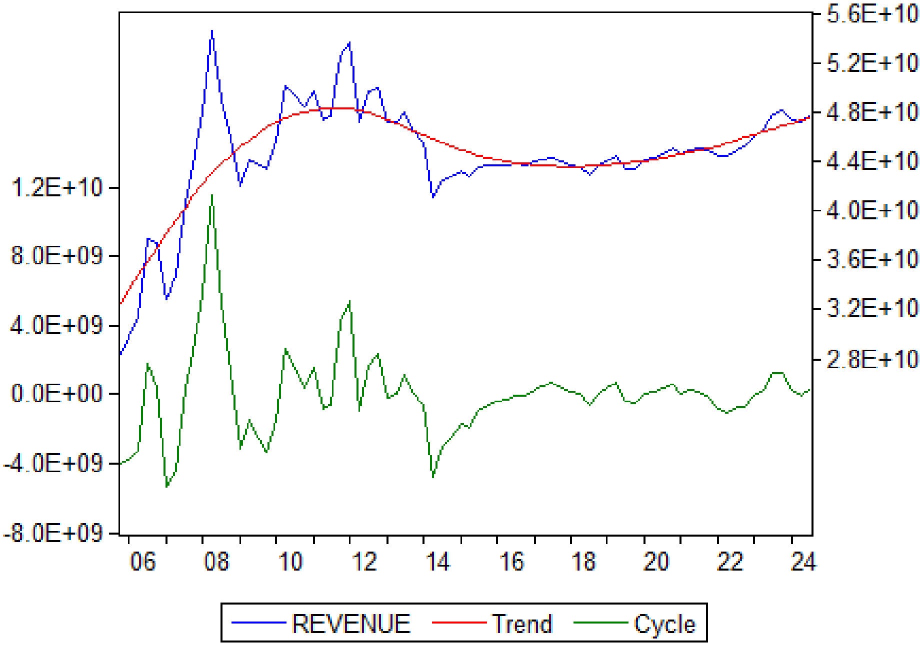


Figure 24. Technology life-cycle determination using Hodrick-Prescott filter (lambda=1600)

Considering the actual total wireless revenues data and forecasted data using the GBM process, the Hodrick-Prescott filter results showed the fluctuations of the mobile technology life cycle. It must be noticed that the existing (4G/4G+ also known as LTE), and the previous mobile generations (G1, G2, G3) were based on the same technology Meanwhile, the 5G generation shall be developed under new standards and prototypes. Thus, the results of the Hodrick-Prescott filter are logically validated and showed that the forecasted beginning of 5G technology generation shall start in the Y2018 Q1. In contract, Huawei (2015) like other companies is forecasting the beginning of the 5G product around the end of Y2019 and to begin product deployment 2020+. Figure 25 shows a proposed time line for the development of the 5G standards and subsequent product introduction in relation to the 3GPP LTE standard releases. Oracle (2015) is also predicting up to 37 times higher data traffic increase by 2019, which would mean new technology for cloud applications, that machine to machine (M2M) connections shall be running on. The ITU are also working in parallel with 3GPP and will finalise their vision for 5G during 2015 and deliberate on additional spectrum requirements during the forthcoming World Radio Conference WRC-15.

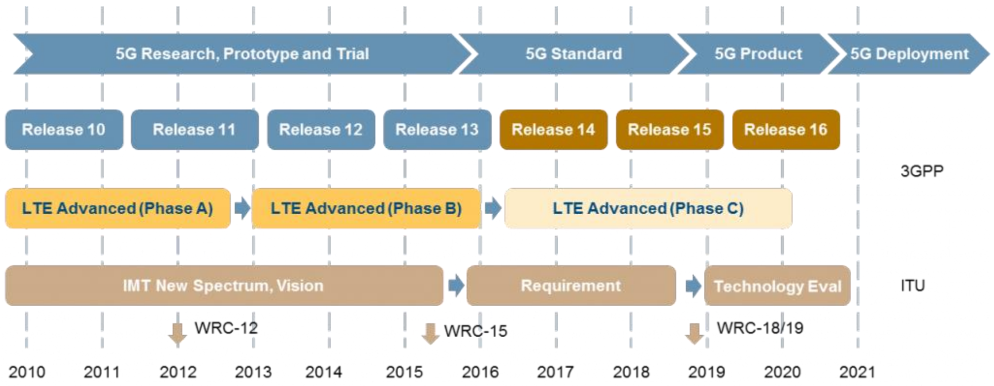


Figure 25. 5G standardisation timeline Source: Huawei, (2015)

It must be underlined, that just because the standards have been developed does not mean that fully featured 5G technology will be widely deployed. There are many standardised features in 4G LTE that have not yet been widely deployed on a commercial basis. Also, many network operators are conservative when it comes to adopting new technology early in the product life cycle, preferring to wait until the network infrastructure and devices are more established in the market place. However, in this study it is assumed that network operators shall manage technology adoption decisions considering MARPU (to satisfy demand), which includes both total wireless Revenues changes and total wireless Subscribers changes, and technology life cycle parameters. In the network operators' and mobile service associations' posts ideas can be found that 4G is unlikely to be replaced by 5G, but more of complementary technology delivering features and functionality that current technology either cannot provide, or in some areas of 5G would be more cost effective. Therefore, network operators are faced with the challenges leading up to the adopting of 5G technology. And because of the necessity to carefully plan their network architecture strategy, potential investments and costs, it is extremely important to identify the optimal investment time frame in order to keep competitiveness and maximum possible company's value.

Finally, if Sorensen (2011), is to consider the technology adoption life-cycle and the innovation hype cycle, which is shown in Figure 26, according to the statistics in the previous sections, the beginning of the 5G technology life cycle was started in 2012, meanwhile, the Determination phase shall be in 2018 Q1 and the Plateau shall be reached in Y2024. According to the scheme, it is clear which strategical role in terms of investment timing, the company shall achieve.

5. Selection of companies operating in the selected geographical territory

For further analysis 18 mobile service providers were selected, which are operating in the selected geographical area (the selection was based on main telecommunication market players' financial data in the Europe region). According to the procedure mentioned in Section 2.6., financial parameters and ratios are calculated for each competing market player as it is presented in Annex 1, for a maturity of 5 financial years in the period of 2010-2014 (on a quarterly basis). Detailed information within calculated financial ratios for each company are presented in Annex 5. It is important to underline that the consolidated financial statements are taken into consideration, which means that the financial parameters can be affected by other services revenues, capital expenditure and cash flow changes.

The batch size of companies has more than EUR 561 million of assets and EUR 278 million of revenues (5-year average). The selected companies generated more than EUR 551 million of EBITDA and spent more than EUR 203 million of capital expenditure (CAPEX) with a maturity of 5 years. It should be noted that the average growth rate of EBITDA is negative starting from 2012 and equal to -1.13%. Meanwhile, the sales growth ratio is positive and the average value is 2.78%. The 5-year average Return on Capital Employed is 14.7% within a maximum of 40.18% and a minimum -4.71%. The average in each year of technological efficiency ratio has decreased from 16.75% to 40.00% in 2010 and 2014 respectively, meanwhile, average TER (technological efficiency ratio) with a maturity of 5 years reached 14.38%. Average 5-year CAPEX to Revenues ratio is 18.30%, which means that up to 1/5 of Revenues shall be allocated for capital expenditure. It must be underlined that the ratio used to grow with a maturity of 5 years is 15.47% in 2010 and 17.20% in 2014 with an extraordinary ratio in 2013, when CAPEX to Revenues reaches 23.85%. Another important insight is about CAPEX growth rates, where the average Y5 growth is 8.00%, however, in the period analysed the ratios are reducing from 22.58% to -3.31%, which means that mobile service providers are reducing the CAPEX, or the current technology does not require such high capital expenditure. Naturally, after new technology is adopted, CAPEX growth rates will increase and reduce both the Free Cash Flows and profitability in the short-term period.

General information about each selected company is provided in Annex 2 (detailed financial parameters are presented in Annex 5). Within the list of mobile service providers according to the structure of the comprehensive technology adoption investment timing valuation support model, the next technology adoption time window determination process shall be implemented.

6. Technology adoption time window determination

Looking through the technology adoption decision management point of view, as was mentioned previously, all companies are facing investment timing issues and are forced to stay competitive. Thus, let’s assume that competing companies have the same technology adoption information as was analysed. To define the technology adoption investment timing window the CAPEX to Revenues ratio is required (taking into account that this ratio reflects the capital expenditure payback term most objectively). In this study the 18 companies’ ratios were taking into consideration. It was found that the average CAPEX to Revenues (of selected companies) is around 16.4% (5-year statistics). From now on there are two different strategies analysed under the same technological and informational environment: (Method No. 1) taking decisions considering average deviation from market mean ratio and (Method No. 2) using its own company’s information.

Method No. 1

The results of Method No. 1 are presented in Table No. 7, the column named Method No. 1, where the technology adoption decision was taking considering the standard deviation from the market CAPEX to Revenues for each company. Actual historical CAPEX to Revenues for the selected companies is equal to 16.38% as of 2014.12.31, within the maximum value of 25.96% for Telekom Austria AG and the lowest ratio of 10.67% for Deutsche Telekom AG. Afterwards, standard deviations from the average CAPEX to Revenues value (16.38%) were calculated for each company. For TAW_c calculations it is necessary to define the average market CAPEX level in the Plateau moment, which was retrieved by the absolute value in the amount of EUR 7.0 billion (it is assumed that the CAPEX level for the company shall stay relatively the same as it is now, thus, since the mobile service market Revenue is projected for the Plateau moment, it is possible to calculate absolute value). It was calculated that the average market CAPEX to Revenues ratio shall decrease to 14.64% in the Plateau moment, when the 5G shall be at its highest. Hence, CR_c (CAPEX to Revenues level in the Plateau moment) is calculated assuming that the deviation from the market average shall stay the same as it was in 2014.12.31.

Table 7. Time window calculation for competing company[7]

Company name	CAPEX to Revenues	Method No. 1			Method No. 2		
		Stand dev.	CR_c	TAW^1_c, Y	Market $CAPEX_2$	NCR_c	TAW^2_c, Y
Belgacom SA	13.88%	2.50%	15.0%	**6.7**	5 939	12.4%	**8.1**
BT Group PLC	13.07%	3.31%	15.1%	**6.6**	5 592	11.7%	**8.6**
Deutsche Telekom AG	10.67%	5.71%	15.5%	**6.5**	4 566	9.5%	**10.5**
Elisa OYJ	12.93%	3.46%	15.1%	**6.6**	5 530	11.5%	**8.7**
Mobile TeleSystems OJSC	18.50%	2.12%	14.9%	**6.7**	7 916	16.5%	**6.0**
Orange Polska SA	17.05%	0.66%	14.7%	**6.8**	7 293	15.2%	**6.6**
Rostelecom OJSC	23.28%	6.90%	15.6%	**6.4**	9 959	20.8%	**4.8**
Swisscom AG	21.58%	5.20%	15.4%	**6.5**	9 232	19.3%	**5.2**
TDC A/S	11.38%	5.01%	15.4%	**6.5**	4 866	10.2%	**9.8**
Tele2 AB	15.10%	1.28%	14.8%	**6.7**	6 460	13.5%	**7.4**
Telecom Italia SpA	11.28%	5.10%	15.4%	**6.5**	4 827	10.1%	**9.9**
Telefonica SA	16.60%	0.21%	14.7%	**6.8**	7 100	14.8%	**6.7**
Telekom Austria AG	25.96%	9.58%	16.0%	**6.2**	11 106	23.2%	**4.3**
Telenor ASA	16.73%	0.35%	14.7%	**6.8**	7 157	14.9%	**6.7**
TeliaSonera AB	15.06%	1.32%	14.8%	**6.7**	6 444	13.5%	**7.4**
Turk Telekomunikasyon AS	17.11%	0.72%	14.7%	**6.8**	7 317	15.3%	**6.5**
Turkcell Iletisim Hizmetleri AS	13.06%	3.32%	15.1%	**6.6**	5 587	11.7%	**8.6**
VimpelCom Ltd	18.54%	2.16%	15.0%	**6.7**	7 931	16.6%	**6.0**
Average	*16.38%*		*15.1%*	*6.6*	*7 009*	*14.6%*	*7.2*
Median	*16.60%*		*15.0%*	*6.7*	*7 100*	*14.8%*	*6.7*
Stand. Dev	*4.08%*		*0.4%*	*0.2*		*3.6%*	*1.7*
Variance	*0.17%*		*0.0%*	*0.0*		*0.1%*	*2.9*
Minimum	*10.67%*		*14.7%*	*6.2*	*4 566*	*9.5%*	*4.3*
Maximum	*25.96%*		*16.0%*	*6.8*	*11 106*	*23.2%*	*10.5*

[7] Market $CAPEX_2$ calculated using each company CAPEX to Revenues ratio expressed in millions of Euros

Since CR_c are calculated for each company, the difference between the decision making time period (using 1 sigma) was retrieved. The time frame (TAW^1_c) was calculated for each company starting back from Y2024 as it is considered as the Plateau of 5G technology. As it is shown in the table below, the average TAW^1_c is 6.6 years back from the Plateau, however, the distribution of the values is very low, confirmed with a variance level of 0.0%, and the difference between the highest and lowest value is only 0.6 years, or in other words 7.2 months. It was noted that this method has a crucial constraint; all the companies will adopt the technology between Y2017 and 2018 and the difference is mostly in months. Thus, the results of this method is being rejected.

Method No. 2

Despite the fact that different mobile technology adoption time windows were calculated in Method No. 1, logically it does not create a competitive advantage for separate companies, which is why a second methodology was implemented (Models' part V, Method No. 2). As was described in Section 2, the main difference and the crucial idea for this method is recalculation of adjusted CAPEX to Revenues ratios, which were used to calculate the time windows.

Thus, 18 different Market CAPEX absolute values are calculated using CAPEX to Revenues ratio from the 1st column in the table above (see Table 7, Annex 7 and Annex 8). As it was mentioned, since the absolute amount of Revenues is being projected using the Geometric Brownian Motion process based on the Monte Carlo simulation in the technologies, the Plateau moment and market $CAPEX^2$s are achieved for each competing company, and the NCR_c can be calculated, which shows the adjusted new CAPEX to Revenues comparative level (%) for each single company. The adjusted average level of CAPEX to Revenues is lower in comparison as of 2014.12.31 and equal to 14.6%. Hence, using the same formula as in Method No. 1, TAW^2_c is calculated for each company. The results had shown that the investment time window started in Y2014 and ended in Y2019, in other words 4.3-10.5 years back starting from Y2024. From the financial management and technology adoption point of view, it could be said that despite the fact that all the companies have more or less the same information and technological environment surrounding investment timing and technology adoption timing, the decision will be made at different times. This conclusion approves the fact that a separate company has different financial abilities to adopt and implement technology, stay competitive and move forward with technological development. According to the analysis results, the financial effect would be the same for both companies (Telekom Austria AG (4.3 years) and Deutsche Telekom AG (10.5 years)), meanwhile, the investment decision taking time differs by 6.2 years. Such insights prove the different strategical managerial positions of companies in the context of technology adoption timing. Despite the fact that the companies have similar information about volatile demand changes, technology development cycle and last inventions, each of the companies have a different investment managerial role with different resources, thus the entrance into the technology adoption cycle has various parameters. A brief summary of the average financial ratios is presented in Table 10 according to different investors' strategical roles, which were assigned in the table below (see Table 8)

Table 8. Strategical technology adoption investment roles for analysed companies

Strategical role	Companies assigned
Pioneers-innovators	Deutsche Telekom AG TDC A/S Telecom Italia SpA
Pragmatics	Belgacom SA BT Group PLC Elisa OYJ Turkcell Iletisim Hizmetleri AS
Followers	Tele2 AB TeliaSonera AB
Other (laggards; in the context of this research)	Mobile TeleSystems OJSC Orange Polska SA Rostelecom OJSC Swisscom AG Telefonica SA Telekom Austria AG Telenor ASA Turk Telekomunikasyon AS VimpelCom Ltd

The pioneers-innovators roles could be assigned to such companies as Deutsche Telekom AG, TDC A/S and Telecom Italia SpA, which according to the comprehensive model, will start adopting 5G generation (or in other words, investing CAPEX into new technology) earlier, 9-10 years back from the Plateau moment, in the period of 2015-2016. The average CAPEX to Revenues ratio of these companies is 11.11%, meanwhile, the average adjusted CAPEX to Revenues ratio (NCR_c) is 9.9%. The actual historical average Return on Capital Employed (ROCE) is 6.15% and the actual historical average EBIT margin is 12.67%, meanwhile, EBITDA is 44.06%.

