UNIVERSITY OF TAMPERE

UNIVERSITY OF HELSINKI
ALEKSANTERI INSTITUTE

Faculty of Management

Master's Degree Program in Economics

Aleksanteri Institute

The Expertise in Russian and Eastern European Studies

THE SHORT-RUN DYNAMICS AND ANALYSIS OF MICRO-LEVEL PRODUCTIVITY GROWTH

Evidence from a manufacturing plant in Ukraine

2018

Economics
Master's Thesis

Author: Juuli Jäntti
Supervisor: Hannu Laurila

December 2018

ABSTRACT

University of Tampere, Faculty of Management

Author *Juuli Jäntti*
Title of the Master's Thesis *The Short-Run Dynamics and Analysis of Micro-Level Productivity; Evidence from a Manufacturing Plant in Ukraine*
Degree Programme *Business Studies (Economics)*
Thesis supervisor *Professor Hannu Laurila*
Year *2018* **Number of pages** *89, appendices 7* **Language** *English*
Keywords: *productivity growth, technical change, the Cobb-Douglas production function, micro-level estimation, autoregressive process*

Productivity is widely acknowledged to be an important part of economic dynamics, both at micro- and macro-level. Hence multiple studies have been applied to understand the sources of productivity growth and its development over the past decades. The importance of productivity growth on long-run output development has been realized already in the 20th century, whilst the discussion on short-run implications of productivity and technical progress is still ongoing among economists. On the contrary, the importance of short-run productivity growth is not well understood. Additionally, there is not a unique model for estimating technological growth at firm-level. These circumstances provide an interesting framework to this study´s focus on short-run productivity dynamics in a firm.

Productivity growth is created amid firms' production processes and it refers to better and more efficient use of resources, leading to output growth and economic welfare. This study investigates micro-level dynamics of productivity growth in an unconventional market environment. The empirical part of this research utilizes data of the case plant, which operates in Ukraine. The study will apply a widely used approach, the Cobb-Douglas production function, to estimate productivity growth. This estimation is conducted with data of the plant's production process dating from 2011 to 2018.

This study estimates two productivity models. These models are defined with respect to the Cobb-Douglas production function and they are differentiated by measuring labor input differently. One of the models uses number of workers as a proxy for labor input, while the other applies the hours worked to the function. Both models are estimated as a first-order autoregressive process and the findings from both models are similar. The productivity growth in the case manufacturing plant has been decreasing between 2011 and 2018 and hence, supports the findings in the existing literature. Nevertheless, the overall productivity level during the examination period has contributed positively to the output development, but the most recent data suggests otherwise. Consequently, the quarterly production process at the manufacturing plant is not at a sustainable level because the improved productivity, attributed to the productivity shock of 2011, gradually diminishes. Even though the empirical data set is challenging, the results offer valuable insights to the company's managers to reevaluate profitability and resource usage.

TIIVISTELMÄ

Tampereen yliopisto, Johtamiskorkeakoulu

Tekijä *Juuli Jäntti*
Pro Gradu -tutkielman otsikko *The Short-Run Dynamics and Analysis of Micro-Level Productivity; Evidence from a Manufacturing Plant in Ukraine*
Maisterin tutkinto *kauppatieteissä (taloustieteet)*
Työn ohjaaja *Professori Hannu Laurila*
Vuosi *2018* **Sivumäärä** *89, liitesivuja 7* **Kieli** *Englanti*
Avainsanat: *tuottavuuskasvu, tekninen muutos, Cobb-Douglas tuotantofunktio, mikrotason estimointi, autoregressiivinen prosessi*

Tuottavuuden on laajalti tunnustettu olevan tärkeä osa talouden dynamiikkaa sekä mikro- että makrotasolla. Tämän vuoksi tuottavuuskasvun lähteitä sekä tuottavuuden kehitystä on yritetty ymmärtää viime vuosikymmeninä monien tutkimusten valossa. Tuottavuuskasvun tärkeys pitkän aikavälin taloudellisen tuotoksen kehityksessä on todettu jo 1900-luvulla, kun taas tuottavuuden ja teknisen kehityksen lyhyen aikavälin merkityksellisyydestä käydään vielä keskustelua. Lyhyen aikavälin tuottavuuskasvun tärkeyttä ei ole täysin ymmärretty, eikä yritystason teknisen muutoksen estimointiin ei ole tarjolla yksikäsitteistä mallia. Nämä lähtökohdat tarjoavat mielenkiintoisen viitekehyksen tälle tutkimukselle, sillä tämä työ keskittyy tutkimaan lyhyen aikavälin tuottavuuden dynamiikkaa yrityksen sisällä.

Tuottavuuskasvu syntyy yritysten tuotantoprosesseissa ja tuottavuuden kasvulla viitataan parempaan ja tehokkaampaan resurssien hyödyntämiseen, mikä johtaa tuotannon kasvuun sekä taloudelliseen hyvinvointiin. Tämän tutkimuksen painopisteenä on tutkia mikrotason tuottavuuskasvun dynamiikkaa epätavanomaisessa markkinaympäristössä. Tutkimuksen empiirinen osuus hyödyntää dataa esimerkkiyrityksestä, jonka tuotantolinja sijaitsee Ukrainassa. Tutkimuksessa sovelletaan laajalti tunnustettua lähestymistapaa, Cobb-Douglas tuotantofunktiota, tuottavuuskasvun estimoimiseksi. Tuottavuuden estimointi perustuu esimerkkiyrityksen tuotantoprosessiin vuosina 2011–2018.

Työn estimoi kaksi tuottavuusmallia. Nämä mallit perustuvat Cobb-Douglas tuotantofunktioon ja ne eroavat toisistaan työpanoksen suhteen. Toinen malleista hyödyntää henkilömäärää ja toinen työtunteja työpanosta määrittäessä. Mallit on estimoitu ensimmäisen asteen autoregressiivisenä prosessina ja niistä voidaan tehdä yhdenmukaiset päätelmät. Ukrainan tehtaan tuottavuuskasvu on hidastunut vuosien 2011 ja 2018 välillä. Tämä havainto tukee aikaisemman kirjallisuuden tutkimustuloksia. Vaikka tuottavuuden taso on kokonaisuudessaan tukenut tuotannon kehitystä tarkasteluajanjaksona, tuorein data antaa ymmärtää toisin. Kvartaalitason tuotantoprosessi ei tuloksien valossa ole kestävällä tasolla. Vuonna 2011 tapahtuneella positiivisella tuottavuusshokilla on vähenevät tuotot ja sen vaikutus katoaa ajan myötä. Vaikka empiirinen aineisto on haastava, työn tutkimustulokset tarjoavat arvokasta tietoa yrityksen johdolle ja niiden avulla voidaan arvioida tehtaan kannattavuutta ja resurssien käyttöä.

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Productivity isn't everything, but in the long run it is almost everything.

- *Paul Krugman, The Age of Diminishing Expectations (1997)*

1 Introduction

Nations pursue economic growth, and companies' main interest lay in maximizing output in a sustainable way, while minimizing costs. This guarantees sustainable development possibilities for both society and firms. Productivity is one of the factors enchased in economic processes and it is widely acknowledged as the key driver of long-term economic growth. Paul Krugman, a recognized economist, noted in the late 1990s that "the only way in which sustained, long-term growth in living standards can be achieved is by raising productivity" (Krugman 1997, pp. 11-12). The term productivity may seem abstract, but it is crucial for micro- and macroeconomic development. As a result, this study focuses on the source of productivity creation in a short-run micro-level production process.

Productivity is linked to multiple economic processes and the importance of productivity growth stands firm since it has contributed to better living standards in economies. Productivity can be described as "a critical success factor of economy" (Saari 2006, p. 1) and changes in productivity integrate in a national health and economic well-being, especially on the long-run. In addition, productivity has been identified as one of the driving forces behind income differences between nations (Hsieh & Klenow 2010) since the better productivity level occur, the better average living standards can be achieved. Productivity is present in many economic processes and it should not be disregarded.

Even though the benefits of productivity are evident in a wider context, all productivity growth begins from micro-level. This study focuses on microeconomic implications of productivity growth, deriving the ideology from the nationwide context to processes of a single firm. Furthermore, this study creates a model for productivity development assessment using data of the case manufacturing plant, which operates in Ukraine. This aids in identifying the main components in production and as such, the key drivers of productivity growth. This further assists in informing the firm's managers on analyzing resource usage effectively.

The topic of productivity impacts many businesses because in today's hectic and competitive business environment only the most productive companies survive. In recent years, companies have made great investments in software applications and work processes to achieve higher levels of productivity to better compete with other players in the market. Moreover, the changing world affects firms globally. Managers need to be able to adapt to these changing conditions. These new investments and different phases in productions' adjustment cause dispersion in productivity levels between firms (Cette, Corde & Lecta 2018, p. 78). That is why it is important to measure a firm's productivity and analyze the profitability and resource utilization constantly. The greater productivity is achieved at business level, the better economic growth at nation level is fostered.

There is evidence that productivity plays an important role in companies' resource utilization assessment (Goshu, Kitaw & Matebu 2017, p. 1) and productivity performance management plays an essential role in manufacturing. Nowadays, with cost controlling pressures and intense global competition, productivity measurement at firm level can help managers to better understand productivity development and its related trade-offs. In addition, new technologies and information technology solutions improve efficiency of production, resulting in changes in the substitution rate between input factors (Bartel, Ichniowski & Shaw 2007, p. 1721) which can be crucial to attain higher productivity levels in production. The sources of productivity growth can be different depending on the industry and timeframe of the analysis. Total productivity analysis helps managers control production costs and efficiency of used inputs. Hence, resulting in better performance. This is especially eminent in countries such as Ukraine where the analysis of productivity and real measures of costs have been vague in recent years because of heavily fluctuating inflation rates and market uncertainty. Accurately conducted productivity analysis at firm level takes this issue into consideration.

Even though productivity is a widely acknowledged phenomenon its proper measurement is a challenge. Productivity growth has been thoroughly researched, but productivity estimates still ignore some underlying economic factors. Furthermore, the productivity framework has usually only been applied nationwide, aimed at identifying productivity gains in the long-run. Despite its problems, productivity is linked to better well-being and therefore it can be regarded as an important factor both in micro- and macroeconomy. This study differs from these common approaches as it is mainly interested in the specific properties of micro-level economic processes.

But what does productivity mean and how is it measured? This study provides an answer to these questions and applies productivity measurement practices to the micro-level, focusing on the short-run productivity fluctuations. The thesis is conducted as a case study, using plant level data of a manufacturing firm which has an operating plant in Ukraine. This study builds on economic theories and applies productivity measurement tools onto firm level. Hereby it becomes possible to analyze factory level data with econometric models aimed at identifying new approaches to productivity measurement in the case plant. Firm level data is very accurate and therefore it generates more trustworthy results than in the nationwide context. Micro-level data also makes it possible to identify the main components driving productivity growth of a specific production process.

This study approaches productivity analysis by starting at the wider context and working towards micro-level application of productivity analysis, as visualized in figure 1. First, the concept of productivity in economic research is explained and its importance at the national level will be discussed. Because all economic activity and economic growth is generated by single firms operating within the nation, to analyze the concept of productivity, one needs to understand how firms work and how productivity can generate output growth at micro-level. Therefore, after discussing productivity in the nationwide context and the principles of Solow growth model, the phenomenon of productivity will be applied onto firm level. Different types of measurement tools will be presented and linked to theory of the firm.