The pragmatic roles could be assigned to such companies as Belgacom SA, BT Group PLC, Elisa OYJ and Turkcell Iletisim Hizmetleri AS, which according to the model will start investing in Y2017. The average CAPEX to Revenues ratio for these companies is higher than the pioneers and equal to 13.24%, the same as with the average adjusted CAPEX to Revenues ratio (NCR_c), which is equal to 11.8%. The actual historical average Return on Capital Employed (ROCE) for the pragmatics is 16.65% with 17.77% of EBIT and 31.53% of EBITDA.

The followers role could be assigned to Tele2 AB and TeliaSonera AB, which according to the model will start investing in Y2018. The average CAPEX to Revenues ratio of these companies is higher than the pioneer and pragmatics and equal to 15.08%, meanwhile, the average adjusted CAPEX to Revenues ratio (NCR_c) is 13.5%. The actual historical average Return on Capital Employed (ROCE) for followers is 10.06% with 15.20% of EBIT and 28.35% of EBITDA.

For a comparison basis, the statistical analysis of those companies, which, according to the model will adopt 5G mobile technology in the period of 2019-2021, average CAPEX to Revenues ratio of these companies is 23.61%, average adjusted

CAPEX to Revenues ratio (NCR_c) is equal to 21.10%. The actual historical average Return on Capital Employed (ROCE) for laggards is 12.94% with 17.92% of EBIT and 41.18% of EBITDA. Obviously the time period in which EBITDA is being generated is the shortest, so such companies do not take the risk of unsuccessful technology foundation.

In Annex 6 a correlation matrix is presented in order to evaluate the relationships between the variables (within the next sections variables are included as well).

Summing up the strategies, which were analysed in the context of the comprehensive technology adoption investment timing valuation support model, the most crucial insights are as follows:

1. The beginning and the peak, or in other words Plateau, of the mobile technology life cycle was forecasted using actual and projected statistical mobile technology development parameters and the Hodrick-Prescott filter tool. The mobile wireless service market Revenues was projected using the Geometric Brownian Motion process method based on the Monte Carlo simulation. These variables are extremely necessary for technology adoption investment time window determination. It was found that deployment of 5G mobile technology was started in Y2012 and the peak period (Plateau) is expected in Y2024.
2. Method No. 1, where the investment timing valuation support model was based on average deviation from the market mean, was rejected because the investment time gaps between companies are significantly close to each other (investment time frame in a period of 6.2-6.8 years) and in the real world does not create competitiveness for the market players, even more, all companies will adopt the technology in the maturity of the same year.
3. Method No. 2, where the investment timing valuation support model was based on the market player's own company information, was approved with several conditions:
    a. Despite the fact that the reach of the technological development information is the same for all market players, strategic managerial investment timing decisions are based on each market player's own managerial strategies.
    b. The Method No. 2 presents an investment time frame for all market players with a maturity of 6+ years, or in this case, the period determined calculating time back from the Plateau moment with a maturity of 4.3-10.5 years.
    c. CAPEX to Revenues ratio as the variable that reflects the capital expenditure payback term most objectively and could be used to determine the technology adoption investment timing window in the context of the model. Market players were distributed according to the investment time windows, where investment strategies could be assigned with crucial insights: pioneers / innovators have the lowest CAPEX to Revenues ratio (13.24%) and the highest EBITDA (44.06%) in comparison with pragmatics (31.53%) and followers (28.35%). This could be explained because of the longest

investment period, where depreciation makes its role in the EBITDA calculation. However, the EBIT (12.67%) is the lowest in comparison with the other strategies (17.77% and 15.20% respectively). On the other hand, the latest market players have the highest CAPEX to Revenues ratio (23.61%) and almost the same EBITDA as innovators at 41.18%.

In the next step, the competing companies value assessment, based on Free Cash Flow changes, shall be calculated.

7. Decision value (NPV) calculation based on Free Cash Flow changes

After the mobile technology adoption investment time windows are defined for competing companies, it is important to assess the affect for each company in value changes, or in other words, the size of the effect. For this aim, an investigation on the value for the company evaluation determined including Free Cash Flow changes and Net Present Value calculation method. It shall be underlined in the Free Cash Flow changes forecasting process, that the FCF is determined as cash flow from the main activity reduced by investment amounts for tangible and intangible assets, for this reason it is assumed that the component of investment, which is reducing cash flow, is already included. Also, inflation or other factors effects are not taken into consideration with the purpose to assess the net present value of the decision made.

As it is determined in the structure of the model NPV_c, TF_c and additional ratios shall be calculated to achieve CV_c in order to comprehend the FCF impact for the companies' value considering the current market capitalisation. Using Formulas (19-23) calculations are done and presented in the table below (see Table 79).

This part of the research has several calculation method lines: using individual company ROCE ratio and average market ROCE. Individual actual $ROCE_c$ is calculated using Formula 20 with a maturity of 5 years. The distribution of the ratios' value is from 3.7% to 33.1% with an average value of 13.8%. The ratio called $ROCE_{avg.}$ is calculated using the actual historical data with a maturity of 5 years considering each company each year ROCE ratio and equal to 14.1%. In the context of the present value of the strategic technology adoption decision evaluation, the Net Present Value (NPV_c) is calculated taking into consideration each company's Free Cash Flow amounts with a maturity of 10 years. The duration of this period is based on the technology life cycle development and covers the time frame starting from Y2015 to Y2024, as it is the technology peak calculated previously. FCF changes are based on MARPU changes (growth rates) in the forecasted period. Under this methodology the net present values in each year for each company are calculated using both individual and market average ROCE. The value generated using the individual ROCE is 12.8% higher in comparison with the average ROCE, as a discount factor. Variables NPV_c and $ROCE_c$ have a negative relationship with the correlation strength, -41.3%. To assess the effect of the decision made, market capitalisation is taken ($MCap_c$) of each company as of 2014.12.31. Next, TF_c is calculated as a proportion of NPV_c in $MCap_c$, thus TF_c is achieved for each company. At the end, continues values ($ConV_c$) are calculated to finalise the companies' values assessment (CV_c). By analogy of the previous calculations, the Plateau time moment is considered as of Y2014, thus, NPV_c, TF_c, $ConV_c$ and CV_c using both individual ROCE and average market ROCE, are calculated until this time frame. It must be noted that the FCF base period taken is 2014.12.31, the same as the Market Capitalisation calculation.

Table 9. Company value change and the impact of decision timing considering market capitalisation[8]

Company name	$MCap_c$	Individual ROCE					Average ROCE				
		$ROCE_c$, %	NPV_c	TF_c, %	$ConV_c$	CV_c	$ROCE_{avg}$, %[9]	NPV_c^2	TF_c^2, %	$ConV_c^2$	CV_c^2
Belgacom SA	9.7	19.1	3.0	**31.1**	3.7	3.7		3.6	**37.4**	5.0	5.0
BT Group PLC	43.8	18.5	15.5	**35.4**	19.3	19.1		18.2	**41.6**	25.3	25.0
Deutsche Telekom AG	61.6	3.7	32.8	**53.3**	109.2	108.6		20.8	**33.9**	29.0	28.6
Elisa OYJ	1.5	18.4	0.7	**46.9**	0.9	0.9		0.8	**54.9**	1.1	1.1
Mobile TeleSystems OJSC	8.8	33.1	3.8	**43.0**	4.0	4.0		6.8	**77.9**	9.5	9.4
Orange Polska SA	2.5	8.4	0.9	**35.4**	1.7	1.6		0.7	**27.9**	1.0	1.0
Rostelecom OJSC	6.1	12.8	2.9	**47.6**	4.3	4.2		2.8	**45.2**	3.9	3.8
Swisscom AG	22.5	15.2	5.8	**25.6**	7.7	7.6		6.0	**26.7**	8.4	8.3
TDC A/S	5.2	10.3	2.6	**49.4**	4.2	4.1		2.2	**42.4**	3.0	3.0
Tele2 AB	4.2	9.7	0.3	**6.7**	0.5	0.5		0.2	**5.6**	0.3	0.3
Telecom Italia SpA	16.4	4.4	24.6	**149.8**	71.3	70.8		16.1	**98.4**	22.4	22.1
Telefonica SA	274.1	10.2	22.7	**8.3**	37.3	36.9		19.4	**7.1**	27.0	26.6
Telekom Austria AG	3.6	10.8	0.9	**25.0**	1.4	1.4	14.1	0.8	**21.9**	1.1	1.1
Telenor ASA	25.2	14.0	7.2	**28.7**	10.1	10.0		7.2	**28.7**	10.1	9.9
TeliaSonera AB	23.2	10.4	8.2	**35.3**	13.3	13.1		7.1	**30.4**	9.8	9.7
Turk Telekomunikasyon AS	9.0	27.1	3.0	**33.5**	3.4	3.3		4.6	**51.6**	6.5	6.4
Turkcell Iletisim Hizmetleri AS	11.0	10.7	1.5	**13.7**	2.4	2.4		1.3	**11.9**	1.8	1.8
VimpelCom Ltd	6.5	10.8	6.1	**94.0**	9.7	9.6		5.4	**82.5**	7.5	7.4
Average	*29.7*	*13.8*	*7.9*	*42.4*	*16.9*	*16.8*		*6.9*	*40.3*	*9.6*	*9.5*
Median	*9.3*	*10.8*	*3.4*	*35.3*	*4.2*	*4.2*		*5.0*	*35.6*	*7.0*	*6.9*
Stand. Dev	*63.0*	*7.4*	*9.6*	*33.3*	*28.9*	*28.7*		*6.9*	*25.5*	*9.6*	*9.5*
Variance		*0.5*		*11.1*					*6.5*		
Minimum	*1.5*	*3.7*	*0.3*	*6.7*	*0.5*	*0.5*		*0.2*	*5.6*	*0.3*	*0.3*
Maximum	*274.1*	*33.1*	*32.8*	*149.8*	*109.2*	*108.6*		*20.8*	*98.4*	*29.0*	*28.6*

After the analysis with the parameters defined (see Table 9 and Table 10), it was noticed that there is a significant linear correlation between variables, which presents logical evidence of theoretical insights and the real world decision making process. Variables TAW^2_c and NPV_c have a 50% linear correlation ratio value, which means that early adopters, according to the model, can expect a higher NPV value in the Plateau stage of the mobile technology cycle. This fact again was proved by the positive correlation between the company value (CV_c) and Technology Adoption Window (TAW^2_c) with a value of 56%. Even more significant, the correlation between Market Capitalisation ($MCap_c$) and both NVP_s*'s* (calculated with individual ROCE ratio and market average ROCE ratio) are recorded as follows; 56% and 63%

[8] In billions of Euros except $ROCE_c$, $ROCE_{avg.}$, TF_c, TF_c^2.

[9] Actual average ROCE of all companies with a maturity of 5 years.

respectively, thus, these parameters prove the relationships between actual companies' market capitalisation (as of 2014.12.31) and calculated net present value (as of 2024.12.31). Also, there is up to 32% positive correlation mean between the Free Cash Flow share in Market Capitalisation value (TF_c) and Technology Adoption Window (TAW^2_c). In general, one of the main insights is the average of TF_c*s*, which are both similar, 42.4% and 40.3% with individual ROCE and average ROCE respectively. Only one company has TF_c more than 100 p.p., Telecom Italia SpA at 149.8%. It means that around 40% of current Market Capitalisation is affected by Free Cash Flow based on the investment timing decision, thus, it could be said that mobile service market capacities in terms of subscribers are almost fulfilled and the future company value and success shall depend on the share of the market. In other words, technological shift in a mature market, talking about mobile service providers, is only irreversible investment to become a real market player with a growing number of Subscribers, therefore, mergers and acquisitions between market players is expected. Another important insight is between Market Capitalisation ($MCap_c$) and companies continues value ($ConV_c$) or Companies value (CVc), which have a strong correlation in the value of 63% with the average ROCE and only 35% with the individual ROCE. Also, it was noticed that the higher (average) Technological efficiency ratio a company has, the higher the Return on Capital Employed (ROCE) the company generates (correlation equal to 69%). In the Annexes the correlation matrix is presented in order to evaluate the relationships between variables.

In Table 10 below, the average financial ratios are presented within the previous section results according to the different investors' roles. It was found that the earlier a company starts to adopted new technologies, the higher the company value share (proportion) in its market capitalisation will be generated, or in other words, TF_c is the highest for pioneers-innovators, the average ratio is up to 84.2% (individual ROCE) and 58.2% (average ROCE), meanwhile for pragmatics, 37.8% and 44.6% respectively. Followers have the smallest proportion in market capitalisation, the average value is only 21.0% and 18.0% respectively.

Table 10. Average financial ratios under different investors' role

Investors' role	Time back starting from peak of technology life cycle	CAPEX to Revenues, %	Adjusted CAPEX to Revenues, %	ROCE, %	EBIT, %	EBITDA, %	TF_c, %	TF_c^2, %
Pioneers-innovators	9-10 year	11.11	9.90	6.15	12.67	44.06	84.2	58.2
Pragmatics	8 years	13.24	11.08	16.65	17.17	31.53	37.8	44.6
Followers	7 years	15.08	13.50	10.06	15.20	28.35	21.0	18.0
Others	4-5 year	23.61	21.10	12.94	17.92	41.18	37.9	41.1

Another approach exists in the context of model results. Taking into account the average TF_c values it could be noticed that the ratio fluctuation gap is between 6.7 and 149.9% with the individual ROCE and between 5.6 and 98.4% with the average ROCE. This value diffusion could be affected by both $MCap_c$ and NPV_c ratios, however all companies are on the threshold of mobile technology shift and operate on their own platform, which according to TF_c ratios updates with a maturity of 24-25 years (depends on the ROCE type), meanwhile mobile generation technology evolves over a 20-year life cycle. Thus, the mobile (wireless) technology based companies are forced to shift technological platform every time period of 24-25 years. Historically, mobile service providers were used to provide a common GSM connection and sold new mobile devices, meanwhile, the new generation (the upcoming 5G) will be met with a higher data transmission service and mobile device rental service, which means that with the shift of new mobile technology generation, companies will shift their business models as well. In accordance with the statistical company business model life cycle defined analysing 20 years of actual and forecasted data, it could be said that in the perspective of mobile service company value assessment, the maturity period shall be selected as 24-25 years depending on the ROCE type. Meanwhile, those companies that have a TF_c ratio around 90%, shall be assessed with a maturity of 10 years. This shows the additional risks on the Cash Flow basis and unsustainable potential growth abilities. On the other hand, each 24-25-year period mobile (wireless) service company values come up to the same level, when the technological platform shall be shifted together with the new mobile technology.

3.4. Summarising models applicability research results and its interpretation

Companies face a problem of caching the optimal timing of new technology adoption, what drives the loss or gain of competitiveness, value creation or disruption for the company, investment payback target setting, building reactivated business models, etc. These issues are more complicated for a mature market, where demand changes can be modelled with uncertainty presumptions, because competition is very acute and technology investments are irreversible. Currently new 4G (LTE networks) are becoming increasingly available in the world. Meanwhile, mobile service providers are forecasting that 5G shall be available in 2020+, with more than 1,000-time higher traffic capacity limit, ultra-reliable and with low energy consumption. This type of network shall correspond and satisfy the technical requirements for M2M industry (Machines to Machines). Even more, this shall change the income structure of service providers, because a high speed internet connection occupies cellular connections. Unlike other industries, these companies do not have the ability to leapfrog new technology releases.

The constructed comprehensive technology adoption investment timing valuation support model presented in the thesis is focused on the analysis of historical mobile network technology demand parameters of mobile service market revenues, analysed for 31 quarters in the period from 2007 Q2 to 2014 Q4 (Bloomberg finance, 2015). Analysed demand volatility in the thesis depends on two parameters, average market revenue and quantity of subscribers. The selected market involves such countries as Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine and United Kingdom (market data selection was limited to data availability, thus in this research it is assumed that these countries and companies operating in them are the mobile network market).

Due to penetration rates analysis, the highest jumps were made in Finland, Russia, Sweden and Ukraine. Furthermore, there are countries where penetration rates do not exceed 100 p.p. such as Turkey. From the penetration rates point of view as of 2014 Q4, Austria, Bulgaria, Estonia, Finland, Russia and Sweden are identified as exceeding 150%, meanwhile, the mobile wireless penetration ratio worldwide in 2011 Q4 was up to 87%, meanwhile at the end of 2014 it was 93%.

According to Chetan (2015), mobile network technologies evolve over a 20-year technology life cycle. On average, the time-to-peak has been 12 years, meanwhile the time from peak-to-sunset is around 7 years. For each technology cycle, the standardisation time period is around 7-8 years. METIS (2015), Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society stated that 5G technology deployment was started in 2012, thus statistically, it is expected to have standards running in 2019-2020 and its peak period in 2024.

The analysis of actual historical data of wireless market Subscribers showed that the average growth rate of Total Wireless Subscribers is around 1.41%, however, the pace of growth is reducing, in the period 2005 Q4 to 2008 Q4 the average growth rate was around 3.19%, meanwhile, in the period of 2008 Q4 to 2014 Q3 it was 0.49%. The identified pace of reduced growth rate could be easily explained as an aftereffect of the Global financial crisis. In the maturity of the analysed period, the average growth rate of wireless revenues is around 1.60%. Meanwhile, in the period of 2005 Q4 to 2008 Q4 the average growth rate was around 4.77% and in the period of 2008 Q4 to 2014 Q3 it was negative and reached -0.18%. The reason for the decreasing market Revenues is several fold: firstly, it could be assumed that in the period before the Global financial crisis mobile service users used to have higher expenses as a share of household income (and in a company level as well). At this time competing companies were forced to revise pricing structures in order to survive and keep the number of subscribers. Providers reconsidered their pricing plans and started offering personal solutions to their customers. Secondly, in the same period technology expansion in waves increased the abilities to use more wireless based connections in comparison with GSM, moreover, smartphones started to replace mobile phones with a high intensity.

After the statistical analysis was successfully implemented in this thesis using the Dickey-Fuller test, Q-Q plots, autocorrelation test and Kolmogorov-Smirnov test, 40 iterations of both subscribers and market average returns per user were calculated using the Monte Carlo simulation of demand paths of the Geometric Brownian Motion process. In defining the parameters, the Drift (μ) value for Total wireless service revenues is 1.15% and Volatility (σ) parameter reaches 7.55%, meanwhile, considering the total wireless subscribers it is 1.39% and 1.82% respectively. As it was mentioned previously, MARPU is being calculated (total revenue divided by the number of subscribers) for each iteration as of 40 time steps. It is very important to underline that the methodology selected (GBM based on the Monte Carlo simulation) is not used to forecast neither marker Revenues, nor market Subscribers. The aim of this method is to simulate the dynamics of the selected time series in accordance with the historical statistical dynamics parameters based on the chaos uncertainty process.

The Hodrick-Prescott filter tool is applied to determine the mobile technology (5G) life cycle. The results of the Hodrick-Prescott filter are logically validated and showed that forecasted the beginning of 5G technology generation shall start at Y2018 Q1.

An empirical analysis of mobile technology (5G) investment timing is presented analysing 18 competing companies' financial results (all companies are operating in the European market). The simulation results have showed that the different companies analysed have financial potential to adopt new technology in the time window of 4.3 to 10.5 years before Y2024. In fact all the companies have almost the same available information from the market, technology adoption investment timing decisions will be made in different times, depending on the financial management and technology adoption strategies of the companies based on the current financial state of the particular market player. The research results also allow the concluding remarks about mobile communications company life cycle, depending on the main resource life cycle expectancy to be made. These research results motivate the selection of a 25 years' period for such type of company valuation.

The batch size of the companies has more than EUR 561 million in assets and EUR 278 million of revenues (5-year average). The selected companies generated more than EUR 551 million of EBITDA and spent more than EUR 203 million of capital expenditure (CAPEX) in period of 5 years. It shall be noted that the average growth rate of EBITDA is negative starting from 2012 and equal to -1.13%. Meanwhile, the sales growth ratio is positive and the average value is 2.78%. The 5-year average Return on Capital Employed is 14.7% within a maximum of 40.18% and a minimum -4.71%. The average in each year of the technological efficiency ratio has decreased from 16.75% to 40.00% in 2010 and 2014 respectively, meanwhile, the average TER (technological efficiency ratio, see Annex 1) with a maturity of 5 years reached 14.38%. The average 5-year CAPEX to Revenues ratio is 18.30%, which means that up to 1/5 of Revenues shall be allocated for capital expenditure. It must be underlined that the ratio used to grow with a maturity of 5 years is 15.47% in 2010 and 17.20% in 2014 with an extraordinary ratio in 2013, when the CAPEX to Revenues reached 23.85%. Another important insight is about CAPEX growth rates, where the average Y5 growth is 8.00%, however, in the period the analysed ratios are reduced from 22.58% to -3.31%, which means that mobile service providers are reducing their CAPEX, or the current technology does not require such high capital expenditure.

There are two different strategies analysed under the same technological and informational environment: (Method No. 1) taking the decision considering the average deviation from the market mean ratio and (Method No. 2) using their own company information. The results of Method 1 showed that the average TAW^{1}_{c} (see Formula 18) is 6.6 years back from the Plateau, however, the distribution of the values is very low, confirmed with a variance level of 0.0% and the difference between the highest and lowest value is only 0.6 years. For this reason, Method No. 1 was rejected because the investment time gaps between the companies are significantly close to each other and in the real world do not create competitiveness for the market players, even more so, all companies will adopt the technology with the maturity of one and the same year. Meanwhile Method No. 2, where the investment timing valuation support model was based on the market player's own company information, was approved with several conditions. Firstly, despite the fact that the reach of the technological development information is the same for all market players, strategic managerial investment timing decisions are based on each market player's own managerial strategies. Secondly, Method No. 2 presents the investment time frame for all market players with a maturity of 6+ years, or in this case, the period determined calculating time back from the Plateau moment with a maturity of 4.3-10.5 years. The results of the model are graphically presented in Figure 26.

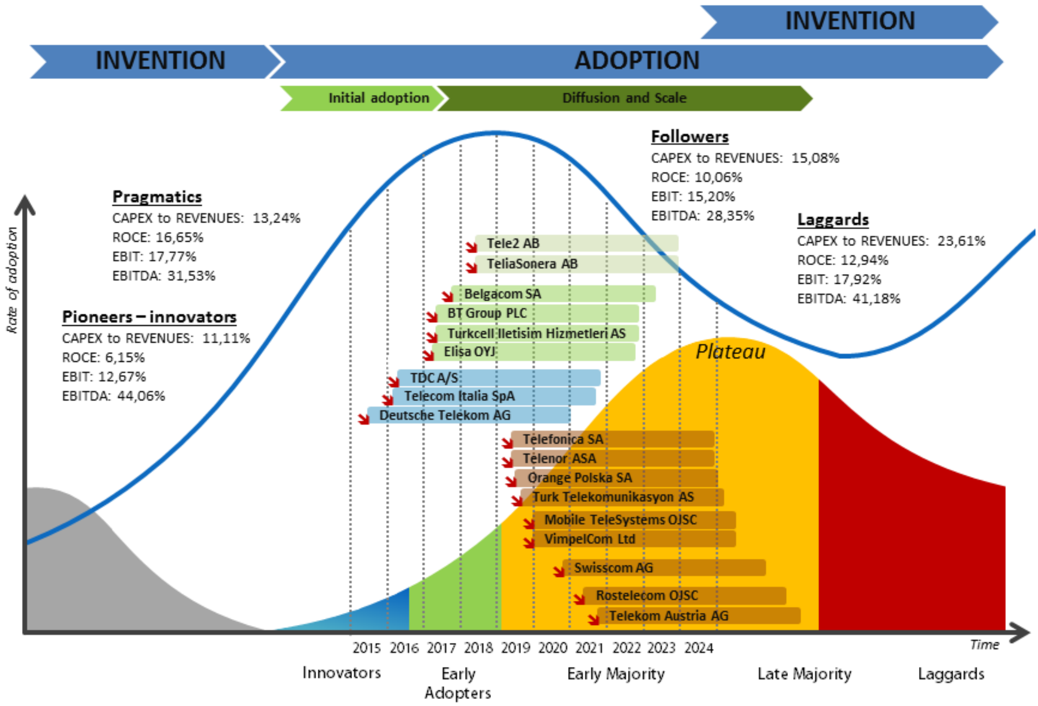


Figure 26. Mobile 5G technology adoption optimal investment cycle and technology hype life-cycle

Thirdly, market players were distributed according to the technology adoption windows TAW^2_c, where investment strategies could be assigned with crucial insights: pioneers / innovators have the lowest CAPEX to Revenues ratio (13.24%) and the highest EBITDA (44.06%) in comparison with pragmatics (31.53%) and followers (28.35%). This could be explained because of the longest investment period, where depreciation makes its role in the EBITDA calculation. However, the EBIT (12.67%) is the lowest in comparison with the other strategies (17.77% and 15.20% respectively). On the other hand, the latest market players have the highest CAPEX to Revenues ratio (23.61%) and almost the same EBITDA as the innovators at 41.18%. Thus, the CAPEX to Revenues ratio as the variable that reflects the capital expenditure payback term most objectively could be used to determine the technology adoption investment timing window in the context of the model. The models results are graphically presented in Figure 26.

After the mobile technology adoption investment time windows are defined for the competing companies, it is important to assess the affect for each company in the value changes, or in other words, the size of the effect. For this aim, the investigation on value for a particular company evaluation was made including the net present value calculation based on the free cash flow changes. This part of the research has several calculation method lines: using the individual company ROCE ratio and average market ROCE.

After the analysis with the defined parameters (see Table 9), it was noticed that there is a significant linear correlation between the variables, which presents logical evidence of the theoretical insights and decision making process in practice. Variables TAW^2_c and NPV_c have a 50% linear correlation ratio value, which means that early adopters according to the model, can expect a higher NPV value in the Plateau stage of the mobile technology cycle. This fact was again proved by the positive correlation between the company value (CV_c) and Technology Adoption Window (TAW^2_c) in the value of 56%. An even more significant correlation between Market Capitalisation ($MCap_c$) and both NVP_s*'s* (calculated with the individual ROCE ratio and the market average ROCE ratio) were recorded as follows; 56% and 63% respectively, thus, these parameters prove the relationships between the actual companies' market capitalisation (as of 2014.12.31) and the calculated companies' value (as of 2024.12.31). Also, there is up to 32% positive correlation mean between the Free Cash Flow share in the Market Capitalisation value (TF_c) and the Technology Adoption Window (TAW^2_c). In general, one of the main insights is the average of $TF_c s$, which both are similar at 42.4% and 40.3% with the individual ROCE and the average ROCE respectively. Only one company has a TF_c of more than 100 p.p., Telecom Italia SpA at 149.8%. It means that around 40% of the current Market Capitalisation is affected by the Free Cash Flow based on the investment timing decision, thus, it could be said that mobile service market capacities in terms of subscribers are almost fulfilled and the future company value and success shall depend on the share of the market. In other words, the technological shift in a mature market, talking about mobile service providers, is the only irreversible investment to become a real market player with a growing number of Subscribers, therefore, mergers and acquisitions between market players is expected. Another important insight is between Market Capitalisation ($MCap_c$) and companies continues value ($ConV_c$) or Companies value (CVc), which has a strong correlation in value of 63% with the average ROCE and only 35% with the individual ROCE. Also, it was noticed that the higher (average) Technological efficiency ratio the company has, the higher the Return on Capital Employed (ROCE) company generates (correlation equal to 69%).

Another approach exists in the context of the model results. Taking into account the average TF_c values it could be noticed that the ratio fluctuation gap is between 6.7 and 149.9% with the individual ROCE and between 5.6 and 98.4% with the average ROCE. This value diffusion could be affected by both $MCap_c$ and NPV_c ratios, however, all the companies are on the threshold of the mobile technology shift and operate on their own platform, which according to TF_c ratios updates with a maturity of 24-25 years (depending on the ROCE type), meanwhile, mobile generation technology evolves over a 20-year life cycle. Thus, the mobile (wireless) technology based companies are forced to shift the technological platform each time period of 24-25 years. Historically, mobile service providers were used to provide a common GSM connection and sold new mobile devices, meanwhile, the new generation (upcoming 5G) will be met with a higher data transmission service and mobile device rental service, which means that with the shift of new mobile technology generation, companies will shift their business models as well. Finally, the crucial factor in the company's valuation and perspectives assessment is the duration of the main assets life cycle. This research showed the time frame for mobile technology (wireless) based companies that could be considered as a maturity of the company's business cycle in a term of new technology adoption shifts.

CONCLUSIONS

This research shows the theoretical and empirical managerial decision implication abilities for a science and technology based company in order to make the optimal investment timing solutions under the assumption that demand, expressed by total wireless subscribers, total wireless service revenues and their derivative amounts, follow the GBM processes and are based on the data analysis for the separate company. The results of this analysis underline the explanation potential of the model for both firms, with regard to their optimal investment and investment strategies, as well as for policy decision makers with respect to the detailed policy impact analyses.

1. The analysis of the academic literature revealed the fact that there is a scientifically based approach, that the development of technologies has a significantly crucial impact for economy growth. It must be underlined that technologies and innovations in different sectors and areas are interconnected and the technological change or shift is basically affecting the whole economic level neither single city, country, region, etc.
2. The economy has to be expressed as a demand in terms of technological change in order to perceive the best possible time for innovation deployment. These issues force the exploitation of demand, and the factors that can express and describe the demand uncertainty, and even future possible demand changes under the influence of technological change, or in other words historical development analysis of product and/or service with demand paths volatility have to be analysed. Also it was found that the connection of industrial progress, scientific research works, organisational changes and economic competitiveness have increased.
3. The competitiveness of the competing company is directly dependent on its ability to acquire and implement new business methods and new technologies, as well as use them in the production of new competitive products. Although the conception of technology definition was changing in due course, the general direction of the paradigm stays the same as the complexity of techniques, methods and approaches, which empower the supplier and customer to better reveal a more effective and reliable product, service, process, structure, mechanism or whatever it is. Thus the development of the interrelated paradigms creates a synergy in the world economy and in each of its subjects accordingly. For this reason, the variety of different research can be found in academic literature in terms of those paradigms analysis, better understanding and manipulations, which at the same time upgrades or creates new technologies, techniques or new technological shifts.
4. The most crucial factor for the business is the irreversibility of technology adoption costs, which means that market members are not only considering technology adoption as an element of the strategic management process, but together must accept the investors role such as pioneers, pragmatics, followers, or laggards in terms of technology adoption time selection.
5. After the review of the academic literature, which evolved the forecast methods of technology adoptions timing, it was found that environmental

changes must be included in the methodology. Therefore, the environment considered as a demand, has an uncertainty feature, which can be modelled as a random walk. Different models could be found in the academic literature for optimal technology adoption investment timing such as dynamic impulse-control methods (Black-Scholes), options-pricing model, learning curve method, real options approach, net present value (NPV) extended by real options approach etc., but the most commonly used method for uncertainty valuation is the Geometric Brownian Motion process. Authors jointly agree that time and value factors are the most important in optimal time selection, thus, it is necessary to define both the optimal time moment and the value of the decision for the company.