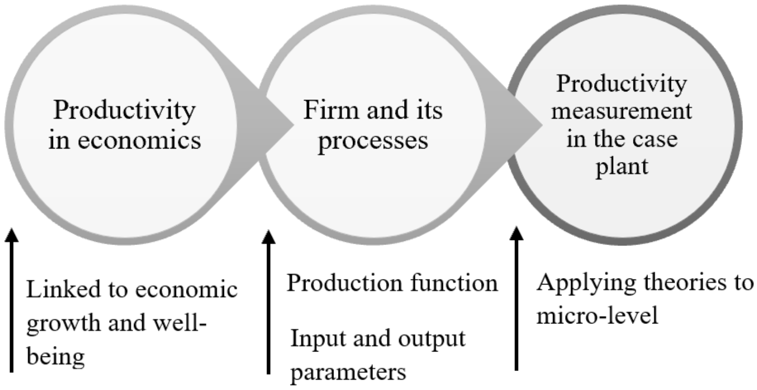

Figure 1. The framework of the thesis

To analyze the firm’s productivity, one needs to identify the components of the production process and output creation. Firm processes, on the other hand, can be described by use of a production function, of which the identification will be an essential part of this study. Finally, the study will apply a widely recognized theoretical model in practice to measure the short-run productivity development in Ukraine. The proper understanding of characteristics and determinants of productivity and output growth requires empirical tools and a specific growth accounting framework. The empirical results will be compared to other theoretical studies in the field.

The theoretical framework of the economic approach in productivity measurement is rooted in the microeconomic theory of production. This research aims to identify different types of productivity measures applicable at firm level. This will be achieved by presenting productivity measurement approaches conducted by previous studies, and by consecutively analyzing the production process in the case plant. Consequently, it becomes possible to analyze productivity performance and the components affecting productivity growth in the case plant. The study will also describe the importance of productivity measurement with the purpose of identifying the key factors determining the productivity levels and driving output growth at any given time.

The case plant's operating environment, Ukraine, offers an interesting but challenging context for the productivity measurement. One main issue related to productivity measurement is the heavy inflation, triggered by the Ukrainian crisis in 2014, which has a direct effect on the firm's operation costs. This study aims to eliminate the effect of the inflation on the productivity calculations to derive actual and reasonable measures for productivity change. Another challenge for the productivity measurement is the consequence of the crisis on the production volumes in the case plant. The Ukrainian crisis has caused some fluctuation in output volume development, and the produced output has not maintained constant over the last few years. When production processes ongoingly need to adapt to a changing market environment it becomes more difficult to manage productivity of the manufacturing processes. These challenges are discussed in-depth under chapters 4 and 5.

This study focuses on the themes mentioned above and analyses the productivity as a part of the short-run microeconomic activity. The key objective of this study is to find a solution to the main research question, which focuses on short-run productivity growth in the case plant and its relationship with the firm's output. The main research question can be stated as:

Has productivity contributed to the output growth in the case plant between 2011-2018?

To properly answer the above-stated question one needs to understand the tools that can be used for measuring productivity and what kind of factors can influence the productivity at micro-level. Therefore, it is important to investigate whether one can find the trendline for recent productivity growth development with these tools. The focus points can be summarized to the following questions:

How can productivity growth be measured at firm level?

How has the case manufacturing plant's productivity growth developed in 2011-2018?

The answers to the aforementioned questions are based on both existing literature of the productivity analysis and on the results of an empirical study, which is conducted with the case plant's time-series. The topics presented in the research questions will be discussed throughout the thesis and the full answers will be given in the conclusions-section. This study focuses on disembodied technical change and productivity growth, since the models used in the estimation process already capture the embodied technical change in inputs. Disembodied technical progress refers to the productivity gains, which are not achieved by new investments or by increasing the amount of used inputs.

As shown by the research questions, the empirical part of this study focuses solely on quantitative factors in the production processes and takes softer parameters, such as the labor force skills, as given. These qualitative factors cannot be quantified in monetary values but can nevertheless be important drivers behind productivity dynamics. Since this study disregards these qualitative aspects in the models, the labor force considered in the productivity model will not be divided into separate components of skilled and less skilled workforce.

The study is structured as follows. The first part describes the phenomenon of productivity and will discuss the theoretical background in the field. Before examining productivity in an individual firm, one needs to understand the main concepts and productivity movements on aggregate level. Closely related to productivity analysis, the concept of technical change will be explained and illustrated by figures. Next, the theoretical basis of a firm economics and a production function will be introduced, the latter being a key concept in productivity analysis in economics. Following this section, the mathematical model for productivity analysis will be constructed. The empirical part of this study focuses on applying the designed model to measure the productivity development in the case plant. The estimation will be conducted on two distinct models by using the most applicable econometric techniques, derived from theory. Finally, the conclusions will provide answers to the research questions grounded in the insights in the existing literature and on the estimation results with production plant data. However, at first, the existing literature and the main studies in the field of productivity analysis are introduced.

2 Defining productivity and technical change

2.1 State of the art

Given this study's focus of a productivity analysis on a single production plant, it is important to discuss what productivity means in an economic context. Productivity has been widely studied since the mid-1900s. Especially the contribution of long-run productivity growth at national level has been of interest to economists, but also its contribution to firm-level has become more evident in the literature. For a long time, economic studies in the field of productivity were heavily focused on economy of nations and contributions to growth theory.

Robert Solow (1957) was one of the pioneers in developing growth models with the concept of productivity and production function in his study *Technical Change and the Aggregate Production Function*. He focuses on separating the component of technical change from the changes in capital usage as an explanatory factor of variations in output per capita. Solow argued that an increase in input usage does not contribute to the whole increase in output and therefore, he introduced the concept of total factor productivity (TFP), herewith explaining growth rates and variations in the value of output per capita in the economy (p. 312). He showed that productivity stems from the marginal productivity of inputs combined with the rate of technical change. Only a higher productivity growth rate leads to enduring higher output growth rates. (Solow 1957) This contribution to the long-term productivity analysis' development is considered fundamental. The term technical change refers to development in economic processes, which eventually modifies the share of input needed in a production. This study will elaborate on the importance of this finding later.

Davis (1955), on the other hand, was one of the forerunners in developing productivity analysis for a single firm's purposes. Davis concluded that production efficiency affects incomes of a business enterprise. His study's focus area is on the development of a productivity model, which simultaneously considers the changing market prices over time. (p. 2) This is an important basis for the analysis. When the productivity level is analyzed with stable prices the estimation results are coherent and become useful for the manufacturing firm's purposes. Otherwise the results may reflect both productivity gains and increased price levels, which are generated by annual inflation. Davis's ideology will be applied in this study to make the estimation results coherent and commensurate over time.

In the end of the 20th century, interest in microeconomic productivity analysis increased among other economists. For example, Morrison (1993) explained productivity growth with a link to the microeconomic context and capacity utilization (Morrison 1993) and in the 21st century, OECD (Organization for Economic Cooperation and Development), a club of mostly rich countries, published a manual for productivity accounting, which is applicable both to industry- and firm-level estimation (Schreyer 2001). The manual explains a variety of different measurement tools and provides a deeper analysis on how to conduct these methods in practice. Wei and Liu (2018), on the other hand, consider an interesting approach to productivity measurement with their resource-specific productivity estimation. The basic principles, such as utilization of the Cobb-Douglas production function in the analysis, are similar in other studies in the field, but their model allows estimation of the input parameters and their contribution level to the overall productivity (Wei & Liu 2018). Their model makes the separation of internal and external factors' influence on productivity level possible.

Even though nation and industry level productivity analysis are widely studied, recent years saw the focus area shift to plant-level productivity measurement. These studies focus on various specific aspects, such as how worker skills or trade policies affect productivity levels (Kasahara & Rodrigue 2015; Bartel et al. 2007) or how managerial ownership influences productivity in different companies (Palia & Lichtenberg 1999). There is a wide range of interesting studies in the field of productivity analysis, but this study focuses only on the core of productivity estimation and will disregard some external and internal factors, despite these factors possibly being linked to firms' processes. Examples of these factors are the qualitative aspects or the changing exchange rate which influence productivity through, for example, demand.

Productivity as a phenomenon is mainly studied by economists, but when productivity analysis is applied to firm or plant level, the field of accounting should be considered. Saari (2006) in his study *Theory and Measurement in Business* focuses on firms' processes and needs without constructing an econometric model for estimation purposes. Instead, he provides some productivity calculation methods for business management's use. (Saari 2006) In addition, Hannula (2000) has focused on the usefulness of productivity measurement for managerial purposes. Therefore, Hannula developed a simple total productivity model in his study making a daily assessment of business processes possible. His model considers productivity as output over sum of all inputs used, such as labor, capital and intermediates, and provides an interesting alternative to the production function approach (Hannula 2000). Even though these studies have not applied the same analysis methods as those that will be used in this study, they provide relevant perspectives that are valuable for this study's purposes.

This study relates to the key insights of the authors mentioned above and each of the studies have had a contribution to the model and method selection. However, the literature on modelling firm or plant level productivity is scarce and there is no one method found to be more appropriate. The correct productivity model highly depends on its using purposes and on the qualities of a production process. In a nationwide analysis the measurement of specific data variables can be a challenge, but the micro-level analysis provides a unique setting for the modelling and enables the use of detailed data. These circumstances provide an interesting starting point for this study.

Table 1 presents some key studies in productivity literature in the field of economics. The studies show consensus on the understanding that productivity is a relevant part of the economy and that productivity growth provides advantages which cannot be achieved in any other way. That is why productivity as a phenomenon is unique and its importance, both at national and at firm level, is not debatable. The table lists the studies in ascending order, based on publication year. Some main qualities of the studies are divided under specific categories and marked in the table. First, the table indicates the main approach and the type of the productivity model that authors have considered in the estimation. In addition, the table separates the studies with respect to the level of analysis, and whether the study is most relevant to nation level, industry level or to firm-level. From the categories derived, the study's focus is on the production function approach in a firm-level analysis.

Table 1. List of key studies in field of productivity analysis[1]

	Productivity model		**Level of analysis**		
Author (Year)	**Production function approach**	**Other**	**Nation level**	**Industry level**	**Firm or plant level**
Davis (1955)		x			x
Solow (1957)	x		x		
Baily, Hulten & Cambell (1992)	x			x	
Morrison (1993)	x		x		
Hannula (2000)		x			x
OECD (2001)	x		x	x	
Brynjofsson & Hitt (2003)	x		x		x
Saari (2006)	x				x
Wazed & Ahmed (2008)		x			x
O'Mahony & Timmer (2009)	x			x	
Raval (2010)	x			x	
Goshu, Kitaw & Matebu (2017)		x			x
Bournakis & Mallick (2018)	x				x
Wei & Liu (2018)	x		x		

The table comprises some of the relevant studies in the field of productivity analysis and productivity estimation in economics. Based on table 1, the most common approach in economic research is the production function, which will also be utilized in this study. In addition, there are some theoretical studies, which have been an inspiration in for example data gathering or history of economics of productivity. In recent years, the use of accounting perspectives in the context of single firm's productivity measurement has gained popularity. The standpoint of these studies is different than those used in economics, and therefore these have been omitted from the table above. The next section of this study will provide an explanation of the term productivity and what it means in the economic context.

[1] The authors, who have not considered production function in estimation, or have used non-parametric methods, their models' performance can be highlighted mainly in business accounting, not in economic research.