6. Having examined various models of the process for technology adoption, the following basic stages of the process for the adoption of the new technology in a mature market were identified: (I) historical demand paths analysis; (II) applying of statistical data validity tests; (III) the forecast of data array using the Geometric Brownian Motion method based on the Monte Carlo simulation; (IV) determination of the technology life cycle using the Hodrick-Prescott filter; (V) technology adoption time window determination; and (VI) company value (NPV) calculation based on the free cash flow changes. In this thesis, factors expressing demand uncertainty are market wireless subscribers, market revenues and their derivative and average market revenues per subscriber.
7. According to the analysis of the mobile technology generations and mathematical methods used (Hodrick-Prescott filter), the technological plateau of the mobile 5G technology is defined as the year 2024. Considering the overall mobile network technology evaluation era in the last 35 years it is assumed that the 5G ecosystem, technology and control points in Y2024 and beyond will be markedly different from the previous mobile generations. From today's point of view, many organisations are committing their resources to 5G technology features and this will force the mobile as itself to shift in the industry and all other processes from the ecosystem, supply chain structure and ordinary individual's life comprehension into becoming a part of the human's digital consciousness. Thus, in understanding the importance of the 5G technology adoption, all mobile communications industry institutional players are facing crucial strategic financial management decisions of when to invest and adopt new standards in order to be in-line players of the upcoming digital ecosystem, staying competitive and providing upselling services for the world.
8. These research results empower companies to continue to discuss whether it is possible to define the technology adoption investment valuation support model based on chaos theories. The results of this analysis shows the real decision taking options and environment issues, when the investment timing window for different company is particularly distinct, meanwhile, information about market and technology adoption content are nearly the same. This review of the academic literature shows that the GBM process

could be an appropriate model for characterising the volatility of mobile service demand, which was approved by empirical testing in this thesis. It should not be perceived that the GBM process is a forecast model, the GBM process can solve a problem of demand dynamics. Furthermore, the model empowers managers to compare decision timing issues between competing companies, when the technology itself is a source of market power. Especially, if companies compete in the product market in such a way that each firm's instantaneous profits are declining once one of its competitors adopts a new technology, then each firm has an incentive to itself adopt the new technology as soon as it becomes available in order to forestall being pre-empted by another firm.

9. According to the selected universal technology model constructed, empirical analysis of the research encompasses the period starting from Y2005 until the end of Y2014 with actual data and forecasted data in the period starting from Y2014 until the end of Y2024 (the overall analysis time frame covers around 20 (quarterly based) years). The generated results have shown the crucial insight of the TF_c ratio, which the average result for companies analysed reached 42.4% (individual ROCE) and 40.3% (average ROCE). This means that currently the mobile (wireless) service providers have around 24 years and 25 years (using 10-years (period) ROCE ratios) of the companies' business life cycle in terms of technology shifts. During this period a technology adoption shift is inevitable. Moreover, this means, that such kind of company life cycle with a strategic critical importance resource and major technology, should be evaluated with a maturity of 24-25 years (instead of the classic common company value determination of a 5 year period adding perpetuity value). Therefore, for those companies that have a TF_c of more than 90%, the assessment maturity term shall be up to 10 years. In this case, companies are facing riskier Cash Flows and development perspectives. Finally, the crucial factor in the company's valuation and perspective assessment is the duration of the main assets life cycle. This research showed the time frame for the mobile technology (wireless) based companies that could be considered as a maturity of the company's business cycle in a term of new technology adoption shifts.
10. In accordance with the selected technology in the empirical part and following previous research results, current study findings allows companies to define the technology adoption investment strategies and generalise the market window duration estimates. Market players were distributed according to the investment time windows, where investment strategies could be assigned with crucial insights: pioneers / innovators have the lowest CAPEX to Revenues ratio (13.24%) and the highest EBITDA (44.06%) in comparison with pragmatics (31.53%) and followers (28.35%). This could be explained because of the longest investment period, where depreciation makes its role in the EBITDA calculation. However, the EBIT (12.67%) is the lowest in comparison with other strategies (17.77% and 15.20% respectively). On the other hand, the latest market players have the highest CAPEX to Revenues

ratio (23.61%) and almost the same EBITDA as innovators at 41.18%. Thus, the CAPEX to Revenues ratio as the variable which reflects the capital expenditure payback term most objectively could be used to determine the technology adoption investment timing window in the context of the model. Accordingly, it is shown that the implementation or the extension of market interventions generally increases the willingness to invest.

11. Further research trends would seek to amend the technology adoption investment timing model in companies within different industrial sectors, technologies and/or maturity of technology life cycle. Also, to examine other specific discount ratios in terms of decision value evaluation.

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ANNEXES

Annex 1. Financial parameters for market player assessment

Financial ratio	Formula and meaning
Revenues	Revenue is the gross inflow of economic benefits (cash, receivables, other assets) arising from the ordinary operating activities of an enterprise (such as sales of goods, sales of services, interest, royalties, and dividends). Revenue does not comprise gains on the sale of property, plant and equipment (PPE), unless the PPE items were leased out under an operating lease, or other fixed assets and net finance income (Source: IAS 18, 2015)
EBIT	EBIT (Earnings Before Interest and Taxes) is a measure of an entity's profitability that excludes interest and income tax expenses. Interest and taxes are excluded because they include the effect of factors other than the profitability of operations. EBIT (also called operating profit) shows an entity's earning power from ongoing operations (Source: Ready Ratios, 2016a).
EBITDA	EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortisation) is an indicator of a company's financial performance. It measures a company's financial performance by computing earnings from core business operations, without including the effects of capital structure, tax rates and depreciation policies. EBITDA is a rough approximation for cash flow; it ignores many factors that impact on true cash flow, such as debt payments (Source: Ready Ratios, 2016b). EBITDA = Revenues − Expenses (excluding tax and interest, depreciation, and amortisation)
CAPEX	The general definition of capital expenditure can be given as the funds utilised by a company for acquiring or upgrading the physical assets like property, equipment, or industrial buildings. This outlay type is created by the companies to maintain or raise the scope of their operations. These expenditure count everything from roof repairing to building a brand new factory. The capital expenditure (CAPEX) includes expenses like building renovations or equipment up grading, which adds value to the assets of a company (Source: Ready Ratios, 2016c).
FCF	A measure of financial performance calculated as operating cash flow minus capital expenditure. Free cash flow represents the cash that a company is able to generate after laying out the money required to maintain or expand its asset base. Free cash flow is important because it allows a company to pursue opportunities that enhance shareholder value. Without cash, it is tough to develop new products, make acquisitions, pay dividends, and reduce debt (Source: Investopedia, 2016).
Non-current assets	Non-current assets are assets that include amounts expected to be recovered more than 12 months after the reporting period. Non-current assets are not to be converted to cash within 12 months of the balance sheet date, and is not expected to be consumed or sold within the normal operating cycle of a firm (in contrast to current assets). Non-current assets are formally defined as anything not classified as a current asset. Non-current assets are not directly sold to a firm's consumers (end-users). IFRS use the term "non-current" to include tangible, intangible and financial assets of a long-term nature. Non-current assets include: Property, plant and equipment, Investment property, Goodwill, Intangible assets other than goodwill, Investments accounted for using the equity method, Investments in subsidiaries, joint ventures and associates, Non-current biological assets, Trade and other non-current receivables, Non-current inventories, Deferred tax assets, Other non-current financial assets, Other non-current non-financial assets (Source: Ready Ratios, 2016d).
Total assets	The basic accounting equation states that Assets = Liabilities + Stockholders Equity. In the accounting industry, assets are defined as anything that a business

Financial ratio	Formula and meaning
	owns, has value and can be converted to cash (Source: Total assets: definition and explanation, 2016).
Current liabilities	Current liabilities are those to be settled within the entity's normal operating cycle or due within 12 months, or those held for trading, or those for which the entity does not have an unconditional right to defer payment beyond 12 months. Other liabilities are non-current liabilities. Current liabilities include (according to the IFRS): Current provisions for employee benefits, Other short-term provisions, Trade and other current payables, Current tax liabilities, Other current financial liabilities, Other current non-financial liabilities. Current liabilities other than liabilities included in disposal groups classified as held for sale, Liabilities included in disposal groups classified as held for sale Current liabilities often referred as short-terms debts (Source: Ready Ratios, 2016e).
Return on Capital Employed (ROCE)	A measure of how well a company uses all its sources of long-term financing to generate a profit (before tax and interest). A higher ROCE indicates more efficient use of capital. ROCE should be higher than the company's capital cost; otherwise it indicates that the company is not employing its capital effectively and is not generating shareholder value (Source: Return on capital employed, 2016) See Formula 20.
Technical efficiency ratio, TER	In accordance with the definitions of EBIT and non-current assets, it could be assumed that technology based assets shall be allocated to Non-current asserts, meanwhile, EBIT does not consider different taxes affects to profitability ratios. In general, this ratio shall be calculated to each technology company, however, the lack of information through financial statements force a basic calculation. Finally, the meaning of this ratio shall be considered while a technology adoption decision is being discussed. For the company, which is planning to adopt new technology, the value of the ratio shall be relatively small, showing large companies technology based asset amounts and relatively small profitability from the assets mentioned. After new technology is being adopted, the value of the ratio shall significantly decrease because of asset expansion, however, considering the importance of the strategic technology adoption decision, the company shall be forced to increase competitiveness, and thus the value shall increase over time. On the other hand, if the current value of the ratio is relatively high, it shows technology based profitability because of adopted technology. In this case, it could be said that the company has high technology efficiency ratio and shall not be aware of new technology adoption (except in capacity expansion cases). In general, this ratio is directly related with the technology adoption decision management process. TER= EBIT / Non-current assets
CAPEX to Revenues	The Capex to Revenue ratio measures a company's investments in property, plant, equipment and other capital assets to its total sales. The ratio shows how aggressively the company is re-investing its revenue back into productive assets. A high ratio potentially indicates that a company is investing heavily, which could be a positive or a negative sign depending on how effectively it uses those assets to produce new income (Source: Capex to Revenues, 2016).
CAPEX to FCF	A ratio that measures a company's ability to acquire long term assets using free cash flow. The cash flow to capital expenditure (CF to CAPEX) ratio will often fluctuate as businesses go through cycles of large and small capital expenditure. As the CF to CAPEX ratio increases, it is usually a positive sign. If a company has the financial ability to invest in itself through capital expenditure (CAPEX), then

Financial ratio	Formula and meaning
	it is thought that the company will grow (Source: Cash Flow To Capital Expenditure - CF to CAPEX, 2016).

Annex 2. General information about each selected company

- **Belgacom SA** – Known as the Proximus Group is a telecommunications company operating in the Belgian and international markets. The group is the leading national provider of telephony, internet, television and network-based ICT services.
- **BT Group PLC** - is one of the world's leading communications services companies, serving the needs of customers in the UK and in more than 170 countries worldwide. Our main activities are the provision of fixed-line services, broadband, mobile and TV products and services as well as networked IT services.
- **Deutsche Telekom AG** - is one of the world's leading integrated telecommunications companies, with some 151 million mobile customers, 30 million fixed-network lines, and more than 17 million broadband lines. The company provides fixed-network/broadband, mobile communications, Internet, and IPTV products and services for consumers, and information and communication technology (ICT) solutions for business and corporate customers.
- **Elisa OYJ** - is a telecommunications, ICT and online service company serving 2.3 million consumers, corporate and public administration organisation customers. Elisa provides services for communication and entertainment, and tools for improving operating methods and productivity of organisations. In Finland Elisa is the market leader in mobile subscriptions. Cooperation with Vodafone and Telenor enables globally competitive services.
- **Mobile TeleSystems OJSC** - is the leading telecommunications group in Russia, Central and Eastern Europe. The company provides wireless Internet access and fixed voice, broadband and pay-TV to over 100 million customers who value the high-quality of service at a competitive price. Wireless and fixed-line networks deliver best-in-class speeds and coverage throughout Russia, Ukraine, Armenia, Turkmenistan, Uzbekistan and Belarus.
- **Orange Polska SA** - is the leading supplier of telecommunications services in Poland. Orange Polska provides, amongst other services, fixed voice, fixed broadband access, TV and Voice over Internet Protocol ("VoIP") services. It provides mobile services, including LTE-based services, third generation UMTS services and services based on the CDMA technology.
- **Rostelecom OJSC** - is one of the biggest national telecommunications companies in Russia and Europe, with a presence in every segment of the telecommunications services market and coverage of millions of households in Russia. The company holds a leading position on the Russian broadband and pay-TV markets, with over 11.4 million fixed-line broadband subscribers and more than 8.4 million pay-TV customers, of which more than 3.1 million use the unique nationwide "Interactive TV" product.
- **Swisscom AG** – is a leading telecom provider and one of its foremost IT companies, headquartered in Ittigen, close to the capital city, Bern. Outside Switzerland, Swisscom offers broadband Internet in Italy with Fastweb.
- **TDC A/S** - is the leading Danish provider of communications solutions and Pay-TV with market leadership across all segments in the domestic market. In all other Nordic countries, TDC is the main challenger in the business market.
- **Tele2 AB** - is one of Europe's fastest growing telecom operators. The company has 13 million customers in 9 countries.
- **Telecom Italia SpA** - is an Italian telecommunications company which provides telephony services, mobile services, and DSL data services.
- **Telefonica SA** - is a Spanish broadband and telecommunications provider with operations in Europe, Asia, North America and South America. Operating globally, it is one of the largest telephone operators and mobile network providers in the world.

- **Telekom Austria AG** - is a provider of a range of fixed-line, broadband Internet, multimedia services, data, and IT solutions, wholesale as well as mobile payment solutions.
- **Telenor ASA** - is a Norwegian multinational telecommunications company. It is one of the world's largest mobile telecommunications companies with operations in Scandinavia, Eastern Europe and Asia.
- **TeliaSonera AB** - is the dominant telephone company and mobile network operator in Sweden and Finland. TeliaSonera brings the world closer by providing leading communication services to millions of customers every day in the Nordic and Baltic countries, Eurasia and Spain.
- **Turk Telekomunikasyon AS** - is Turkey's leading integrated telecommunication and technology services provider with its Group Companies. It offers its customers a wide range of services from fixed voice to mobile voice, data, Internet, and innovative convergence technologies.
- **Turkcell Iletisim Hizmetleri AS** - is the leading mobile phone operator of Turkey, based in Istanbul.
- **VimpelCom Ltd** - is a global provider of telecommunication services incorporated in Bermuda. It is the sixth largest mobile network operator in the world.