2.2 Productivity in economics

By one definition, nations and economies are described by satisfying peoples' needs and creating welfare, which is affected by how well the resources are utilized in the economy. The use of resources, on the other hand, is determined by firms' production processes and by the level of available technology. These factors together determine the level of output from the firm, and the more output a firm can produce from a fixed amount of inputs, the more productive the firm is. Productivity, which usually stems from new innovations or technology in production, changes the quality of inputs and outputs and allows more efficient use of resources. This, in turn, creates welfare, better living standards and economic growth.

The economic processes are highly dependent on each other, and eventually, the more efficient and productive firms generate better economic growth and, when managed right, create welfare. Therefore, innovative and productive business processes, which produce goods or services satisfying the needs of humans, are a crucial part of the economy (Saari 2000, p. 138). Hence, it is not surprising that economists around the world have pointed out that one important factor determining well-being and living standards is the long-run improvements found especially in labor productivity.

Economic growth, questions of employment, cost analysis in companies, economic performance, efficiency and many other factors are all affected by productivity (Morrison 1993, p. 1) and each of these factors can be influential for the speed of economic growth. Productivity measurement tries to capture the fluctuations in both output and input quantities or prices (Morrison 1993, p. 3), irrespective of the level of analysis. Together, these elements determine economic performance at a given time. Productivity is at the center of economists' interests, both at firm and aggregate level and it has been studied for many decades. The same economic laws can be applied to both nation level and micro-level productivity analysis, and therefore it is also good to understand the contribution of productivity to nations' economy.

Economists are generally interested in the relation between different components, such as production fluctuations, costs and resource utilization, and productivity is one important variable to be added to this list of interests. Productivity, as a term, refers to the relation between output and input components, which are associated with a firm's production. The better resources are allocated and utilized in the firm's production, the greater the effect on productivity growth. Wazed and Ahmed (2008) describe that “productivity is the ratio of what is produced by an operation of process to what is required to produce it” (p. 988). Davis (1955), on the other hand, summarizes the main idea of productivity improvements as “getting a greater output from the same man or the same machine or the same output from a smaller number of men or machines” (p. 2). This basic idea applies to a variety of situations, such as firm’s processes or nationwide resource utilization. Productivity, at its core, means economic performance measure, and it can be understood as a ratio between final output obtained from production inputs, such as labor and capital. Therefore, productivity describes how much a firm or nation has been capable of producing relative to its resources. Traditional macroeconomic models have also associated productivity shocks with business cycle fluctuations.

In table 2 basic calculations for productivity between three periods have been illustrated (Davis 1955, p. 6). The purpose of this example is to clarify the main idea of productivity and its importance for both production processes and economic growth. The input and output values are measured in base-year prices to exclude the effect of possible inflation. In this example, the base year is set to be period 1. All the values are presented in terms of Ukraine’s currency, Ukrainian Hryvnia (UAH).

Table 2. Basic example of productivity growth between periods

	Period 1	**Period 2**	**Period 3**
Value of Output (Y)	500 UAH	600 UAH	750 UAH
Value of Inputs (I)	500 UAH	550 UAH	600 UAH
Productivity (Y/I)	1.00	1.09	1.25
Productivity change		+9 per cent	+25 per cent

As illustrated in table 2, productivity, measured as output volume over input volume, has increased from period 1 to period 2, and from period 2 to period 3, where $1 < 2 < 3$. The implication of this simple example is the positive effect of the productivity growth. When productivity level increases in production less inputs are needed to produce an equal amount of output and as such, the resources are used more efficiently. This idea is behind all the productivity calculations. Hence, previous literature has constructed multiple different models in purposes of describing and estimating this relationship as accurately as possible.

Productivity and technical change are driving factors of economic growth because inputs have bounded growth potential in the long run due to limited resources. For instance, at macroeconomic level the labor supply is determined by population and its growth. Traditionally, the most important driving force of economic growth has been an increase in production factors. Capital share in production has increased by help of additional savings (Saari 2000, p. 136), but neither capital nor labor inputs can be increased continuously in the long run, because resources are scarce. Therefore, in the long run, there can't be sustainable economic growth without new innovations and improvement in productivity (Jorgenson 2009, p. 10).

Consequently, the importance of technical change and productivity is significant in economic theories as a main component of economic growth. Solow (1957) showed already in the 1950s that in fact the technical change and the quality of inputs play a more important role in economic growth than increasing the amount of inputs in production (Solow 1957; Saari 2000, p. 137). Modern growth theories are based on this finding and as Jorgenson (2009) states "the economics of productivity remains central to understanding the forces driving world economic growth" (p. 10). Even though the models of economic growth and productivity has been constructed for many decades, economists struggle even nowadays with finding an inclusive explanation to these phenomena. The framework of growth accounting cannot fully separate growth to its fundamental sources and therefore, it remains examining the proximate sources of growth (Bosworth & Collins 2003, p. 3). Theoretical models are only the best possible illustration of economic processes.

Interestingly, productivity growth has slowed down in the last decades in multiple countries (OECD 2008) and there is no clear and detailed understanding of this occurrence. In addition, history has proved that not always the new technology and resource utilization move hand in hand with the measured productivity. Hence, differing from the implications of theories. This phenomenon is called "productivity paradox" and it refers to the mismatch of productivity growth and information technology investments' growth reported in the United States in 1970s and 1980s (Brynjolfsson & Hitt 1998). In addition to the resource utilization, productivity development can be influenced by changing input shares, input qualities or structural changes in production. The challenge, however, is correct measurement of the various input parameters. This study will come back to this problem later. The next section will discuss why it is important to measure productivity and what can be the benefits of the productivity analysis, especially in the case of a firm.

2.3 Importance of productivity

Productivity has been in the core of economic studies for several years and theories have made many implications of why productivity, and especially productivity growth, is important. Dogramaci (1981) points out some main factors why productivity is an essential part of the economy. First, at macroeconomic level, productivity growth guarantees higher standard of living in a long run and it makes possible to produce more output from fixed amount of inputs. When analyzing productivity growth for company, it means lower unit costs of output, better international competitiveness and it can be also seen as inflation controller. (Dogramaci 1981, pp. 2-3) Also, aggregate level productivity has been in the main interest of economists because it influences the rate that economy is capable to produce from its own resources and it denotes average conditions for assessing the comparative performance of particular industrial subunits (Melman 1981, p. 71). In addition, productivity analysis makes possible to identify growth and its main sources (Saari 2006, p. 9). When the sources are identified, it is easier to focus on maintaining the productivity. There are wide range of gains in productivity analysis and each of the models are built up to correspond the certain needs.

Due to these useful elements, aggregate level productivity measures and its theoretical framework is utilized as a basis of multiple important decisions, such as in monetary and fiscal policy. With productivity calculations one can estimate the current state of a business cycle and forecast the future trendline, when compared results with the trend level of economic growth and economic capacity. If nationwide productivity is below its growth trend level, most likely the economy is in a downturn or recession. Furthermore, this theory applies counter-clockwise. If the estimated productivity is above its trend level, the economy can be overloaded and be in its boom. Therefore, in macro-level analysis, productivity can be understood as an indicator of economic performance and its sustainability (Morrison 1993, p. 3).

There has been evidence, especially from emerging economies that during the financial crisis the level of total factor productivity falls under the trend level. Consequently, the inefficiency in the economy rises. (Pratap & Urrutia 2011, p. 336) Therefore, total factor productivity measure is an indicator, alongside Gross Domestic Product (GDP), to determine the economic state, such as depression, of a nation. TFP also plays a key role in defining the main forces causing movements in productivity levels and understanding the effect on real economy of crises (Pratap & Urrutia 2011, p. 336). Pratap and Urrutia (2011) also report that an economy’s total productivity suffers from firms’ lower performance during financial crises, due to their financial constraints, more expensive credit costs and resource misallocation (p. 337). It is crucial to understand the microlevel dynamics and businesses to be able to understand the development process in an entire economy.

Many of the benefits are noticeable in a wider context, but productivity starts from a single firm and its processes. Melman (1981) describes productivity change as “a function of variation in microeconomy” (p. 71). Consequently, productivity measurement is at least as important at microlevel and hence, this study focuses on applying productivity analysis to firm level, analyzing the its benefits and sources with business data. Business level analysis focuses on firm’s production and because aggregation is not done it is rather straightforward to analyze the key inputs driving the enhanced level of productivity.

There are also many objectives in productivity measurement, mostly depending on the level productivity calculation is made. These levels depend on whether the analysis is conducted for firm, industry or country level. Productivity measurement can be a way to trace technical change, to find a profit-maximizing combination of used inputs that are needed to produce certain amount of output, to identify possible cost savings in production or, at aggregate level, to estimate economy's production capacity and measure growth possibilities, or even pressures on inflation (Schreyer 2001, pp. 11-12). This study mainly focuses on the first point, with the objective to analyze technical process and productivity development with economic models.

In the figure below (figure 2) is illustrated the overall dynamics in the economy. The economic growth can be traced down to two main components: to savings and an increase in labor supply and to the use of better technology (Saari 2000, p. 136). These two components are important both in a nation and firm level context. Economy, or a firm, can increase its output level by using more resources. Because more inputs, such as labor force, are used, more output can be attained. However, economic growth is not sustainable in the long run if it relies only on input growth. Resources are scarce and labor force and capital stocks have their limits. This is where the concept of technical change comes into effect. Wei and Liu (2018) point out that especially technical change and productivity plays an important role in economic growth by being one of its sources (p. 1). When new technology and innovations are utilized, it usually becomes possible to produce more from the same amount of inputs, generating economic growth.

This study will provide some deeper analysis of this relation in the context of a single firm and its processes in chapters 4 and 5. The figure 2 illustrates the two growth elements and provides one view on economic growth. One needs to remember that an economy is highly complex and multiple shocks affects its development. Therefore, the figure provides insights only on one economic relation in a plain form. The output growth contributes to economic well-being only if its managed well.

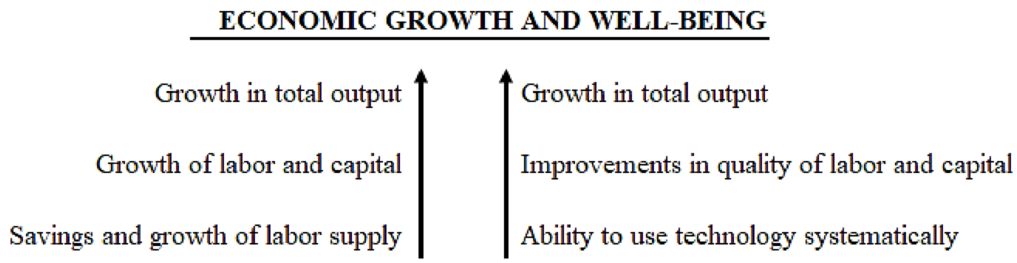

Figure 2. Sources of economic growth and well-being

Even though figure 2 is presented in the context of a nation, the same dynamics is applicable also at micro-level and in a firm’s processes. The output growth is driven by the two sources, increases in input variables and the productivity benefits of better technical solutions. The left side of the figure illustrates the non-productivity side, growth in input supply, and the right-hand side illustrates the effect of productivity gains, which is the focus area of this study. Alongside of these, productivity growth can be due to skilled and educated labor force, which may improve the quality of labor supply. The benefits of productivity analysis are plausible when analyzing economic growth. Both elements, increasing input supply and the better productivity, generate growth in output volume and eventually leading to economic growth on aggregate level. Next, this study will continue with insights in gains in productivity measurement in business and microlevel analysis which, based on OECD manual, enchase the understanding of drivers and dynamics of productivity growth in wider context (Schreyer 2001, p. 120).