Annex 3. The results of GBM process calculating Total Wireless Revenues

Period	Drift component $\mu\Delta t$	Non stoch. evolution $S0+\Sigma\mu S0\Delta t$	$\mu X_{(t)}\Delta t$	ε_t	Wiener process ΔZ	$\sigma\Delta Z$	$\sigma X_{(t)}\Delta z$	Random shocks $\Sigma\sigma S\Delta z$	$\Delta X_{(t)}$	$X_{(t)}$	$\log X_{(t)} - \log X_{(t-1)}$
0		1 093 614 901						0		**42 444 796 319**	
1	0,34638%	1 097 402 925	**147 018 758**	0,47833	0,23917	0,00436	**185 114 832**	185 114 832	**332 133 589**	**42 776 929 909**	0,00779
2	0,34638%	1 101 204 070	**148 169 190**	0,90193	0,45097	0,00822	**351 778 133**	536 892 965	**499 947 323**	**43 276 877 232**	0,01162
3	0,34638%	1 105 018 381	**149 900 890**	-1,66447	-0,83223	-0,01518	**-656 775 119**	-119 882 154	**-506 874 229**	**42 770 003 003**	-0,01178
4	0,34638%	1 108 845 904	**148 145 197**	1,68404	0,84202	0,01535	**656 713 836**	536 831 682	**804 859 033**	**43 574 862 036**	0,01864
5	0,34638%	1 112 686 684	**150 933 039**	-0,22106	-0,11053	-0,00202	**-87 825 887**	449 005 796	**63 107 152**	**43 637 969 188**	0,00145
6	0,34638%	1 116 540 768	**151 151 627**	-0,08800	-0,04400	-0,00080	**-35 014 837**	413 990 959	**116 136 790**	**43 754 105 977**	0,00266
7	0,34638%	1 120 408 202	**151 553 897**	-0,39492	-0,19746	-0,00360	**-157 549 691**	256 441 268	**-5 995 794**	**43 748 110 184**	-0,00014
8	0,34638%	1 124 289 032	**151 533 129**	-0,14324	-0,07162	-0,00131	**-57 137 290**	199 303 977	**94 395 839**	**43 842 506 023**	0,00216
9	0,34638%	1 128 183 303	**151 860 094**	-0,59269	-0,29635	-0,00540	**-236 924 848**	-37 620 870	**-85 064 754**	**43 757 441 269**	-0,00194
10	0,34638%	1 132 091 064	**151 565 450**	0,26624	0,13312	0,00243	**106 221 278**	68 600 408	**257 786 728**	**44 015 227 997**	0,00587
11	0,34638%	1 136 012 360	**152 458 362**	-0,14980	-0,07490	-0,00137	**-60 118 721**	8 481 687	**92 339 641**	**44 107 567 639**	0,00210
12	0,34638%	1 139 947 239	**152 778 205**	-0,00201	-0,00100	-0,00002	**-807 378**	7 674 308	**151 970 827**	**44 259 538 465**	0,00344
13	0,34638%	1 143 895 747	**153 304 596**	-1,02923	-0,51462	-0,00938	**-415 340 729**	-407 666 421	**-262 036 133**	**43 997 502 332**	-0,00594
14	0,34638%	1 147 857 932	**152 396 965**	-1,14511	-0,57255	-0,01044	**-459 367 309**	-867 033 730	**-306 970 345**	**43 690 531 988**	-0,00700
15	0,34638%	1 151 833 841	**151 333 692**	-0,64560	-0,32280	-0,00589	**-257 180 641**	-1 124 214 371	**-105 846 949**	**43 584 685 039**	-0,00243
16	0,34638%	1 155 823 522	**150 967 063**	-1,89991	-0,94996	-0,01732	**-755 009 354**	-1 879 223 726	**-604 042 291**	**42 980 642 747**	-0,01396
17	0,34638%	1 159 827 022	**148 874 803**	1,47303	0,73651	0,01343	**577 255 417**	-1 301 968 308	**726 130 221**	**43 706 772 968**	0,01675
18	0,34638%	1 163 844 389	**151 389 947**	0,47188	0,23594	0,00430	**188 047 974**	-1 113 920 334	**339 437 921**	**44 046 210 889**	0,00774
19	0,34638%	1 167 875 671	**152 565 680**	0,57236	0,28618	0,00522	**229 859 237**	-884 061 097	**382 424 917**	**44 428 635 806**	0,00864
20	0,34638%	1 171 920 917	**153 890 309**	-2,90094	-1,45047	-0,02645	**-1 175 131 949**	-2 059 193 046	**-1 021 241 640**	**43 407 394 166**	-0,02325
21	0,34638%	1 175 980 174	**150 352 969**	-0,28270	-0,14135	-0,00258	**-111 886 560**	-2 171 079 606	**38 466 409**	**43 445 860 575**	0,00089
22	0,34638%	1 180 053 492	**150 486 208**	1,27683	0,63842	0,01164	**505 785 776**	-1 665 293 830	**656 271 984**	**44 102 132 559**	0,01499
23	0,34638%	1 184 140 919	**152 759 379**	0,21338	0,10669	0,00195	**85 801 894**	-1 579 491 936	**238 561 273**	**44 340 693 832**	0,00539
24	0,34638%	1 188 242 504	**153 585 699**	0,43838	0,21919	0,00400	**177 230 804**	-1 402 261 133	**330 816 503**	**44 671 510 335**	0,00743
25	0,34638%	1 192 358 295	**154 731 569**	0,48897	0,24448	0,00446	**199 156 419**	-1 203 104 714	**353 887 988**	**45 025 398 323**	0,00789
26	0,34638%	1 196 488 343	**155 957 354**	-1,23062	-0,61531	-0,01122	**-505 203 061**	-1 708 307 775	**-349 245 707**	**44 676 152 616**	-0,00779
27	0,34638%	1 200 632 696	**154 747 649**	0,31101	0,15550	0,00284	**126 686 875**	-1 581 620 900	**281 434 524**	**44 957 587 141**	0,00628
28	0,34638%	1 204 791 405	**155 722 472**	-0,07265	-0,03632	-0,00066	**-29 778 037**	-1 611 398 937	**125 944 435**	**45 083 531 576**	0,00280
29	0,34638%	1 208 964 518	**156 158 714**	-0,87372	-0,43686	-0,00797	**-359 150 619**	-1 970 549 556	**-202 991 905**	**44 880 539 671**	-0,00451
30	0,34638%	1 213 152 085	**155 455 598**	-1,44957	-0,72478	-0,01322	**-593 173 074**	-2 563 722 630	**-437 717 476**	**44 442 822 195**	-0,00980
31	0,34638%	1 217 354 158	**153 939 448**	-0,44502	-0,22251	-0,00406	**-180 330 607**	-2 744 053 236	**-26 391 159**	**44 416 431 036**	-0,00059
32	0,34638%	1 221 570 785	**153 848 035**	0,94414	0,47207	0,00861	**382 355 255**	-2 361 697 982	**536 203 290**	**44 952 634 325**	0,01200
33	0,34638%	1 225 802 018	**155 705 317**	0,13949	0,06974	0,00127	**57 171 417**	-2 304 526 565	**212 876 734**	**45 165 511 059**	0,00472
34	0,34638%	1 230 047 907	**156 442 671**	1,71222	0,85611	0,01561	**705 100 437**	-1 599 426 128	**861 543 108**	**46 027 054 167**	0,01890
35	0,34638%	1 234 308 503	**159 426 853**	1,01261	0,50631	0,00923	**424 953 367**	-1 174 472 761	**584 380 220**	**46 611 434 387**	0,01262
36	0,34638%	1 238 583 856	**161 451 009**	2,63008	1,31504	0,02398	**1 117 755 304**	-56 717 457	**1 279 206 313**	**47 890 640 700**	0,02707
37	0,34638%	1 242 874 018	**165 881 877**	0,16502	0,08251	0,00150	**72 057 962**	15 340 505	**237 939 839**	**48 128 580 539**	0,00496
38	0,34638%	1 247 179 041	**166 706 045**	-2,10118	-1,05059	-0,01916	**-922 040 867**	-906 700 363	**-755 334 823**	**47 373 245 717**	-0,01582
39	0,34638%	1 251 498 975	**164 089 743**	-0,62345	-0,31173	-0,00568	**-269 291 271**	-1 175 991 633	**-105 201 527**	**47 268 044 189**	-0,00222
40	0,34638%	1 255 833 872	**163 725 350**	1,05780	0,52890	0,00964	**455 887 653**	-720 103 980	**619 613 003**	**47 887 657 193**	0,01302

Annex 4. The results of GBM process calculating Total Wireless subscribers

Period	Drift component $\mu\Delta t$	Non stoch. evolution $S0+\Sigma\mu S0\Delta t$	$\mu X_{(t)}\Delta t$	Wiener process ε_t	Δz	$\sigma\Delta z$	$\sigma X_{(t)}\Delta z$	Random shocks $\Sigma\sigma S\Delta z$	$\Delta X_{(t)}$	$X_{(t)}$	$\log X_{(t)} - \log X_{(t-1)}$
0		1 093 614 901						0		**1 093 614 901**	
1	0,34638%	1 097 402 925	**3 788 024**	-0,23030	-0,11515	-0,00210	**-2 296 374**	-2 296 374	**1 491 650**	**1 095 106 551**	0,00136
2	0,34638%	1 101 204 070	**3 793 191**	0,41318	0,20659	0,00377	**4 125 575**	1 829 201	**7 918 766**	**1 103 025 317**	0,00721
3	0,34638%	1 105 018 381	**3 820 619**	-0,18375	-0,09187	-0,00168	**-1 847 934**	-18 733	**1 972 685**	**1 104 998 002**	0,00179
4	0,34638%	1 108 845 904	**3 827 452**	0,17863	0,08931	0,00163	**1 799 657**	1 780 924	**5 627 109**	**1 110 625 111**	0,00508
5	0,34638%	1 112 686 684	**3 846 943**	-0,93288	-0,46644	-0,00851	**-9 446 621**	-7 665 697	**-5 599 678**	**1 105 025 434**	-0,00505
6	0,34638%	1 116 540 768	**3 827 547**	0,11299	0,05650	0,00103	**1 138 434**	-6 527 263	**4 965 981**	**1 109 991 415**	0,00448
7	0,34638%	1 120 408 202	**3 844 748**	-1,12532	-0,56266	-0,01026	**-11 388 840**	-17 916 103	**-7 544 092**	**1 102 447 323**	-0,00682
8	0,34638%	1 124 289 032	**3 818 617**	-1,43219	-0,71609	-0,01306	**-14 396 036**	-32 312 139	**-10 577 419**	**1 091 869 904**	-0,00964
9	0,34638%	1 128 183 303	**3 781 980**	1,22657	0,61329	0,01118	**12 210 923**	-20 101 216	**15 992 903**	**1 107 862 807**	0,01454
10	0,34638%	1 132 091 064	**3 837 375**	1,17075	0,58537	0,01067	**11 825 922**	-8 275 294	**15 663 297**	**1 123 526 105**	0,01404
11	0,34638%	1 136 012 360	**3 891 629**	1,26123	0,63061	0,01150	**12 919 962**	4 644 668	**16 811 591**	**1 140 337 696**	0,01485
12	0,34638%	1 139 947 239	**3 949 861**	-0,25032	-0,12516	-0,00228	**-2 602 652**	2 042 016	**1 347 208**	**1 141 684 904**	0,00118
13	0,34638%	1 143 895 747	**3 954 527**	-0,47031	-0,23515	-0,00429	**-4 895 659**	-2 853 644	**-941 132**	**1 140 743 772**	-0,00082
14	0,34638%	1 147 857 932	**3 951 267**	0,59694	0,29847	0,00544	**6 208 733**	3 355 089	**10 160 000**	**1 150 903 772**	0,00887
15	0,34638%	1 151 833 841	**3 986 459**	-0,36441	-0,18221	-0,00332	**-3 823 988**	-468 898	**162 472**	**1 151 066 244**	0,00014
16	0,34638%	1 155 823 522	**3 987 022**	1,41477	0,70739	0,01290	**14 848 157**	14 379 259	**18 835 179**	**1 169 901 422**	0,01623
17	0,34638%	1 159 827 022	**4 052 262**	1,72876	0,86438	0,01576	**18 440 349**	32 819 608	**22 492 612**	**1 192 394 034**	0,01904
18	0,34638%	1 163 844 389	**4 130 172**	-1,13090	-0,56545	-0,01031	**-12 295 015**	20 524 593	**-8 164 843**	**1 184 229 191**	-0,00687
19	0,34638%	1 167 875 671	**4 101 890**	-0,21483	-0,10741	-0,00196	**-2 319 568**	18 205 026	**1 782 323**	**1 186 011 514**	0,00150
20	0,34638%	1 171 920 917	**4 108 064**	0,61321	0,30661	0,00559	**6 631 110**	24 836 136	**10 739 174**	**1 196 750 688**	0,00901
21	0,34638%	1 175 980 174	**4 145 262**	-1,12985	-0,56493	-0,01030	**-12 328 516**	12 507 620	**-8 183 254**	**1 188 567 434**	-0,00686
22	0,34638%	1 180 053 492	**4 116 917**	0,92556	0,46278	0,00844	**10 030 286**	22 537 906	**14 147 203**	**1 202 714 637**	0,01183
23	0,34638%	1 184 140 919	**4 165 920**	0,11037	0,05519	0,00101	**1 210 340**	23 748 246	**5 376 259**	**1 208 090 897**	0,00446
24	0,34638%	1 188 242 504	**4 184 542**	-1,88102	-0,94051	-0,01715	**-20 719 489**	3 028 756	**-16 534 948**	**1 191 555 949**	-0,01378
25	0,34638%	1 192 358 295	**4 127 269**	1,04481	0,52241	0,00953	**11 351 078**	14 379 835	**15 478 347**	**1 207 034 296**	0,01291
26	0,34638%	1 196 488 343	**4 180 882**	-1,17824	-0,58912	-0,01074	**-12 966 982**	1 412 853	**-8 786 100**	**1 198 248 196**	-0,00731
27	0,34638%	1 200 632 696	**4 150 449**	-0,18546	-0,09273	-0,00169	**-2 026 157**	-613 304	**2 124 292**	**1 200 372 488**	0,00177
28	0,34638%	1 204 791 405	**4 157 807**	-0,52639	-0,26319	-0,00480	**-5 761 107**	-6 374 411	**-1 603 300**	**1 198 769 188**	-0,00134
29	0,34638%	1 208 964 518	**4 152 254**	-0,14718	-0,07359	-0,00134	**-1 608 705**	-7 983 116	**2 543 548**	**1 201 312 736**	0,00212
30	0,34638%	1 213 152 085	**4 161 064**	-0,16028	-0,08014	-0,00146	**-1 755 608**	-9 738 724	**2 405 456**	**1 203 718 192**	0,00200
31	0,34638%	1 217 354 158	**4 169 396**	0,41291	0,20645	0,00376	**4 531 690**	-5 207 034	**8 701 086**	**1 212 419 278**	0,00720
32	0,34638%	1 221 570 785	**4 199 534**	0,58802	0,29401	0,00536	**6 500 282**	1 293 248	**10 699 816**	**1 223 119 094**	0,00879
33	0,34638%	1 225 802 018	**4 236 596**	0,22115	0,11057	0,00202	**2 466 222**	3 759 470	**6 702 818**	**1 229 821 913**	0,00547
34	0,34638%	1 230 047 907	**4 259 813**	-0,00479	-0,00239	-0,00004	**-53 658**	3 705 812	**4 206 155**	**1 234 028 067**	0,00341
35	0,34638%	1 234 308 503	**4 274 382**	0,34601	0,17300	0,00315	**3 893 121**	7 598 933	**8 167 503**	**1 242 195 570**	0,00660
36	0,34638%	1 238 583 856	**4 302 672**	-0,92264	-0,46132	-0,00841	**-10 449 789**	-2 850 856	**-6 147 116**	**1 236 048 454**	-0,00496
37	0,34638%	1 242 874 018	**4 281 380**	-1,23197	-0,61599	-0,01123	**-13 884 198**	-16 735 054	**-9 602 818**	**1 226 445 636**	-0,00780
38	0,34638%	1 247 179 041	**4 248 118**	0,60850	0,30425	0,00555	**6 804 499**	-9 930 555	**11 052 618**	**1 237 498 253**	0,00897
39	0,34638%	1 251 498 975	**4 286 402**	0,65760	0,32880	0,00600	**7 419 833**	-2 510 722	**11 706 235**	**1 249 204 488**	0,00942
40	0,34638%	1 255 833 872	**4 326 950**	-0,41199	-0,20599	-0,00376	**-4 692 502**	-7 203 224	**-365 553**	**1 248 838 936**	-0,00029