2.4 Microeconomic foundations of productivity

Productivity describes overall efficiency of a firm (Craig & Harris 1973, p. 1), and it is continuously influenced by external and internal factors. Macroeconomic conditions and economic trends can affect productivity for example through fluctuating demand, interest rates and rapid inflation. Both higher interest rates and higher inflation can cause increased costs of capital and production expenses. Decreasing demand, on the other hand, causes smaller output volume to which companies fail to adjust production immediately. All these factors have a direct impact on production’s productivity level. Also, internal factors, such as quality of workforce and expenditure on research and development, can cause variation in productivity.

In the 1990s there was a great interest in developing and improving microeconomic-based productivity analysis and applying them to organizations or production plants (Baily, Hulten & Cambell 1992, p. 188). Even though productivity framework can be understood in many different contexts, it is important to understand the difference between productivity at micro- and macrolevel. Dogramaci (1981) explains the linkage from microlevel analysis to a wider context as follows:

“Wide application of changes in the methods and organization of production is the linkage between decision process at the micro level that govern the selection of means of production and the macro effects of average output per worker that are of interest to economists and wider publics.” (p. 72)

The idea is simple. Productivity analysis start from a single firm and the information provided by one firm can be aggregated into industry level analysis and aggregated even further into country level analysis. The latter, country level analysis, is the main interest of central banks and publics. When productivity level increases in a firm, it earns higher revenues due to more efficient input-output relationship, and it ultimately contributes to sustainable growth of business.

For a company, productivity growth, which is based on technological progress, is one of the main sources of competitiveness, profitability and continuous improvement (Maliranta 2003, p. 17). Economic analysis provides tools to identify the development of productivity and its dynamics of a firm. By identifying the productivity levels, production possibilities and production costs, firm can improve its processes and the quality of used inputs. The key concepts in improving quality of inputs is to use a well-educated workforce and to invest in continuous processes in new technologies and implementing new innovations. The long-term adjustments and improvements in the productivity level are stemming from the nature of firm’s processes (Gold 1981, p. 105), which can refer to for example scale of production, efficiency of scale or changes in the input qualities. Better productivity can also be generated by reallocation of input resources from one function to another. These factors, among others, generate productivity growth, or decline, in a long run.

In addition, productivity plays an important role in business management and it influences decision-making. It can be useful for a company to know its short-run and long-run productivity performance. By using this information, a company can analyze whether it was capable of increasing output, relative to used input resources (Davis 1955, p. 35). Long-run productivity trend may also help in understanding whether production has the possibility to increase its productivity. To further support benefits of productivity measurement in a firm level, Melman (1981) explains as follows:

"Productivity is of interest to the managers of enterprise and to trade unions, especially as they seek to escape the limitations of monetary measures for gauging the efficiency of particular aspects of enterprise performance, of sections of manufacturing operations, or of particular work operations" (p. 71).

Above argument provides one explanation on why productivity measurement can be helpful, since it helps companies to quantify the resource efficiency over time. Hannula (2000) supports this claim in his study by pointing out how beneficial productivity measurement can be in improving internal efficiency and competitiveness of a production plant (p. 57). Based on these findings, productivity of an enterprise effects at management-level decision making and it can be a strong tool guiding future process development, but only if the productivity measures are implemented correctly. In addition, productivity measurement in manufacturing should be a long-term indicator of a firm performance. Essentially, productivity analysis enables improving performance of manufacturing processes and gives direction to improvement (Wazed & Ahmed 2008, p. 987).

Previous conditions are just examples of why it is important for companies to understand its own processes and its productivity levels at a given time, especially if it has a target for high productivity levels in production. Furthermore, the importance of management understanding productivity measures and taking right actions based on the implications of the measures are being emphasized (Goshu et al. 2017, p. 9). Good understanding supports the management level decision making. As an outcome, productivity growth measures are designed to reflect best output production possibilities with a given amount of inputs (Morrison 1993, p. 8). When firm understands the link between its previous production development and change in productivity, it becomes easier to analyze the best possible input-output combinations.

Even though the highest achievable productivity growth is in firm’s interests, it is inevitable that productivity levels fluctuate even within one production plant, based on the production decisions and demand conditions. Morrison (1993) describes that one reason for unstable productivity is the nature of the firms. Firms adjust slowly to the changes in the economy or market conditions (p. 22). Demand for firm’s goods is not always stable and input prices, such as capital costs, increase over time. Pratap and Urrutia (2012) show in their study that financial frictions, market and interest rate shocks can easily generate drops in productivity level (p. 337). To support these arguments, in recent years there has been an empirical evidence for slowdown of productivity growth of firms operating in developed countries (Cette et al. 2018, p. 76; Bournakis & Mallick 2018, p. 579). This is partly because of growing dispersion of productivity between firms and multiple shocks that firms need to deal with. (Cette et al. 2018, p. 76) These shocks can include for example changes in world politics, shocks in demand and so forth.

The above findings become interesting in the empirical part of the study, since the case plant is located in Ukraine, where both inflation and interest rate set by the central bank have been fluctuating heavily due to the Ukrainian crisis, which started in 2014. During that time production was reorganized and moved elsewhere because of increased operating risks. Further analysis of the Ukraine’s case and possible external shocks and their possible consequences to plant’s productivity will be provided later in this study.

Productivity needs to be highlighted even more nowadays, because the competition in many industries is getting tougher (Rawat, Gupta & Juneja 2016, p. 1483) and firms need to find sustainable solutions for profitable business, where all the resources are used as efficiently as possible. Especially in the long run it is essential for a firm to maintain and improve its relative productivity to survive the competition and to keep the business profitable. Referring to the various arguments explained above, it is crucial for a firm to adapt productivity measurement as part of their business activities and analysis and use it as a supporting factor in planning and controlling. This can help in efficiency improvements and input reorganizations within the firm by strengthening the understanding of investment requirements or changes in costs through productivity analysis.

Moreover, one feature of a firm is the interest of satisfying the needs to the maximum with minimal sacrifices (Saari 2006, p. 1). This refers to producing as much as possible with minimum inputs. At its core, also productivity analysis is built on this assumption. The firm's productivity is on a higher level the more it can produce output utilizing minimum inputs, and this is where firm aims to. However, even though changes in firm's relative productivity is a key determinant of firm's competitive position in the market it is difficult to detect without detailed analysis. For further assessment of the firm's feasible input-output combinations, the detailed explanation of production process and its dynamics are needed. The next chapter will provide information of the firm's production system and its development throughout changes happening in production technology and shifts in the production possibilities.

2.5 Technical change

The term technical change has been referred to many times in previous studies of economics of productivity and will be used frequently in this study, too. Solow (1957) was one of the first to study technical change in the context of productivity and aggregate production function. Based on his study, technical change is something that causes growth in output per capita and it can be separated from growing amounts of used capita inputs. (Solow 1957) Technical change can be related to new innovations, usually defined as new and more efficient ways of turning inputs into outputs, which has contribution to productivity improvements. Innovations help the progress of better output-input ratio, hence the better productivity, which is generated via new machinery or technology, for example.

The available technology defines input-output dynamics and therefore the micro-level analysis of productivity is heavily influenced by firm's technological choices and by how efficiently firm uses this technology (Maliranta 2003, p. 25). These technological choices can be called generally technical change, which reflects the level of technology and its development in a firm. In addition, technical change refers to qualitative improvements in input parameters, such as physical capital, which eventually lead to growth in productivity. For example, Solow (1957) has theorized that any kind of technical progress influences productivity growth (Solow 1957). The phenomena of productivity and technical change are integrated to each other, but the difference between economic productivity and technical change has been defined for example by Davis (1955):

"It has been suggested that in national productivity analysis the measure which includes the effects of shifts to different valued output should be called "economic productivity" and that which eliminates the effects of shifts and deals with resource efficiency per se should be called "technical efficiency"." (p. 35)

The above definition suggests that productivity can be linked to the output growth itself, while the technical change is something that effects resource efficiency and works as a tool for reaching better productivity levels in production. In the context of a production function, which is defined later in this study, technical change can be appeared in a form of a speedup or slowdown of a production function or as an improvement in labor force. (Solow 1957, p. 312) Hence, the technical change represents all the qualitative improvements, which trigger the productivity growth in a production.

Technical change can be derived from new equipment in production, more educated workforce or better efficiency in organizational processes, to name a few (Saari 2000, p. 137). Therefore, the technical change is not always influenced by technology itself, but also organizational aspects and internal shocks. Fraumeni and Jorgenson (1981), on the other hand, define the technical change as "rate of growth of output, holding all inputs fixed" and it reflects the reallocations of output and inputs, capturing the changes in production technologies (p. 50). In this sense the technical change and productivity refers to the same phenomenon. In addition to these, new innovations and better technology can cause technical change via more efficient input utilization.

Generally, the technical change is caused by better technology or new innovations in production. These cause shifts in a firm's production function and affect the production possibilities. Gold (1981) concludes that "technological changes should be seen as a bigger concept than just something affecting the quantities of inputs and outputs" (p. 97). The relationship between productivity and technical change will be emphasized even more in the future due to developing technological solutions, which make the technological changes and more efficient production possible. In addition, globalization creates constantly new opportunities for utilization of information technology (Jorgenson 2009, p. 10), which boosts productivity growth both at firm and national economy level.

Technical change has multiple positive aspects. Innovations, which can be perceived as a productivity-improving manner, usually leads to the reduction of total unit costs and prices and also, they tend to increase profitability in the short or in the long-run (Gold 1981, p.

112). “Technical change will cause both productivity and capacity utilization to change in the short run” (Morrison 1993, p. 12). This argument is supported by Brynjolfsson and Hitt (2003), who have found empirical evidence using firm-level data that in the long-run new technology and information technology contribute to total factor productivity growth. In short-run, on the other hand, new computers and technology tend to affect only output growth positively, not productivity itself. (p. 794) This is one reason why in some studies economic growth and productivity growth has been modelled considering also research and development (R&D) expenditure in the economy.

Already in 1957, Solow (1957) found empirical evidence from USA markets, supporting the technical change on aggregate level. During the years 1909-1949 the increase in production function can be traced down to two components. One-eighth of the total increase was because of increased share of capital per men hour and the rest, seven eighths, were accomplished due to technical change during that period. (Solow 1957, p. 316) Yet, one should bear in mind that the of capital and technical change are connected to each other and it is possible that the notable benefits from technical change would not have been possible without the increased capital inputs at the same time. However, the conclusion of the finding is inevitable. The increase in output per man hour was generated almost fully by technical change. Therefore, productivity analysis and the gains of productivity growth have been in the spotlight of economists for many years.

Technical change can have different kinds of characteristics. The most common approach is to assume Hicks-neutral technical change where the technical change does not affect marginal rates of substitution (MRS) between used inputs, only the amount of attainable output with these inputs (Solow 1957, p. 312). In addition, neutral change affects each input variable’s marginal productivities in same proportion (Raval 2010, p. 1). Marginal rate of substitution refers to the shares of different inputs used in production. When MRS remains untouched the increases or decreases are symmetrical in all the input variables. Other possibility is that the technical change has bigger impact on one input variable than to others. One can conclude that no matter which type technical change, as long as it is positive, it leads to better productivity level in a company. Therefore, it is heavily linked to productivity analysis and some studies have used technical change as a synonym for productivity.