Annex 5. Detailed financial ratios of companies analysed

Belgacom SA

Main parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Revenues	7,040	6,417	6,462	6,318	6,112
EBIT	1,619	1,141,000	1,038,000	917,000	934,000
EBITDA	2,428,000	1,897,000	1,786,000	1,699,000	1,755,000
CAPEX	686,000	764,000	789,000	814,000	771,000
FCF	980.000	788,000	691,000	505,000	711,000
Non-current assets	6,185,000	6,217,000	6,192,000	6,254,000	6,339,000
Total assets	8,511,000	8,312,000	8,242,000	8,417,000	8,522,000
Current liabilities	2,804,000	2,260.000	2,472,000	2,511,000	2,221,000
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE	28.37%	18.85%	17.99%	15.53%	14.82%
Technical efficiency ratio, TER (EBIT/ITT)	25.57%	17.96%	16.36%	14.19%	14.46%
CAPEX to Revenues	9.74%	11.91%	12.21%	12.88%	12.61%
CAPEX to FCF	70.00%	96.95%	114.18%	161.19%	108.44%
Revenues growth rates		-8.85%	0.70%	-2.23%	-3.26%
EBIT growth rates		-29.52%	-9.03%	-11.66%	1.85%
EBITDA growth rates		-21.87%	-5.85%	-4.87%	3.30%
CAPEX growth rates		11.37%	3.27%	3.17%	-5.28%
FCF growth rates		-19.59%	-12.31%	-26.92%	40.79%
Non-current assets growth rates		0.36%	-0.16%	1.86%	-0.06%
TER growth rates		-29.78%	-8.88%	-13.27%	1.92%

BT Group PLC

Main parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Revenues	25,977,858	24,977,323	23,614,947	23,547,987	22,986,554
EBIT	3,707,260	3,942,907	4,249,377	4,405,187	4,806,947
EBITDA	7,543,288	7,769,921	7,910.280	7,875,512	8,075,104
CAPEX	3,386,625	3,296,486	3,139,388	3,020.921	3,104,621
FCF	2,589,545	2,984,865	2,951,385	2,795,575	3,582,354
Non-current assets	28,837,818	25,250.313	25,003,077	26,017,776	24,713,346
Total assets	36,930.949	30,312,223	30,837,600	32,060.906	32,060.906
Current liabilities	1,341,773	9,053,748	11,917,571	9,049,885	9,898,473
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	10.42%	18.55%	22.46%	19.14%	21.69%
Technical efficiency ratio, TER (EBIT/ITT)	12.86%	7.85%	8.46%	12.30%	13.89%
CAPEX to Revenues	13.04%	13.20%	13.29%	12.83%	13.51%
CAPEX to FCF	130.78%	110.44%	106.37%	108.06%	86.66%
Revenues growth rates		-3.85%	-5.45%	-0.28%	-2.38%
EBIT growth rates		6.36%	7.77%	3.67%	9.12%
EBITDA growth rates		3.00%	1.81%	-0.44%	2.53%
CAPEX growth rates		-2.66%	-4.77%	-3.77%	2.77%
FCF growth rates		15.27%	-1.12%	-5.28%	28.14%
ITT growth rates		74.26%	0.00%	-28.74%	-3.34%
TER growth rates		-38.97%	7.77%	45.48%	12.90%

Tele2 AB

Main parameters	2010	2011	2012	2013	2014
Revenues	3,241,031	3,144,682	3,272,863	3,174,385	2,763,228
EBIT	453,210	372,299	210.263	233,365	371,553
EBITDA	754,072	719,685	664,324	637,709	630.895
CAPEX	435,963	649,952	568,083	589,162	423,294
FCF	639,625	438,412	433,301	60.896	45,992
Non-current assets	3,639,732	3,960.715	4,062,706	3,149,686	2,996,593
Total assets	4,480.464	4,989,247	5,236,772	4,243,053	4,242,308
Current liabilities	1,112,637	1,206,217	1,552,965	1,223,038	1,139,785
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	13.46%	9.84%	5.71%	7.73%	11.98%
Technical efficiency ratio, TER (EBIT to ITT)	12.45%	9.40%	5.18%	7.41%	12.40%
CAPEX to Revenues	13.45%	20.67%	17.36%	18.56%	15.32%
CAPEX to FCF	68.16%	148.25%	131.11%	967.48%	920.37%
Revenues growth rates		-2.97%	4.08%	-3.01%	-12.95%
EBIT growth rates		-17.85%	-43.52%	10.99%	59.22%
EBITDA growth rates		-4.56%	-7.69%	-4.01%	-1.07%
CAPEX growth rates		49.08%	-12.60%	3.71%	-28.15%
FCF growth rates		-31.46%	-1.17%	-85.95%	-24.48%
ITT growth rates		8.82%	2.58%	-22.47%	-4.86%
TER growth rates		-24.51%	-44.94%	43.16%	67.35%

Deutsche Telekom AG

Main parameters	2010	2011	2012	2013	2014
Revenues	62,400.000	58,700.000	58,200.000	60,100.000	62,700.000
EBIT	5,500.000	5,600.000	-4,000.000	4,900.000	7,200,000
EBITDA	32,200,000	31,800,000	30,900,000	28,900,000	28,000,000
CAPEX	9,900,000	8,400,000	8,400,000	11,100,000	11,800,000
FCF	6,500,000	6,400,000	6,200,000	4,600,000	4,100,000
Non-current assets	101,100,000	97,400,000	86,095,000	90,421,000	89,609,000
Total assets	127,800,000	122,500,000	107,900,000	118,100,000	129,400,000
Current liabilities	26,452,000	24,338,000	22,995,000	22,496,000	28,198,000
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	5.43%	5.70%	-4.71%	5.13%	7.11%
Technical efficiency ratio, TER (EBIT to ITT)	5.44%	5.75%	-4.65%	5.42%	8.03%
CAPEX to Revenues	15.87%	14.31%	14.43%	18.47%	18.82%
CAPEX to FCF	152.31%	131.25%	135.48%	241.30%	287.80%
Revenues growth rates		-5.93%	-0.85%	3.26%	4.33%
EBIT growth rates		1.82%	-171.43%	-222.50%	46.94%
EBITDA growth rates		-1.24%	-2.83%	-6.47%	-3.11%
CAPEX growth rates		-15.15%	0.00%	32.14%	6.31%
FCF growth rates		-1.54%	-3.13%	-25.81%	-10.87%
ITT growth rates		-3.66%	-11.61%	5.02%	-0.90%
TER growth rates		5.69%	-180.81%	-216.64%	48.27%

Elisa OYJ

Main parameters	2010	2011	2012	2013	2014
Revenues	1,463,200	1,530,000	1,553,000	1,547,000	1,535,000
EBIT	268,000	294,800	305,000	281,000	299,000
EBITDA	484,700	506,200	501,000	491,000	520,000
CAPEX	199,000	183,900	187,700	304,100	227,000
FCF	172,100	207,400	154,800	108,000	161,100
Non-current assets	1,614,000	1,597,200	1,599,400	1,798,300	1,815,500
Total assets	1,971,700	1,999,400	2,009,900	2,324,300	2,243,400
Current liabilities	645,600	493,400	419,900	559,600	476,300
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	20.21%	19.58%	19.18%	15.92%	16.92%
Technical efficiency ratio, TER (EBIT to ITT)	16.60%	18.46%	19.07%	15.63%	16.47%
CAPEX to Revenues	13.60%	12.02%	12.09%	19.66%	14.79%
CAPEX to FCF	115.63%	88.67%	121.25%	281.57%	140.91%
Revenues growth rates		4.57%	1.50%	-0.39%	-0.78%
EBIT growth rates		10.00%	3.46%	-7.87%	6.41%
EBITDA growth rates		4.44%	-1.03%	-2.00%	5.91%
CAPEX growth rates		-7.59%	2.07%	62.01%	-25.35%
FCF growth rates		20.51%	-25.36%	-30.23%	49.17%
ITT growth rates		-1.04%	0.14%	12.44%	0.96%
TER growth rates		11.16%	3.32%	-18.06%	5.40%

Mobile TeleSystems OJSC

Main parameters	2010	2011	2012	2013	2014
Revenues	9,334,907	10,181,355	10,279,722	9,929,200	10,236,089
EBIT	3,761,026	3,873,238	2,704,218	3,119,277	2,785,411
EBITDA	5,414,246	5,803,373	4,584,756	4,944,741	4,647,185
CAPEX	1,803,663	2,111,989	2,529,427	2,409,041	2,631,253
FCF	1,186,185	1,069,633	972,920	1,562,634	1,343,936
Non-current assets	9,391,116	10,155,730	9,210,089	9,191,692	11,383,531
Total assets	11,967,660	12,669,451	12,382,618	12,099,258	15,174,461
Current liabilities	2,607,955	2,946,865	3,086,562	2,538,401	3,424,980
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	40.18%	39.84%	29.09%	32.63%	23.71%
Technical efficiency ratio, TER (EBIT to ITT)	40.05%	38.14%	29.36%	33.94%	24.47%
CAPEX to Revenues	19.32%	20.74%	24.61%	24.26%	25.71%
CAPEX to FCF	152.06%	197.45%	259.98%	154.17%	195.79%
Revenues growth rates		9.07%	0.97%	-3.41%	3.09%
EBIT growth rates		2.98%	-30.18%	15.35%	-10.70%
EBITDA growth rates		7.19%	-21.00%	7.85%	-6.02%
CAPEX growth rates		17.09%	19.77%	-4.76%	9.22%
FCF growth rates		-9.83%	-9.04%	60.61%	-14.00%
ITT growth rates		8.14%	-9.31%	-0.20%	23.85%
TER growth rates		-4.77%	-23.01%	15.58%	-27.90%

Orange Polska SA

Main parameters	2010	2011	2012	2013	2014
Revenues	3,667,881	3,482,795	3,300,509	3,016,228	2,850,281
EBIT	544,947	517,448	367,138	186,020	234,100
EBITDA	1,338,782	1,115,652	1,130,823	911,194	951,338
CAPEX	326,760	254,406	636,949	508,812	502,510
FCF	326,760	952,039	-201,891	259,541	140,040
Non-current assets	5,627,507	5,389,439	5,123,830	4,837,215	4,674,068
Total assets	6,738,958	6,586,315	5,639,644	5,321,987	5,159,074
Current liabilities	1,099,081	1,711,522	1,517,567	1,895,208	1,901,043
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	9.66%	10.61%	8.91%	5.43%	7.19%
Technical efficiency ratio, TER (EBIT to ITT)	9.68%	9.60%	7.17%	3.85%	5.01%
CAPEX to Revenues	8.91%	7.30%	19.30%	16.87%	17.63%
CAPEX to FCF	100.00%	26.72%	-315.49%	196.04%	358.83%
Revenues growth rates		-5.05%	-5.23%	-8.61%	-5.50%
EBIT growth rates		-5.05%	-29.05%	-49.33%	25.85%
EBITDA growth rates		-16.67%	1.36%	-19.42%	4.41%
CAPEX growth rates		-22.14%	150.37%	-20.12%	-1.24%
FCF growth rates		191.36%	-121.21%	-228.55%	-46.04%
ITT growth rates		-4.23%	-4.93%	-5.59%	-3.37%
TER growth rates		-0.85%	-25.37%	-46.33%	30.24%

TeliaSonera AB

Main parameters	2010	2011	2012	2013	2014
Revenues	11,389,226	11,157,671	11,167,678	10,845,310	10,759,076
EBIT	2,493,133	2,550,729	1,651,975	2,168,530	2,090,280
EBITDA	3,928,138	3,962,738	3,838,923	3,788,353	3,749,920
CAPEX	1,594,492	1,852,173	1,675,152	1,736,399	1,388,907
FCF	1,373,470	1,002,342	2,527,414	1,736,399	1,388,907
Non-current assets	22,499,947	23,014,266	20,969,658	20,542,425	22,402,001
Total assets	26,674,225	26,922,495	27,077,717	26,916,640	28,964,761
Current liabilities	5,249,548	6,925,157	6,328,543	5,937,826	6,315,341
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	11.64%	12.76%	7.96%	10.34%	9.23%
Technical efficiency ratio, TER (EBIT to ITT)	11.08%	11.08%	7.88%	10.56%	9.33%
CAPEX to Revenues	14.00%	16.60%	15.00%	16.01%	12.91%
CAPEX to FCF	116.09%	184.78%	66.28%	100.00%	100.00%
Revenues growth rates		-2.03%	0.09%	-2.89%	-0.80%
EBIT growth rates		2.31%	-35.24%	31.27%	-3.61%
EBITDA growth rates		0.88%	-3.12%	-1.32%	-1.01%
CAPEX growth rates		16.16%	-9.56%	3.66%	-20.01%
FCF growth rates		-27.02%	152.15%	-31.30%	-20.01%
ITT growth rates		2.29%	-8.88%	-2.04%	9.05%
TER growth rates		0.02%	-28.92%	34.00%	-11.61%

Swisscom AG

Main parameters	2010	2011	2012	2013	2014
Revenues	9,965,864	9,532,746	9,463,747	9,505,313	9,728,938
EBIT	2,183,878	2,228,769	2,020,939	1,877,121	1,930,325
EBITDA	3,823,241	3,810,771	3,642,013	3,576,339	3,668,615
CAPEX	1,582,002	1,741,615	2,102,408	2,127,348	1,950,277
FCF	1,798,976	1,680,929	1,430,702	1,306,835	1,183,800
Non-current assets	14,311,174	12,936,171	13,513,938	13,883,044	14,553,088
Total assets	17,520,069	16,169,174	16,704,544	17,038,735	17,401,190
Current liabilities	3,343,569	3,204,739	3,489,881	3,824,903	3,706,025
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	15.40%	17.19%	15.29%	14.21%	14.09%
Technical efficiency ratio, TER (EBIT to ITT)	15.26%	17.23%	14.95%	13.52%	13.26%
CAPEX to Revenues	15.87%	18.27%	22.22%	22.38%	20.05%
CAPEX to FCF	87.94%	103.61%	146.95%	162.79%	164.75%
Revenues growth rates		-4.35%	-0.72%	0.44%	2.35%
EBIT growth rates		2.06%	-9.32%	-7.12%	2.83%
EBITDA growth rates		-0.33%	-4.43%	-1.80%	2.58%
CAPEX growth rates		10.09%	20.72%	1.19%	-8.32%
FCF growth rates		-6.56%	-14.89%	-8.66%	-9.41%
ITT growth rates		-9.61%	4.47%	2.73%	4.83%
TER growth rates		12.90%	-13.20%	-9.59%	-1.90%