The following figure represent characteristics of technical change in a graphical form and its contribution to the production process and output growth. The study will come back to the concept of technical change in the next chapter, in which technical change is integrated with a firm's production function and production possibilities.

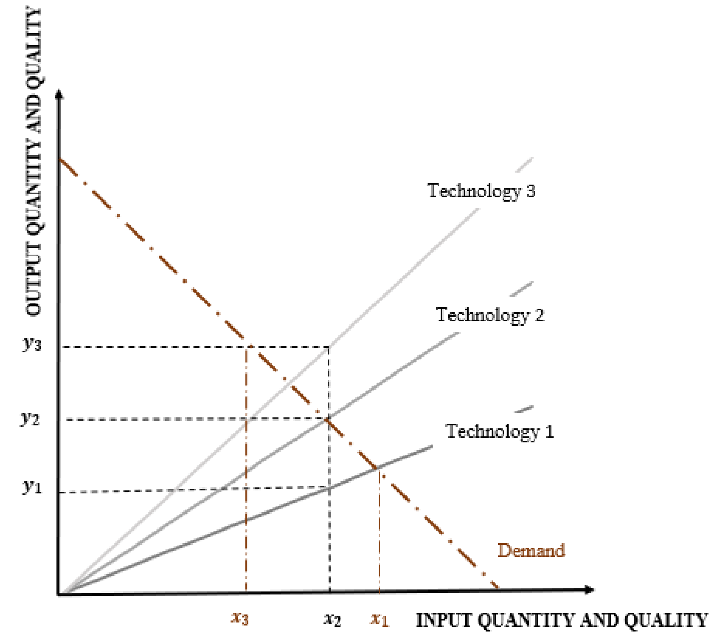

Figure 3. The quantity and quality of production illustrated as shifts in a supply function

Figure 3 presents the production possibilities of a firm with different levels of technology.[2] These production possibilities are presented by upward sloping supply functions. Here x represents the amount of inputs used and y achievable level of output from these inputs. The interpretation of the figure can be divided into two parts. First, one can analyze what happens to the output volume when only the technology changes and all the other factors, demand and input volume, stay constant. Now the output volume is increasing with the technology level. As visualized in the figure, technology 1 enables output value of y_1 with input x_2. In the same way, technology 2 provides output quantity of y_2 and finally, technology 3 makes volume y_3 possible. Clearly, $y_1 < y_2 < y_3$, which represents one of the main qualities of a technical change. Higher level of technology and better quality of inputs, such as workforce, enables firms to produce more output from a fixed amount of inputs. It is in the interest of a firm to introduce new technological solutions and reorganize production in a new innovative manner, because they make the long-run cost savings possible, improve productivity and they may be a source of a competitive advantage.

[2] All the graphic illustrations shown in this study are considered *Ceteris paribus*. In economics, this means all the other things being unchanged so that "when calculating an impact of one variable all other variables are hold constant" (Saari 2006, p. 7).

An alternative interpretation of the figure takes place, when the production function and changing technology are combined with the downward sloping market demand. Now the demand is kept constant, but supply is allowed to change with respect to the technology level and input usage. The input volume needed is fully determined by the demand and the technology. As noticed from the figure 3, when the input usage and the output production are adjusted to match the demand and technology, the better the technology is available, the less input factors are needed in production, since $x_3 < x_2 < x_1$.

The above intuitions reflect the positive effects of increased technical capabilities and productivity change. They generate cost efficiency. To analyze technical change and productivity, and to get contribution of these in a firm, one needs to build up an analytical framework, which allows for productivity measurement. This kind of framework will be built in the next section.

3 Productivity measurement in economics

3.1 Theory of the firm and production function

It is important for quantitative economic analysis to understand the relationship between output and inputs in manufacturing. In addition, to better understand microlevel interpretation of productivity analysis one needs to know the basic ideology behind a firm. For this reason, a production function, which is an essential part of economic theories, needs to be identified (Goshu et al. 2017, p. 8). This chapter will provide an analysis of firm´s processes and the dynamics of productivity for a good producing firm. We start of by defining the firm's business process to get an overview of the key concepts required for the analysis. Saari (2006) defines firm's business process as follows:

"Production is a process of combining various immaterial and material inputs of production so as to produce tools for consumption. The way of combining the inputs of production in the process of making output is called technology. Technology can be depicted mathematically by the production function which describes the function between input and output. The production function is the measure of production performance." (p. 2)

This states the relation between business process, production function, and technology, which are the main concepts of firm productivity analysis. The business process constitutes producing goods from a certain amount of inputs for which a certain level of technology is utilized. Production function, on the other hand, combines all the relevant components, such as labor and capital, of a business process and defines the amount of output which a firm can produce from production inputs with its current level of technology. The production function states the best combination of various inputs to maximize profits. The function can be presented in a mathematical form and therefore it becomes very useful in productivity analysis and quantifying the productivity growth.

Best achievable productivity level of a firm can be understood as a company's level of potential output, keeping inputs constant. Both the potential output and the given factors of input determine the firm's production function. In other words, a production function combines the state of technology and maximum amount of output possible with given inputs. When combined with the term productivity, productivity growth means a shift in production function, so that "more production is technically possible from the available amount of inputs" (Morrison 1993, p. 9). Businesses tries to obtain the highest productivity level possible with a given level of technology, so that production of one good cannot be better off without reducing another good's production. High productivity, cost minimizing, profit maximization and firm's efficiency identify as the main principles of microeconomics.

Given this information, the productivity measurement starts with a production function. Subsequently, the production function will be combined with parameter A, which represents the process of a technical change (Schreyer 2001, p. 25). The maximum feasible level of output to produce with a fixed amount of inputs is determined by combining the production function and technical change (Schreyer 2001, p. 25). Production function is widely utilized also in a wider context, for example describing and analyzing the simplified mechanism of economic growth (Saari 2000, p. 137). Since the production function illustrates the level of available technology, and hence determines viable input-output combinations, it forms a basis for business level productivity analysis. Saari (2006) concludes that "if the model can describe the production function it is applicable to total factor productivity measurements" (p. 7). Therefore, the properties of a production function will be identified next.

In the economic theory, a firm minimizes its costs subject to its cost function $C(x)$ and to its production constraints, defined by a production function $F(x)$. To start with the mathematical definition of production function let's assume that firm produces output Y, using technology A and labor and capital inputs, L and K, respectively. All these components can be combined in the production function, which corresponds to the properties of production. A production function shows in a simplified manner the maximum output a firm can produce using alternative combinations of inputs. Using the above information, it becomes possible to combine the production components in a functional form. The core of the production function, which combines the primary input capital and labor, can be written as (Solow 1957, p. 312; Bournakis & Mallick 2018, p. 580):

$$Y = F(K, L, t) \qquad (1)$$

Where t is a time index and $F(\cdot)$ is the function of technology. The above equation represents the neoclassical production function, and output is the function of labor and capital. Time index variable is included into the model because it makes technical change and variations in the model parameters possible (Solow 1957, p. 312). The function parameter $F(\cdot)$ combines the needed inputs in an appropriate manner to produce output and therefore it stands for production technologies available.

The equation 1 states that for producing amount of Y output one needs contribution of K and L with proportions identified by function properties. In addition, a firm minimizes its input costs subject to the production technology stated by the production function (Schreyer 2001, p. 129). Consequently, resources will not be wasted since they are used efficiently. In the markets of a perfect competition the firm faces downward sloping demand curve and the profits (π) of a firm equal to zero on every period. The profits can be stated as $\pi_t = Y_t - F(K, L, t) = 0$, where the function $F(\cdot)$ defines the production costs.

Because this study is focusing on productivity levels and technical change, one needs to include these technical changes into the model by use of an additional parameter. This technical change is identified as $A(t)$. With the help of this technology parameter the production function is identified as follows (Schreyer 2001, p. 25; Solow 1957, p. 312; Maliranta 2003, p. 43; Palia & Lichtenberg 1999, p. 327):

$$Y = A(t)F(K, L) \qquad (2)$$

Changes in factor $A(t)$ can be driven by input factors, changes in technology, learning by doing or for example resesarch and development expenditure. More specifically, Solow (1957) concludes that A(t) “measures the cumulated effect of shifts in production function over time” (p. 312). By modifying equation 2 one can calculate the level of productivity at time t, which is the ratio of output over inputs used. The following equation is paramount to this study, since it indicates productivity level.

$$A(t) = \frac{Y_t}{F(K,L,t)} \qquad (3)$$

In equation 3, it become clear that that the technical change gets a positive value only if the output is greater than the term $F(K, L, t)$. This means that productivity change will be positive if the firm is capable of producing at period t a greater volume of output than it was capable of producing in period $(t - 1)$, while using a consistent volume of input variables. Otherwise the technical change is negative and will decrease the level of output. Every firm aims for ascending productivity levels since this makes the business cost-effective in the long run.

The production function, which combines capital and labor inputs, can be presented graphically with the help of isoquants (figure 4). Isoquants are an illustrative way of analyzing all possible combinations of inputs (K and L) that could be used to produce output Y, given the fixed level of technology (Morrison 1993, p. 9). However, when changes in technology and productivity occur new and better technology lead to an inward shift of the isoquant, hence making it possible to produce output Y with less inputs. In the following figure, every isoquant stands for a production function's frontier, which represents all possible combinations of capital and labor that could be potentially used for producing a given amount of output. Technological shifts, on the other hand, are illustrated by shifts of these isoquants. When an increase in the level of technology occurs the isoquant moves inwards towards the origin (Morrison 1993, pp. 9-10). The process is visualized in the following figure.

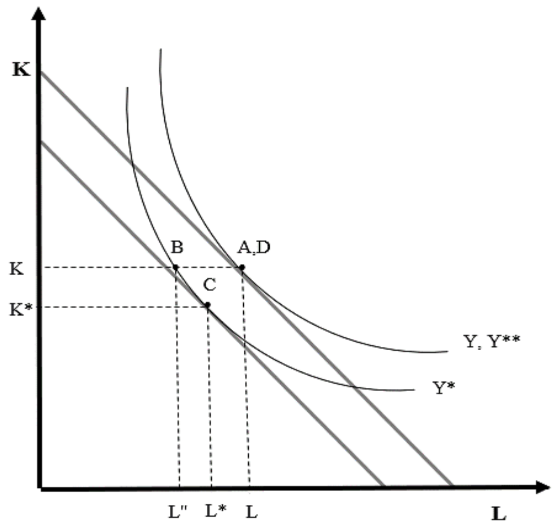

Figure 4. Productivity growth displayed as shifts of isoquants

The interpretation of figure 4 is the following. At period 1 firm produces amount Y of output, using amount L and K inputs. In the following period a positive technological change takes place and the isoquant moves inwards to the point where output is represented by Y^*. Now the firm can produce the same level of output with less inputs, because here $Y = Y^*$ and $L > L^*$ and $K > K^*$. After the technical change, if the firm wants to produce more output, level Y^{**}, it needs to increase the level of capital and labor to the levels of L and K. Now the firm can produce more output with the same amount of inputs, due to the favorable technical change. In the figure, point L'' represent one feasible capital-labor combination for producing level of Y^* output. Simple production function presented in figure 4 assumes constant returns to scale, which may not hold in real life (Baily et al. 1992, p. 199).

Differences between plants can be, to a certain extent, explained by different scales and qualities of production. Especially in old and big manufacturing plants there is an empirical evidence of increasing returns to scale (Baily et al. 1992, p. 199). This means that due to learning and bigger volumes, production can get cheaper per inputs used when volume level increases.

Based on the study conducted by Saari (2006), economic growth, or output growth, can be divided into two sources: an increase in input volume and an increase in productivity. This relation was illustrated earlier in figure 2 and now the following figure supports the same process in a graphical manner. Output growth, caused by an increase in amount of inputs used, can be quantified by moving along the curve of a production function. Productivity growth, on the other hand, shifts the production function itself to a higher level. (Saari 2006, p. 2) In figure 5, the x-axis stands for input volume utilized in production and the y-axis stands for volume of output produced. The difference $y_3 - y_2$ represents the output growth generated by improved productivity and is highlighted since this is the focus area of this study.

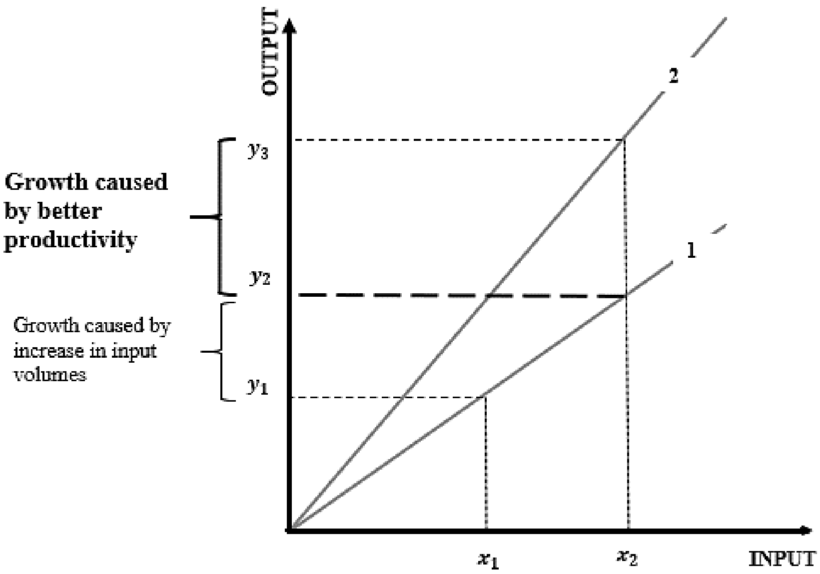

Figure 5. Components of output growth

In figure 5 the relation between the production possibilities and the productivity gains are illustrated. Lines 1 and 2 represent the production function, or the frontiers of production possibilities, at the periods 1 and 2 $(1 < 2)$. At the first period, the production possibilities are defined by line 1. Based on the production function and available technology at time 1, a firm can produce output y_1 with x_1 amount of inputs, or correspondingly output y_2 with inputs x_2 . The growth in output volume $(y_2 - y_1)$ is now caused by an increase in input volume.

Line 2 represents the next period’s increased production possibilities, as a consequence of favorable technical change leading to productivity growth and a shift in the production function. The area $(y_1 - y_2)$ still equals the growth in output due to an increase in inputs used. The upper part in output volume growth $(y_3 - y_2)$, nevertheless, is caused by growth in productivity, because the production function shifts upwards and enables bigger output volumes with same amount of inputs. Hence, the same resources are used more efficiently in production. In the analysis attention must be given to the following: a production function´s input and output can never be negative. Therefore, the axes have values only above zero levels. In addition, it is assumed that the increase in any input variable increases the total costs and therefore decreases level of productivity, ceteris paribus.

One important assumption related to the production function is that labor and capital factors are paid relative to their marginal products (Solow 1957, pp. 312-313). This relation applies to all input parameters that firms use in production. In practice this means that for example less productive workers are paid less than more productive ones. When input factors, such as workers, are paid relative to their marginal products, firms can minimize its costs and become efficient. Based on this assumption, firms’ production moves alongside the production function’s curve and the firm uses only feasible input-output combinations as stipulated by the function.

For simplistic purposes it is common to analyze a neutral production function, like the one shown above. Neutral production function means that when different shifts happen in the function the marginal rates of substitution between components stay untouched, and only the output changes (Solow 1957, p. 312). However, it is also possible that the production function takes different forms than the linear version presented in figure 5. Figure 6 demonstrates the difference between a neutral and non-neutral production function, where marginal rate of substitution is not constant over time. Figure 6 presents production function of a firm with diminishing returns to scale of production.

At some point, when amount of input has increased constantly, production comes to a point where the output is insufficiently affected by the input increase in a positive manner. At micro-level both constant returns to scale and diminishing returns to scale for the input parameters can be present (Maliranta 2003, p. 47) However, in both cases, the level of technology and therefore productivity is dependent on aggregate stock of separate inputs. The production possibilities are now presented as curves, illustrating that when input volumes grow relatively less output is produced.

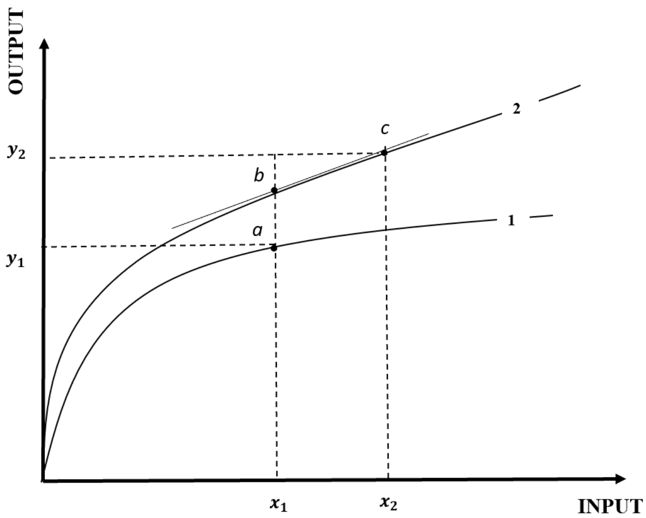

Figure 6. Shifts in production function

Solow (1957) explains the implication of figure 6. After the shift in the production function, it is problematic to estimate the shifts from point a to point c. Because one cannot fit a curve straight from observed points, the technical change and therefore the production function can be estimated with estimating the shift factor and approximating the curve by its tangent at point c or a, depending on the period (p. 313). The line going through points b and c describes the marginal product of input. In the end, the purpose is to "isolate shifts of the production function from movements along it" (Solow 1957, p. 313), which is the main task of productivity analysis. While the movements along the function represents adjustments in production function parameters, the shift represents the technical change.

The productivity models discussed later in this study considers, for simplicity, only neutral shifts in the production function since the marginal rates of substitution of the input parameters are kept constant. This approach fits well with the assumptions of the Cobb-Douglas production function, which will be defined in the next section together with presenting the key models in productivity measurement.

3.2 Measuring productivity

The purpose of the productivity measurement is to come up with a quantified value for productivity at any given time, and based on the measurement, increasing productivity level by better resource utilization (Goshu et al. 2017, p. 1). Productivity measurement also helps in improving firm’s performance by identifying productivity changes and making possible improvements based on these results (Wazed & Ahmed 2008, p. 987). Even though the models discussed in this study are developed for multi-purposes, the models serving purposes of a single firm only, are scarce in the existing literature. Therefore, the used models are modified to match the objectives of this study. There are wide range of perspectives in productivity analysis and the biggest differences are related to measuring capital, the variables included into analysis, choice of the functional form, and deflating method (Dogramaci 1981, pp. 16-17). Even though productivity and technical change are, and have been, in the interest of economists in recent years, its measurement is not unambiguous.

Business level productivity models help to get more accurate productivity estimates than on aggregate level. The main reason is that the data of a single business is more detailed, and hence it can be better utilized. (Saari 2006, p. 7) Because the data differs among firms and since each firm is unique, the challenge in an empirical study of productivity analysis is to obtain solid measures for total productivity at level of a single firm (Bournakis & Mallick 2018, p. 579). There are multiple models developed for productivity analysis purposes, but because testing all models available with the case data is time unfeasible this study will focus only on the most widely used model.

The best model for measuring productivity highly depends on the purpose of the measurement and what are the goals that one wants to achieve with it. Also, availability of data must be considered. (Schreyer 2001, p. 12; Bournakis & Mallick 2018, p. 579) However, many firms find it impractical to include many variables into the analysis. As a result, the benefits of productivity analysis are incomplete and decision making can be influenced negatively. After all, the correct measure depends on the level of analysis and on the purpose for which it is used.

The table below (table 3) classifies four types of productivity measures based on the input factors which are included into this study´s model. The first two, labor and capital productivities, represent single factor productivities where productivity is calculated relative to only one key element of production. This single factor productivity is the purest form of productivity calculation. The third, total factor productivity, considers two main variables in the measurement. The last one, total productivity, is the most comprehensive measure of productivity since it takes into consideration not only labor and capital, but also intermediate inputs, such as energy or materials. All the types of measures can be applied from single firm to nation level analysis.

Table 3. List of widely used productivity measures

Measurement tool	Variables included	Level of analysis
Labor productivity	Output (Y), labor (L)	Firm/industry/nation
Capital productivity	Output (Y), capital (K)	Firm/industry/nation
Total Factor Productivity (TFP)	Output (Y), labor (L), capital (K)	Firm/industry/nation
Total Productivity	Output (Y), labor (L), capital (K) and intermediate inputs (X)	Firm/industry/nation

The productivity measures introduced in table 3 can be applied both to the production function method or dividing output by the sum of corresponding inputs. However, what is common to all productivity measures and calculation methods, they are defined as output relative to inputs. Therefore, the general idea of productivity measure is presented as output over inputs, and it can be formulated accordingly (Saari 2006, p. 2, Rawat et al. 2016, p. 1486; Cobbold 2003, p. 1; Hannula 2000, p. 65):

$$P = \frac{Y}{I} \qquad (4)$$

Where P is productivity, Y is output and I indicates input factors. Here P represents productivity, which is also referred to as Solow residual and it cannot be explained by contribution of inputs, only by productivity gains. Equation 4 states the exact same relation as presented in in equation 3, when $I = F(\cdot)$ and $A(t) = P$. All the measurement tools considered in this study will satisfy the condition represented in equation 4. Hannula (2000) points out that the most common way of productivity in economic literature is measured in ratio output changes over inputs changes (p. 59). This argument is supported by a wide range of economic studies, for example by Morrison (1993), who estimates the productivity as change in output per input ratio over time, not as a rate of growth of output itself (p. 17). More detailed description of input and output variables will be provided later in this study and the next part of the study will start with constructing the full model for the analysis.

3.3 Defining the productivity model

This study has pointed out the main principles of productivity analysis and the idea was summarized in equation 4. In the previous studies, the most common and acknowledged tool in the productivity analysis is the production function of a firm, as shown in table 1. Production function adjusts to firm's production processes and it is a handy tool for combining all relevant inputs in an appropriate manner. Hence, this study uses production function in productivity estimation.