Telecom Italia SpA

Main parameters	2010	2011	2012	2013	2014
Revenues	26,781,000	26,772,000	25,759,000	23,407,000	21,573,000
EBIT	5,748,000	-1,190,000	1,709,000	2,718,000	4,530,000
EBITDA	11,208,000	11,138,000	10,525,000	9,540,000	8,786,000
CAPEX	4,398,000	5,556,000	4,639,000	4,400,000	4,957,000
FCF	6,213,000	5,767,000	6,470,000	4,803,000	3,174,000
Non-current assets	73,062,000	67,331,000	61,334,000	53,440,000	55,370,000
Total assets	89,072,000	83,939,000	77,596,000	70,220,000	71,551,000
Current liabilities	18,071,000	17,411,000	16,816,000	16,349,000	14,616,000
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	8.10%	-1.79%	2.81%	5.05%	7.96%
Technical efficiency ratio, TER (EBIT to ITT)	7.87%	-1.77%	2.79%	5.09%	8.18%
CAPEX to Revenues	16.42%	20.75%	18.01%	18.80%	22.98%
CAPEX to FCF	70.79%	96.34%	71.70%	91.61%	156.18%
Revenues growth rates		-0.03%	-3.78%	-9.13%	-7.84%
EBIT growth rates		-120.70%	-243.61%	59.04%	66.67%
EBITDA growth rates		-0.62%	-5.50%	-9.36%	-7.90%
CAPEX growth rates		26.33%	-16.50%	-5.15%	12.66%
FCF growth rates		-7.18%	12.19%	-25.77%	-33.92%
ITT growth rates		-7.84%	-8.91%	-12.87%	3.61%
TER growth rates		-122.47%	-257.66%	82.53%	60.86%

Telekom Austria AG

Main parameters	2010	2011	2012	2013	2014
Revenues	4,650,800	4,454,600	4,329,700	1,183,900	4,018,000
EBIT	580,300	474,900	491,400	422,800	432,300
EBITDA	1,645,900	1,527,300	1,455,400	1,287,400	1,286,100
CAPEX	763,600	739,000	728,200	1,778,100	757,400
FCF	645,000	479,200	325,400	-716,700	156,000
Non-current assets	6,118,113	5,697,359	5,447,896	6,579,379	6,269,110
Total assets	4,555,820	7,448,804	7,257,148	7,800,600	8,316,400
Current liabilities	1,882,965	2,412,018	2,322,093	1,442,271	1,537,539
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	21.71%	9.43%	9.96%	6.65%	6.38%
Technical efficiency ratio, TER (EBIT to ITT)	9.48%	8.34%	9.02%	6.43%	6.90%
CAPEX to Revenues	16.42%	16.59%	16.82%	150.19%	18.85%
CAPEX to FCF	118.39%	154.22%	223.79%	-248.10%	485.51%
Revenues growth rates		-4.22%	-2.80%	-72.66%	239.39%
EBIT growth rates		-18.16%	3.47%	-13.96%	2.25%
EBITDA growth rates		-7.21%	-4.71%	-11.54%	-0.10%
CAPEX growth rates		-3.22%	-1.46%	144.18%	-57.40%
FCF growth rates		-25.71%	-32.10%	-320.25%	-121.77%
ITT growth rates		-6.88%	-4.38%	20.77%	-4.72%
TER growth rates		-12.12%	8.21%	-28.76%	7.31%

Telefonica SA

Main parameters	2010	2011	2012	2013	2014
Revenues	60,737,000	62,837,000	62,356,000	57,061,000	50,377,000
EBIT	10,798,000	10,064,000	10,798,000	9,450,000	6,967,000
EBITDA	25,777,000	20,210,000	21,231,000	19,077,000	15,515,000
CAPEX	1,797,000	2,468,000	1,692,000	1,529,000	1,732,000
FCF	8,010,000	4,986,000	6,951,000	5,391,000	3,817,000
Non-current assets	108,721,000	108,800,000	104,177,000	89,597,000	99,435,000
Total assets	129,775,000	127,623,000	129,733,000	118,862,000	122,299,000
Current liabilities	33,492,000	32,578,000	31,511,000	29,144,000	29,699,000
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	11.21%	10.59%	10.99%	10.53%	7.52%
Technical efficiency ratio, TER (EBIT to ITT)	9.93%	9.25%	10.37%	10.55%	7.01%
CAPEX to Revenues	2.96%	3.93%	2.71%	2.68%	3.44%
CAPEX to FCF	22.43%	49.50%	24.34%	28.36%	45.38%
Revenues growth rates		3.46%	-0.77%	-8.49%	-11.71%
EBIT growth rates		-6.80%	7.29%	-12.48%	-26.28%
EBITDA growth rates		-21.60%	5.05%	-10.15%	-18.67%
CAPEX growth rates		37.34%	-31.44%	-9.63%	13.28%
FCF growth rates		-37.75%	39.41%	-22.44%	-29.20%
ITT growth rates		0.07%	-4.25%	-14.00%	10.98%
TER growth rates		-6.87%	12.05%	1.76%	-33.57%

Rostelecom OJSC

Main parameters	2010	2011	2012	2013	2014
Revenues	6,915,300	7,782,516	8,283,408	8,116,444	7,747,628
EBIT	1,244,928	1,497,692	1,340,696	1,118,908	1,116,416
EBITDA	2,655,400	2,975,448	2,997,876	2,823,436	2,626,568
CAPEX	1,593,385	2,377,418	2,576,479	2,003,867	1,489,718
FCF	782,488	-77,252	73,987	428,624	545,250
Non-current assets	9,843,400	11,358,536	12,472,460	10,097,584	11,754,764
Total assets	11,194,064	12,793,928	14,134,624	13,980,120	13,671,112
Current liabilities	2,566,760	3,304,392	3,416,532	3,336,788	3,070,144
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	14.43%	15.78%	12.51%	10.51%	10.53%
Technical efficiency ratio, TER (EBIT to ITT)	12.65%	13.19%	10.75%	11.08%	9.50%
CAPEX to Revenues	23.04%	30.55%	31.10%	24.69%	19.23%
CAPEX to FCF	203.63%	-3077.48%	3482.32%	467.51%	273.22%
Revenues growth rates		12.54%	6.44%	-2.02%	-4.54%
EBIT growth rates		20.30%	-10.48%	-16.54%	-0.22%
EBITDA growth rates		12.05%	0.75%	-5.82%	-6.97%
CAPEX growth rates		49.21%	8.37%	-22.22%	-25.66%
FCF growth rates		-109.87%	-195.77%	479.32%	27.21%
ITT growth rates		15.39%	9.81%	-19.04%	16.41%
TER growth rates		4.26%	-18.48%	3.09%	-14.29%

TDC AS

Main parameters	2010	2011	2012	2013	2014
Revenues	3,423,858	3,438,630	3,420,635	3,221,080	3,134,866
EBIT	660,707	697,502	695,085	677,762	681,656
EBITDA	1,364,252	1,383,993	1,361,163	1,340,080	1,316,579
CAPEX	466,121	449,066	457,392	484,250	524,940
FCF	440,471	469,209	420,059	443,426	431,608
Non-current assets	7,861,068	7,792,849	7,679,374	7,294,499	8,663,719
Total assets	8,701,992	8,755,708	8,527,415	8,111,116	9,991,176
Current liabilities	1,611,346	2,037,851	1,493,976	1,456,509	4,188,639
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	9.32%	10.38%	9.88%	10.18%	11.75%
Technical efficiency ratio, TER (EBIT to ITT)	8.40%	8.95%	9.05%	9.29%	7.87%
CAPEX to Revenues	13.61%	13.06%	13.37%	15.03%	16.75%
CAPEX to FCF	105.82%	95.71%	108.89%	109.21%	121.62%
Revenues growth rates		0.43%	-0.52%	-5.83%	-2.68%
EBIT growth rates		5.57%	-0.35%	-2.49%	0.57%
EBITDA growth rates		1.45%	-1.65%	-1.55%	-1.75%
CAPEX growth rates		-3.66%	1.85%	5.87%	8.40%
FCF growth rates		6.52%	-10.48%	5.56%	-2.67%
ITT growth rates		-0.87%	-1.46%	-5.01%	18.77%
TER growth rates		6.49%	1.13%	2.65%	-15.32%

Telenor ASA

Main parameters	2010	2011	2012	2013	2014
Revenues	10,508,604	10,915,573	11,270,354	10,984,490	11,804,632
EBIT	1,449,929	1,686,044	1,937,338	2,353,724	2,777,645
EBITDA	3,237,576	3,382,281	3,533,080	3,790,246	4,412,388
CAPEX	1,362,840	2,149,520	3,213,200	2,005,480	2,659,200
FCF	1,204,950	1,400,734	2,217,773	407,565,169	1,424,223
Non-current assets	15,569,838	14,628,038	15,448,068	16,192,423	16,784,981
Total assets	19,138,595	18,430,361	18,765,531	20,051,587	21,468,054
Current liabilities	4,760,300	5,272,861	4,867,776	4,915,310	5,902,205
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	10.08%	12.81%	13.94%	15.55%	17.84%
Technical efficiency ratio, TER (EBIT to ITT)	9.31%	11.53%	12.54%	14.54%	16.55%
CAPEX to Revenues	12.97%	19.69%	28.51%	18.26%	22.53%
CAPEX to FCF	113.10%	153.46%	144.88%	0.49%	186.71%
Revenues growth rates		3.87%	3.25%	-2.54%	7.47%
EBIT growth rates		16.28%	14.90%	21.49%	18.01%
EBITDA growth rates		4.47%	4.46%	7.28%	16.41%
CAPEX growth rates		57.72%	49.48%	-37.59%	32.60%
FCF growth rates		16.25%	58.33%	18277.23%	-99.65%
ITT growth rates		-6.05%	5.61%	4.82%	3.66%
TER growth rates		23.77%	8.80%	15.91%	13.84%

VimpelCom Ltd

Main parameters	2010	2011	2012	2013	2014
Revenues	8,697,590	16,748,772	19,062,453	18,636,749	16,223,874
EBIT	2,391,383	2,903,881	3,936,317	286,007	2,137,613
EBITDA	4,055,349	6,859,210	8,074,326	6,827,799	6,588,082
CAPEX	1,838,381	5,248,974	3,435,391	3,304,787	3,229,565
FCF	1,917,735	-693,526	2,685,656	1,767,292	1,059,714
Non-current assets	10,489,681	38,162,930	37,875,270	33,985,244	25,963,820
Total assets	12,156,953	44,669,178	45,761,130	41,228,000	33,888,530
Current liabilities	2,846,018	8,509,950	9,823,433	9,453,939	8,724,869
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	25.68%	8.03%	10.95%	0.90%	8.49%
Technical efficiency ratio, TER (EBIT to ITT)	22.80%	7.61%	10.39%	0.84%	8.23%
CAPEX to Revenues	21.14%	31.34%	18.02%	17.73%	19.91%
CAPEX to FCF	95.86%	-756.85%	127.92%	187.00%	304.76%
Revenues growth rates		92.57%	13.81%	-2.23%	-12.95%
EBIT growth rates		21.43%	35.55%	-92.73%	647.40%
EBITDA growth rates		69.14%	17.72%	-15.44%	-3.51%
CAPEX growth rates		185.52%	-34.55%	-3.80%	-2.28%
FCF growth rates		-136.16%	-487.25%	-34.20%	-40.04%
ITT growth rates		263.81%	-0.75%	-10.27%	-23.60%
TER growth rates		-66.62%	36.58%	-91.90%	878.30%

Turk Telekomunikasyon AS

Main parameters	2010	2011	2012	2013	2014
Revenues	3,843,995	4,229,741	4,500,719	4,646,304	4,818,100
EBIT	1,172,822	1,239,770	1,203,994	1,135,629	1,078,600
EBITDA	1,712,654	1,798,375	1,805,105	1,766,141	1,787,748
CAPEX	608,196	806,913	862,526	781,055	760,156
FCF	738,194	676,560	569,232	672,310	913,533
Non-current assets	4,033,857	4,309,795	4,548,539	4,744,777	4,769,572
Total assets	5,348,722	5,729,154	6,095,418	6,462,744	7,041,185
Current liabilities	1,707,695	1,986,112	1,518,895	1,789,874	1,496,934
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	32.21%	33.12%	26.31%	24.30%	19.45%
Technical efficiency ratio, TER (EBIT to ITT)	29.07%	28.77%	26.47%	23.93%	22.61%
CAPEX to Revenues	15.82%	19.08%	19.16%	16.81%	15.78%
CAPEX to FCF	82.39%	119.27%	151.52%	116.17%	83.21%
Revenues growth rates		10.04%	6.41%	3.23%	3.70%
EBIT growth rates		5.71%	-2.89%	-5.68%	-5.02%
EBITDA growth rates		5.01%	0.37%	-2.16%	1.22%
CAPEX growth rates		32.67%	6.89%	-9.45%	-2.68%
FCF growth rates		-8.35%	-15.86%	18.11%	35.88%
ITT growth rates		6.84%	5.54%	4.31%	0.52%
TER growth rates		-1.06%	-7.98%	-9.58%	-5.52%