The model is constructed by defining the formula for the supply side through the CES production function. This function assumes constant elasticity of substitution, and it is a general form of three different types of production functions: Cobb-Douglas, Leontief and linear production functions. The transformation of the production function to these three categories depends on the degree of elasticity of substitution between model parameters. The elasticity of substitution measures how much a firm adjusts its capital intensity, for instance, when the factor prices change (Raval 2010, p. 2). The CES production function can be presented as:

$$Y = A(\propto L^{\frac{\sigma-1}{\sigma}} + \beta K^{\frac{\sigma-1}{\sigma}})^{\frac{\sigma}{\sigma-1}}$$

Where A is the Hicks-neutral productivity and σ is the elasticity of substitution parameter between model parameters labor and capital (Raval 2010, p. 9). The value for the elasticity of substitution varies according to the data set. This study is in line with the majority of productivity studies and assumes that the substitution σ convergences to value 1, which means that the term $\frac{\sigma-1}{\sigma}$ approaches zero. With this assumption, the CES production function transforms to the Cobb-Douglas production function. Moreover, the factor input shares are assumed to stay constant over time, since the input components are not perfect substitutes for each other. This study assumes the Cobb-Douglas production function to reflect appropriately a firm's technology. In addition, application of the Cobb-Doulas production function, both at micro- and macrolevel, receives strong empirical support in the previous studies.

The Cobb-Douglas production function, which will be identified in this section, allows a mathematical identification of the productivity level with a constant link to the firm's processes. (Maliranta 2003, p. 43) However, the Cobb-Douglas production function assumes constant returns to scale. This means that when the volume of inputs increases the effect on the output growth stays constant. In practice, if one person can produce one item of output, based on the Cobb-Douglas production function, two persons can produce two items of output. In addition, technical change and productivity affects the input parameters in an equal manner and therefore it can be described as Hicks-neutral. Hence any positive technical change results in an outward shift in the production function. These assumptions can be mispresenting reality, but they make the productivity analysis easier.

The Cobb-Douglas production function can be derived with the help of a basic production function, in the form of $Y = A(t) * F(K, L)$, and by help of equation 4. By replacing the sum of inputs I with the function $F(\cdot)$, and solving the output Y, the production function takes the form of:

The Cobb-Douglas production function $$Y = AL^{\alpha}K^{(1-\propto)} \qquad (5)$$

The above formation represents the Cobb-Douglas production function in the case of two-input production system. By removing or adding elements into the model, one can derive different kinds of productivity models. When more input variables are included into the model it satisfies the conditions of a more complicated production process. As a drawback, however, the empirical estimation gets more complicated. This study will provide more discussion about the estimation in chapter 5.

In equation 5, Y stands for output, A represents the technical process, L is the labor input, K is the capital input and $\propto$ and $1-\propto$ are the substitution parameters. The traditional form of the Cobb-Douglas production function assumes perfect competition and zero profits. Perfect competition in the market leads to better efficiency of resource usage in production and a good productivity of a firm can be due to the competitive pressure in the markets (Maliranta 2003, p. 27). Therefore, the inputs' relative shares $\propto$ and $(1-\propto)$ must add up to one, while satisfying the condition of $\propto < 1$. Since the parameters are valued at less than one, the input parameters are not full substitutes for each other. This indicating that over a short period of time, even when the output fluctuates, the input parameters are held rather constant because of the adjustment costs. Since this study's main interest lays in the parameter A, it is possible to rearrange the above equation 5 to yield the productivity level at time t as follows:

$$A_t = \frac{Y_t}{{L_t}^{\alpha}{K_t}^{(1-\propto)}}. \qquad (6)$$

Equation 6 is an important part of the analysis and in understanding the underlying factors behind productivity. The technological term A_t, being part of the above equation, can be justified in many ways. It allows change to the efficiency levels, reductions in the unit costs of inputs, and changes in the production structures. However, the parameter representing technology cannot be observed directly, but it can be calculated by help of other variables. This is the key assumption of this study. When the other model variables are identified estimating the productivity dynamics in the production process becomes possible.

The Cobb-Douglas production function, as shown above, presents the output as a combination of production inputs, where certain inputs can be substituted by others till a certain limit (Palia & Lichtenberg 1999, p. 328). One of the advantages of this production function is its simple form and it is easy to represent with a logarithmic transformation (Solow 1957). In addition, Solow (1957) discovered in the 1950s that the Cobb-Douglas production function is a sufficiently accurate model for productivity estimation (p. 319). Based on these findings, the Cobb-Douglas production function has been used widely in economics, for example, as a basis of growth accounting theories in macroeconomics.

Equations 5 and 6 conclude the main production function dynamics and input-output relations. However, for the estimation purposes equation 6 will be further modified. This study is interested in the change in the productivity parameter so one should differentiate the above equation with respect to time. To realize this, the Cobb-Douglas production function needs to be converted into a logarithmic form, after which time variations can be applied. In economics, logarithmic transformations are widely supported due to its properties and calculation rules, which make the model manipulation and the estimation process easier. Therefore, with the logarithmic transformation equation 6 can be written as: $lnA_t = lnY_t - \propto lnL_t - (1-\propto) lnK_t$.[3]

To yield the productivity growth rate the above relation needs to be presented in periodic changes. Consequently, the total productivity growth equals the difference between the rate of growth of logarithmic value of output and logarithmic value of inputs $(lnY_t - lnY_{t-1}) - (lnI_t - lnI_{t-1})$. The different time periods have been noted with parameter t, which gets values of $t \mp n$, where n represents the number of periods. For instance, if the current period is t, then the previous period gets value $t-1$. Based on the information given in equation 4 the periodic change in total productivity, $\Delta a_t = [\mathrm{lnA_t} - \mathrm{lnA_{t-1}}]$, can be presented in logarithmic derivatives as follows:

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[3] $ln\frac{y}{x} = \ln(y) - \ln(x)\,; \ln(yx) = \ln(y) + \ln(x)$

Change in productivity

$$\Delta a_t = [lnA_t - lnA_{t-1}] = [lnY_t - lnY_{t-1}] - s_{I_i}[lnI_{i,t} - lnI_{i,t-1}]^4 \qquad (7)$$

Where $[\mathrm{lnY_t} - \mathrm{lnY_{t-1}}]$ is the output change from period $t-1$ to period t, s_{I_i} is input i's rate of substitution, and $[\mathrm{lnI_t} - \mathrm{lnI_{t-1}}]$ is the change rate of the input i with respect to time t. This indicates that the rate of productivity growth equals the rate of growth in output minus a weighted average of the rates of growth for one or multiple inputs. The equation is applicable irrespective of the amount of input parameters included in the model. The model shows how much productivity changed between two periods, from period $t-1$ to period t, based on the changes in output and inputs during the equivalent times (Schreyer 2001, p. 25). The time differences will also become helpful in the estimation process, since they stabilize the time series over time and the series fluctuate around the mean value. The values will not diverge and hence make the use of econometric techniques possible.

One should note that the productivity change can be positive or negative, depending on the output growth and the input usage. If output volume was greater at period $t-1$ than at current period t, the change rate in output gets a negative value together with productivity, if the input volume stays constant. On the other hand, if both input and output volumes decrease with the same rate between the periods, the productivity level stays untouched. In the short-run when output fluctuation is heavy, it can be normal that the productivity rate gets a negative value. This indicates technical regress, which can occur due to reorganizations in the production or due to new investments. Even though these structural changes of production can negatively affect the short-run productivity growth they tend to lead to higher productivity growth rates in the long run.

The general expression for quantifying the rate of productivity growth is presented in equation 7. If the productivity analysis follows the traditional Cobb-Douglas production function, the model includes two of the key production variables and it can be called total factor productivity model. Growth rate of the logarithmic total factor productivity Δlna_t can now be defined as:

$$\Delta lna_t = \Delta lnY_t - \alpha\Delta lnL_t - (1-\propto)\Delta lnK_t \qquad (8)$$

[4] The same relation, to yield change rates to any given period, can be presented as $\frac{d\ lnA}{d\ t} = \frac{d\ lnY}{d\ t} - \mathrm{s_{I_i}}\frac{d\ lnI_i}{d\ t}$. Generally, this can be noted as $\Delta a = \Delta y - \mathrm{s_{I_i}}\Delta i$.

Translog production function is presented in equation 8 and it is one of the most popular measures for productivity. Equivalently, the relation can be expressed in terms of change in output as $\Delta lnY_t = \propto \Delta lnL_t + (1{-}\propto)\Delta lnK_t + \Delta lna_{\,t}$.

All the factors presented in equations 7-8 are measured as logarithmic growth rates and the difference is denoted with the symbol Δ.[5] Consequently, the productivity is also presented as logarithmic growth rates per period. The main contribution of the above equation is that the productivity change can be calculated as a residual term from the changes in output and the changes in weighted inputs. In other words, productivity is the remaining factor in the production and it explains the rest of the output change, which is not generated using any of the inputs. The relationship holds in all the productivity measures and it will be utilized also in the estimation process of this study. The next section will introduce two specific cases of the productivity measures, which are defined by the primary inputs.

3.4 Single factor productivity

Single factor productivity is an example of a partial productivity measure and it is calculated as a ratio between the output and only one input parameter. Therefore, it does not consider the full production process and reflects only partially the performance of the production. Despite this, single factor productivity measures can be very useful indicators of productivity for a firm, especially when used together with other productivity measures.

The most typical version of a single factor productivity measure is the output relative to labor input. Hence, it is identified as labor productivity (Saari 2006, pp. 4, 6). Another important single factor measure is the capital productivity, in which the productivity is a ratio between output and capital input, such as machine costs. When construing this kind of partial productivity measures, one needs to remember that they cannot satisfy all objectives and benefits of the productivity measurement at firm level (Goshu et al. 2017, p. 10). This claim is justified, since the single factor productivity measures ignore any other key variables of production.

The following table (table 4) compares typical properties of labor and capital productivity measures. Both components are strictly linked to firm's production and are a crucial part of

[5] Deriving the change rate Δ is a straightforward process. In the case of output variable, the periodic change rate can be calculated as following: $\Delta lnY = lnY_t - lnY_{t-1}$, where change in output is defined as the difference between output levels in period t and previous period $t-1$.

the daily processes. However, the measurement of these variables is not always straightforward. Table 4 simplifies the key differences of these main production function components.

Table 4. Measuring labor and capital inputs

	Variable	
	Labor input	**Capital input**
Measurement object	Human capital	Physical capital
Quantity	Labor services used in production	Capital services used in production
Price	-	Compensation of capital per unit of capital service
Contribution into the model	Hours or quantity of labor force	User costs * productive capital services

Schreyer (2001) has listed the main qualities and differences between the labor and capital inputs and the results are presented in table 4. The biggest differences are identified on the first row; the labor input is calculated as human capital used in production, while the capital input is measured in terms of physical capital, such as machines. However, the OECD manual suggests that the different qualities of labor input should be considered in the analysis. (Schreyer 2001, p. 51) This means differentiating labor force between skilled and unskilled workers, based on their respective marginal productivities. This study, however, will exclude this from the analysis, because it's not in the main interest of this study.

Ideally, capital input would be measured as explained in table 4, as used machine hours multiplied by their hourly compensation. However, usually this type of data is not available at firm level. Instead, the depreciation rates of the machines and the value of new investments are used as proxies for the productive capital input.[6] The measurement of labor input, on the other hand, is quite unambiguous and it can be measured as labor hours or as quantity of labor force. As a result, a measure is derived which represents how much one person or one hour worked has contributed to the overall output volume. By following the fluctuations of this measure one can analyze the labor efficiency over time. Even though both worked hours and labor force are equally valid measures, they might result in different productivity levels over time. The main reason for this is that the hours worked are easier adjusted to reflect the actual output volume than the number of people employed. Usually during recessions firms cut down on hours first, not on the labor force itself.