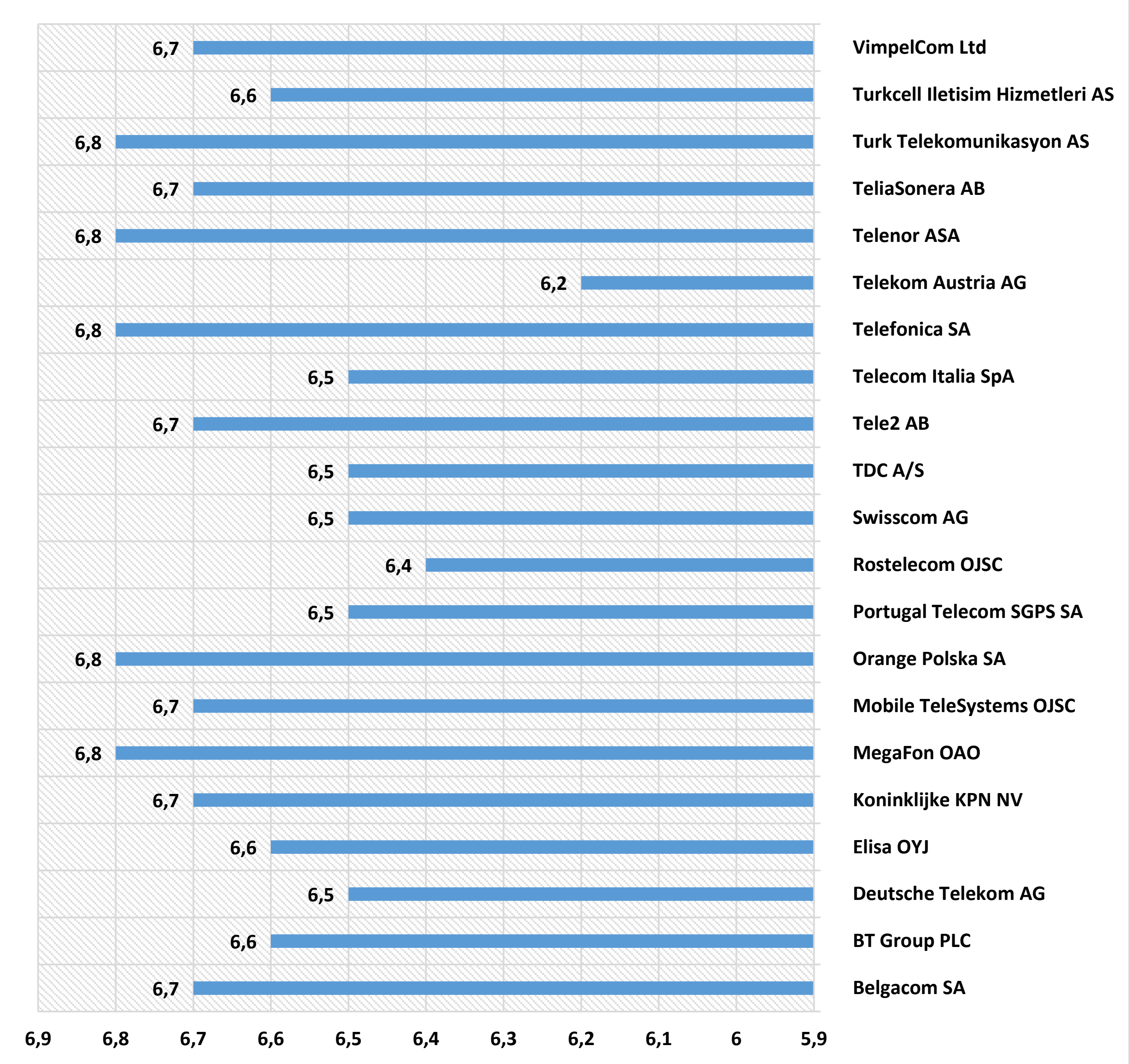
Turkcell Iletisim Hizmetleri AS

Main parameters	2010	2011	2012	2013	2014
Revenues	3,189,255	3,319,077	3,721,790	4,040,906	4,266,084
EBIT	640,642	467,570	648,152	690,764	751,797
EBITDA	1,044,347	1,031,807	1,148,204	1,255,533	1,332,505
CAPEX	590,662	579,433	615,918	645,495	759,731
FCF	197,544	-171,674	528,786	185,730	258,125
Non-current assets	1,897,557	1,641,869	1,770,954	1,600,012	1,586,551
Total assets	5,363,741	6,087,873	6,619,451	7,539,431	8,392,960
Current liabilities	642,171	832,946	730,860	715,478	762,419
Additional parameters	**2010**	**2011**	**2012**	**2013**	**2014**
Return on Capital Employed (ROCE)	13.57%	8.90%	11.01%	10.12%	9.85%
Technical efficiency ratio, TER (EBIT to ITT)	33.76%	28.48%	36.60%	43.17%	47.39%
CAPEX to Revenues	18.52%	17.46%	16.55%	15.97%	17.81%
CAPEX to FCF	299.00%	-337.52%	116.48%	347.54%	294.33%
Revenues growth rates		4.07%	12.13%	8.57%	5.57%
EBIT growth rates		-27.02%	38.62%	6.57%	8.84%
EBITDA growth rates		-1.20%	11.28%	9.35%	6.13%
CAPEX growth rates		-1.90%	6.30%	4.80%	17.70%
FCF growth rates		-186.90%	-408.02%	-64.88%	38.98%
ITT growth rates		-13.47%	7.86%	-9.65%	-0.84%
TER growth rates		-15.65%	28.52%	17.96%	9.76%

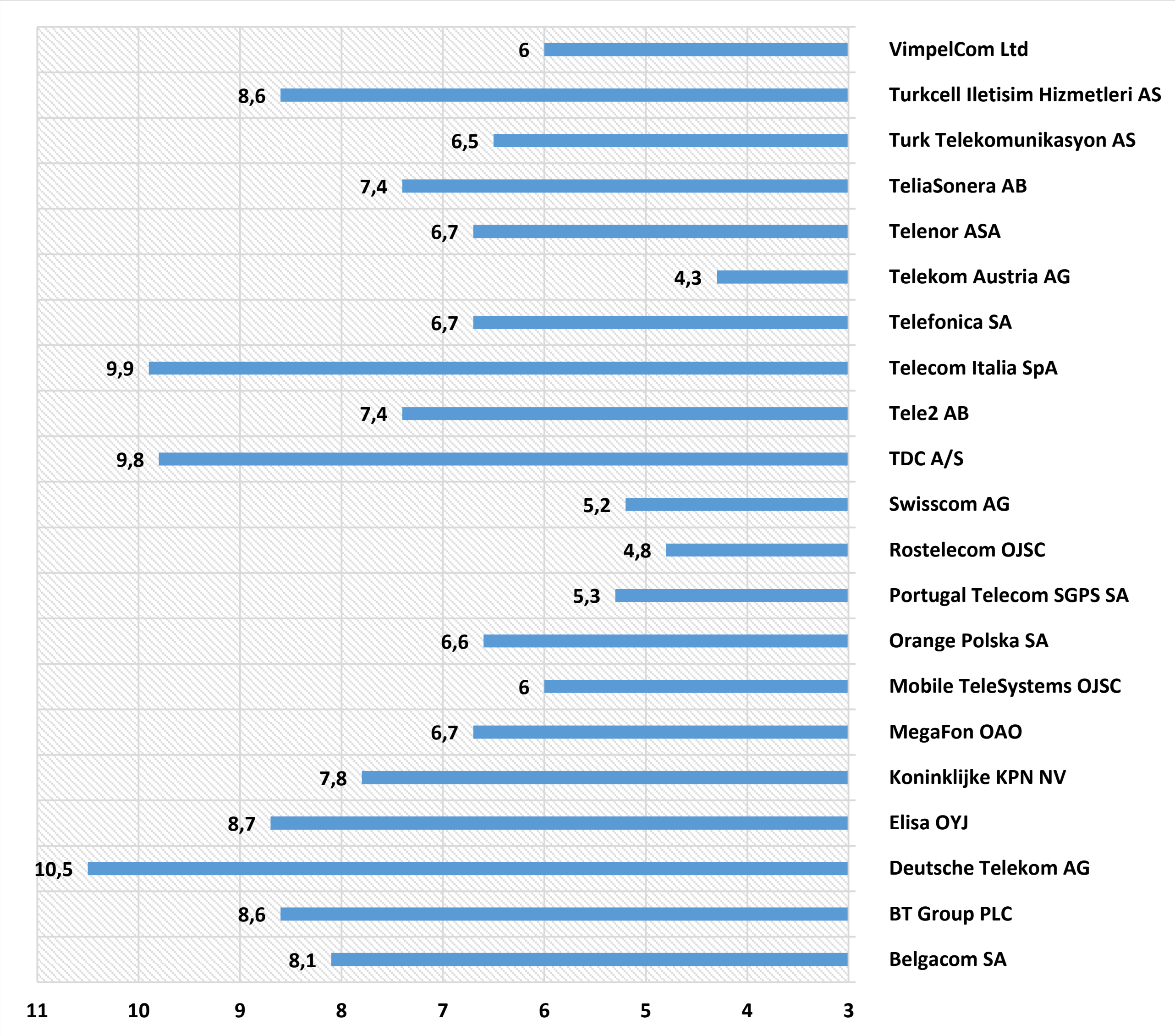
Annex 6. Correlation matrix of ratios calculated

	MCapc	*ROCEc, %*	*NPVc*	*TFc, %*	*ConVc*	*CVc*	*NPVc2*	*TFc2, %*	*ConVc2*	*CVc2*	*avg. Revenues*	*avg. EBIT*	*avg. EBITDA*	*avg. CAPEX*	*avg. FCF*	*avg. non-current*	*avg. current liabilities*	*avg. Total assets*	*avg. TER*	*avg. CAPEX/FCF*	*Revenues*	*EBIT*	*EBITDA*	*CAPEX*	*FCF*	*Non-current assets*	*Current liabilities*	*Total assets*	*TER*	*CAPEX/FCF*	*CAPEX to Revenues*	*Stand dev.*	*CRc*	*TAW1c, Y*	*Market CAPEX2*	*NCRc*	*TAW2c, Y*
MCapc	1.0																																				
ROCEc, %	-0.2	1.0																																			
NPVc	0.6	-0.4	1.0																																		
TFc, %	-0.2	-0.2	0.4	1.0																																	
ConVc	0.4	-0.5	0.9	0.5	1.0																																
CVc	0.4	-0.5	0.9	0.5	1.0	1.0																															
NPVc2	0.6	-0.2	1.0	0.3	0.8	0.8	1.0																														
TFc2, %	-0.3	0.3	0.1	0.9	0.2	0.2	0.1	1.0																													
ConVc2	0.6	-0.2	1.0	0.3	0.8	0.8	1.0	0.1	1.0																												
CVc2	0.6	-0.2	1.0	0.3	0.8	0.8	1.0	0.1	1.0	1.0																											
avg. Revenues	0.8	-0.4	0.9	0.1	0.8	0.8	0.9	-0.1	0.9	0.9	1.0																										
avg. EBIT	0.9	0.0	0.7	0.0	0.5	0.5	0.8	-0.1	0.8	0.8	0.8	1.0																									
avg. EBITDA	0.6	-0.4	0.9	0.2	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.7	1.0																								
avg. CAPEX	0.2	-0.4	0.9	0.4	0.9	0.9	0.8	0.3	0.8	0.8	0.8	0.4	0.9	1.0																							
avg. FCF	0.1	0.0	0.1	-0.1	0.0	0.0	0.1	-0.1	0.1	0.1	0.0	0.1	0.0	0.1	1.0																						
avg. non-current assets	0.8	-0.4	0.9	0.3	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.8	0.9	0.7	0.0	1.0																					
avg. current liabilities	0.8	-0.4	0.9	0.2	0.8	0.8	0.9	0.0	0.9	0.9	1.0	0.9	0.9	0.7	0.0	1.0	1.0																				
avg. Total assets	0.8	-0.4	0.9	0.3	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.8	1.0	0.7	0.0	1.0	1.0	1.0																			
avg. TER	-0.2	0.7	-0.4	-0.3	-0.4	-0.4	-0.3	0.0	-0.3	-0.3	-0.4	-0.2	-0.4	-0.4	-0.1	-0.4	-0.4	-0.4	1.0																		
avg. CAPEX/FCF	-0.3	0.0	-0.2	-0.3	-0.1	-0.1	-0.3	-0.3	-0.3	-0.3	-0.2	-0.3	-0.2	-0.1	-0.1	-0.3	-0.3	-0.3	0.0	1.0																	
Revenues	0.7	-0.4	0.9	0.1	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.8	1.0	0.8	0.1	1.0	0.9	1.0	-0.4	-0.2	1.0																
EBIT	0.7	-0.2	0.9	0.2	0.8	0.8	1.0	0.1	1.0	1.0	1.0	0.9	0.9	0.8	0.2	0.9	0.9	0.9	-0.3	-0.2	0.9	1.0															
EBITDA	0.6	-0.4	0.9	0.2	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.7	1.0	0.9	0.1	0.9	0.9	0.9	-0.4	-0.1	1.0	0.9	1.0														
CAPEX	0.2	-0.3	0.8	0.4	0.9	0.9	0.7	0.2	0.7	0.7	0.7	0.4	0.9	1.0	0.1	0.7	0.7	0.7	-0.3	0.0	0.8	0.8	0.9	1.0													
FCF	0.6	-0.2	1.0	0.3	0.8	0.8	1.0	0.1	1.0	1.0	0.9	0.8	0.9	0.8	0.1	0.9	0.9	0.9	-0.3	-0.3	0.9	1.0	0.9	0.7	1.0												
Non-current assets	0.8	-0.4	0.9	0.2	0.8	0.8	0.9	0.0	0.9	0.9	1.0	0.8	0.9	0.7	0.0	1.0	1.0	1.0	-0.4	-0.3	1.0	0.9	0.9	0.7	0.9	1.0											
Current liabilities	0.8	-0.4	0.9	0.2	0.8	0.8	0.9	0.0	0.9	0.9	1.0	0.8	1.0	0.7	0.1	1.0	1.0	1.0	-0.4	-0.3	1.0	0.9	0.9	0.7	0.9	1.0	1.0										
Total assets	0.7	-0.4	0.9	0.2	0.9	0.9	0.9	0.0	0.9	0.9	1.0	0.8	1.0	0.8	0.0	1.0	1.0	1.0	-0.4	-0.2	1.0	0.9	0.9	0.8	0.9	1.0	1.0	1.0									
TER	-0.2	0.4	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1	-0.2	-0.2	-0.3	-0.2	-0.3	-0.2	0.0	-0.4	-0.3	-0.3	0.9	0.1	-0.3	-0.2	-0.3	-0.2	-0.2	-0.4	-0.4	-0.3	1.0								
CAPEX/FCF	-0.3	-0.3	-0.3	-0.2	-0.1	-0.1	-0.4	-0.3	-0.4	-0.4	-0.2	-0.4	-0.2	-0.1	-0.1	-0.2	-0.3	-0.2	-0.2	0.7	-0.2	-0.3	-0.2	-0.1	-0.4	-0.3	-0.3	-0.2	-0.1	1.0							
CAPEX to Revenues	-0.1	0.2	-0.4	-0.2	-0.4	-0.4	-0.4	-0.1	-0.4	-0.4	-0.3	-0.1	-0.3	-0.3	0.0	-0.3	-0.3	-0.3	0.0	0.1	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3	-0.2	0.2	1.0						
Stand dev.	-0.3	-0.3	0.1	0.2	0.2	0.2	0.0	0.1	0.0	0.0	0.0	-0.2	0.1	0.2	-0.3	0.0	-0.1	0.0	-0.2	0.2	0.0	-0.1	0.1	0.2	0.0	0.0	0.0	0.0	-0.2	0.1	0.3	1.0					
CRc	-0.2	-0.3	0.1	0.3	0.2	0.2	0.0	0.1	0.0	0.0	0.0	-0.2	0.1	0.3	-0.3	0.0	0.0	0.0	-0.3	0.1	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.1	-0.2	0.1	0.3	1.0	1.0				
TAW1c, Y	0.3	0.3	0.0	-0.2	-0.2	-0.2	0.1	-0.1	0.1	0.1	0.1	0.3	0.0	-0.2	0.3	0.0	0.1	0.0	0.2	-0.2	0.0	0.1	0.0	-0.2	0.1	0.0	0.1	0.0	0.2	-0.2	-0.3	-1.0	-1.0	1.0			
Market CAPEX2	-0.1	0.2	-0.4	-0.2	-0.4	-0.4	-0.4	-0.1	-0.4	-0.4	-0.3	-0.1	-0.3	-0.3	0.0	-0.3	-0.3	-0.3	0.0	0.1	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3	-0.2	0.2	1.0	0.3	0.3	-0.3	1.0		
NCRc	-0.1	0.2	-0.4	-0.2	-0.5	-0.5	-0.4	-0.1	-0.4	-0.4	-0.3	-0.1	-0.3	-0.3	0.0	-0.3	-0.3	-0.3	0.0	0.1	-0.3	-0.3	-0.3	-0.3	-0.4	-0.3	-0.3	-0.3	-0.2	0.2	1.0	0.3	0.3	-0.3	1.0	1.0	
TAW2c, Y	0.0	-0.3	0.5	0.3	0.6	0.6	0.4	0.1	0.4	0.4	0.3	0.1	0.4	0.4	0.0	0.3	0.3	0.4	-0.1	0.0	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.1	-0.2	-1.0	-0.1	0.0	0.1	-1.0	-1.0	1.0

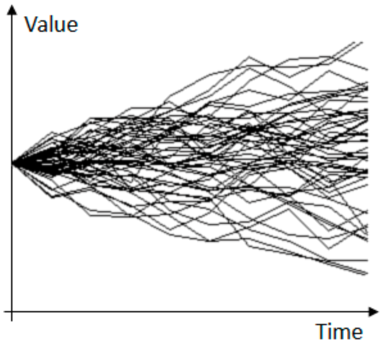
Annex 7. Technology adoption time window determination results using Method No. 1



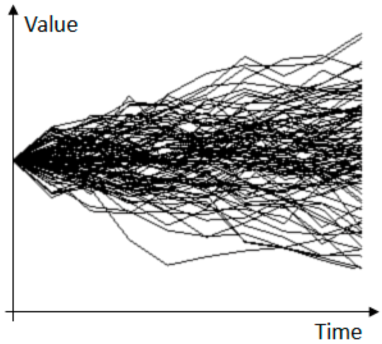
Annex 8. Technology adoption time window determination results using Method No. 2



Annex 9. Samples of Geometric Brownian Motions trials according to possible paths



50 possible paths



100 possible paths

Annex 10. 20 sample paths of Geometric Brownian Motion