[6] This method will be used also in this study due to lack of reported machine hours in production. Detailed description of capital input used in this study's estimation is provided in the appendix 1.

Labor productivity is one of the most commonly used measures in productivity analysis (Saari 2006, p. 4; Schreyer 2001, p. 20; Lieberman & Kang 2008, p. 214) mainly because it's relatively easy to calculate, its interpretation is simple, and it relates to the single most important and costly factor of production (Schreyer 2001, p. 20; Lieberman & Kang 2008, p. 214). Furthermore, labor productivity has been the best-known measure reflecting productivity (Palia & Lichtenberg 1999, p. 327). Labor productivity is easy to measure, but especially in recent years its importance in productivity analysis has diminished due to increasing capital share in production. When more capital resources are utilized, labor share of total inputs becomes more negligible.

In a nationwide analysis, labor productivity indicates real income per capita, or the average welfare, to which a single firm contributes with its processes (Lieberman & Kang 2008, p. 214). Consequently, labor productivity is an important driver of living standards. However, labor productivity accounts only for a limited proportion of total input contributions. Nevertheless, it is widely recognized and it plays an important role in the short-run productivity dynamics. The idea of the labor productivity measure is presented in the following equation (Rawal et al. 2016, p. 1486):

$$a_{L,t} = \frac{Y_t}{L_t} \qquad (9)$$

Where a_L is the productivity of labor, L_t represents the labor hours or employed workers and Y is the value of the produced output. Since only one input type is incorporated into the model, one does not need to include the input factor's respective share in the equation as it equals one.

Since productivity is calculated as a ratio of output over labor input, the greater output volume is relative to labor input, the higher value the productivity receives. This is the objective of every cost-minimizing company, but without harming production possibilities. Labor productivity measure indicates how much output is produced in terms of labor input and the more efficient the labor force is, the fewer working hours are needed to produce a fixed amount of output. Therefore, based on some theories, companies should focus on hiring skilled workers for the production to achieve higher labor productivity. This relationship is very simplified, and there are many other factors influencing the labor productivity at any given time. Even though it is in the interest of a company to have as high labor productivity as possible, some studies have argued that on a national level better productivity correlates with rising unemployment (Chen, Rezai & Semmler 2007, p. 2). This argument seems logical, since based on equation 9, better productivity indicates less workforce needed relative to produced output. To conclude, one could argue that the higher labor productivity is beneficial for a firm but may lead to unwanted unemployment on the aggregate level.

Besides labor input is capital the other critical input factor. The capital productivity focuses on incorporating the capital usage in production, together with the output, into the productivity model. Due to capital's various interpretations is capital productivity more difficult to measure than labor productivity (Lieberman & Kang 2008, p. 214). The purpose of the capital productivity measure is to provide an indicator of efficiency or resource usage (Lieberman & Kang 2008, p. 214). In a mathematic manner, the capital productivity can be presented as shown in equation 10. The principle is similar to labor productivity, but in this instance capital costs need to be included into the equation.

$$a_{K_t} = \frac{Y_t}{K_t} \qquad \textit{(10)}$$

Where a_K represents the capital productivity and $K_t = (1 - \delta_t)K_{t-1} + I_t$ the real capital stock. The term δ is the depreciation rate of capital at time t, and I_t represents firm's investments at time t (Lieberman & Kang 2008, p. 216; Kasahara & Rodrigue 2005, p. 5; Maliranta 2003, p. 289). The above relation states that the current capital stock is the weighted average of the past and new investments. This corresponds to the results of the embodiment analysis, where it is noted that both old and new capital goods need to be incorporated into the model (Jorgenson 1966, Maliranta 2003, p. 45). It may take a long time before the new investments are reflected into the productivity level and hence the full capital accumulation should be considered.

The relation presented in equation 10 states that the higher the output is relative to the capital input, the higher the productivity level. The capital productivity clarifies how productive the business process is in terms of the capital investments made. Moreover, the measure describes how much output the firm has produced per active capital stock and hence indicates to what extent the new investments have contributed to the output development. If productivity level increases from period $t-1$ to period t, it means that either output has increased, holding capital input constant, or the output stayed constant, while the capital volume has decreased. Either way, both variations lead to higher productivity in production. The same interpretation applies to decreasing productivity levels. In this case the output volume has decreased, or the usage of capital has increased between periods.

Even though the relation presented in the capital productivity equation might appear simple, the measurement of the capital input is problematic, since the productivity measurement needs to be adjusted to the changes in the rate of capital and machinery's capacity utilization. Amount of used capital is affected by multiple shocks, such as changing demand conditions, interruptions in supply or machinery breakdowns. (Schreyer 2001, p. 56) Consequently, capital utilization is most likely to fluctuate over time. Especially in the case of Ukraine the production level has not stayed constant during the crisis and this reflects on capital usage and new investments. However, the utilization rate is not accessible at firm level and the simplifying assumption required in the productivity analysis is that the total capital stock is utilized fully during every period. This study will come back to this topic later.

To conclude, the single factor measures provides simple alternatives to the productivity analysis and they can be used as a basis for more complicated productivity measures. However, single factor productivity measures have some drawbacks, mainly because of giving too optimistic estimates for productivity and their interpretation can be difficult, or results can be biased due to a lack of relevant inputs incorporated in the model. That is why it's critical to apply measurement tools which cover more than just one input factor. Therefore, the next section extends the productivity analysis to the models with multiple inputs.

3.5 Total productivity with labor augmenting technology

Previously presented productivity tools are only partial productivity measures and they do not give full benefits for productivity analysis. Especially at business unit level the single factor productivity tools are usually too narrow to present the actual productivity improvements (Hannula 2000, p. 57). In addition, single factor productivity measures do not reflect the substitutions between different input variables nor structural changes in the use of any other input variable. Therefore, the single factor productivity measures should be used deliberately.

Total productivity, defined as output per total inputs (Palia & Lichtenberg 1999, p. 327), is a more comprehensive indicator and it answers to the downsides of the partial measures and it corresponds better to the firm's needs. More specifically, the total productivity measure considers also the intermediate inputs, together with the primary inputs of capital and labor. Therefore, total productivity can be defined as an aggregation measure of the partial productivities. Only by including all the relevant inputs into the analysis the real net saving per unit of output can be measured and the increase in productivity level can be identified (Kendrick 1978, p. 3). The total productivity represents the degree of change in the production function and can be interpreted as technical change (Jorgenson 1966, p. 1). As specified by the Cobb-Douglas production function, the total productivity combines produced output with the weighted sum of used inputs (Dogramaci 1981, p. 7), and like in any other measure, the productivity is the model residual and corresponds to the part of output growth, which cannot be explained by use of input factors.

The importance of total productivity measure can be highlighted in productivity analysis at industry or economic level and it is a useful tool for “reviewing past growth patterns and for assessing the potential for future economic growth” (Schreyer 2001, p. 20). For a single company the assessment of the total productivity enables management to monitor historical performance of productivity and analyze which factors affects sales or profits the most and identify objects for improvements (Wazed & Ahmed 2008, p. 995). This being this study´s aim, to provide the best possible information to company managers about the performance of the manufacturing processes.

Since the basic form of the Cobb-Douglas production function is defined, it is possible to add the intermediate inputs to the model. By doing this, the total productivity measure gives a more complete overview of the real productivity level occurring in production. However, it is good to understand that when the intermediate inputs are included into the model the productivity estimates are usually lower than otherwise. With the help of the Cobb-Douglas production function the model takes the following form: $Y_t = A_t L_t^{\propto} K_t^{\beta} X_t^{\gamma}$. Where X is intermediate inputs, t stands for time, $\propto$ is labor share, β is the share of capital and γ is the share of intermediate inputs. The above model is useful in theory but is not practical for the empirical estimation considered in this study. However, the study takes the value of the intermediate inputs into consideration by measuring the output as value-added. Value-added indicates the increase in the value of produced goods due to manufacturing processes itself, and it can be derived as follows $VA_t = Y_t - X_t$. In other words, the value-added is a residual value between sales volume and the intermediate inputs. Consequently, the total productivity model can be presented as $VA_t = A_t L_t^{\propto} K_t^{(1-\propto)}$, which resembles the total factor productivity model with the exception of different valuations of the output.

With the time differences one can separate the periodic growth rates of each parameter and analyse their influence on the overall output development. When the output is defined as the value-added it is possible to separate the output growth between labor input growth, capital growth, and growth in the technical progress. In logarithmic form, when $lnVA = va, lnL = l, lnK = k$ and $lnA = a$, this can be stated as:

$$\Delta va_t = \Delta l_t + \Delta k_t + \Delta a_t$$

Based on the above notation, the value-added of a firm fluctuates proportionally more than the input factors labor and capital. The remaining part of the value-added fluctuation is generated by the technical parameter of the model. However, what can be problematic in this context, is that this residual reflects also the changes in economy of scale, technical capability, quality of inputs, and production processes, among other intervening factors. More discussion about the possible errors will be provided in chapters 4 and 5.

When also the intermediate inputs are included into the model, estimation results give the best possible outcome and the most accurate estimate for the productivity level. If the model would consider only main input components, such as labor and capital, the productivity estimate would become easily biased upwards. This is called omitted variable bias, which refers to the bias generated by missing model variables. In this study, three variables, energy, materials and services, are considered to reflect the changes in the intermediate input usage relatively well. The more detailed specification of these intermediate inputs' categories will be discussed in the empirical part of the study.

Instead of analyzing the pure Cobb-Douglas function this study will apply the production function, which is divided by the labor input. This creates the labor-augmenting production function and it defines how much output is produced per unit of labor. This is a common approach in the productivity analysis, since it states the growth rate relative to labor unit, and on the aggregate level it refers to the growth in welfare. This kind of function has been used for example by Solow (1957) and by Gourio (2008).

Consequently, the total productivity model needs to be modified further and the Cobb-Douglas production function can be divided by the labor input. Now the model parameters are calculated with respect to the labor units, such as worked hours. Hence the model parameters are the output per unit of labor, the capital per unit of labor, and the share of capital. As a result, the output and capital are converted into proportional form where they refer to the quantities produced or used per labor unit. Based on these modifications, the model can be presented in the labor augmenting form. With the help of equation 9 and the output value of $Y_t = A_t L_t{}^{\propto} K_t^{(1-\propto)}$ one gets the following expression:

$$\frac{Y_t}{L_t} = \frac{A_t L_t{}^{\propto} K_t^{(1-\propto)}}{L_t} \quad \leftrightarrow \quad y_t = A_t k_t^{(1-\propto)} \qquad (11)$$

Where $y = \frac{Y}{L}$ is output per unit of labor, $k = \frac{K}{L}$ is capital per unit of labor, or capital intensity, and $(1-\propto)$ is the capital share. Now the equation states the labor augmenting technical progress together with the output and the capital per labor unit. Consequently, the output per labor can only increase with the higher capital intensity per labor or with the technical progress. With the help of the above equation one can isolate shifts of the production function itself from the movements alongside it (Solow 1957, p. 314), which is the goal of productivity analysis. When the capital input per unit of labor has increased, based on the Cobb-Douglas production function, also the output per unit of labor increases, but with diminishing returns.

The following figure illustrates the labor augmenting production function in a graphical form. In the steady state, the effective capital-labor ratio equals to k^*, which grows at rate $(n+\theta)$, where the n is the growth rate for labor force or labor hours, and θ illustrates the growth rate, which is defined by the technical progress.

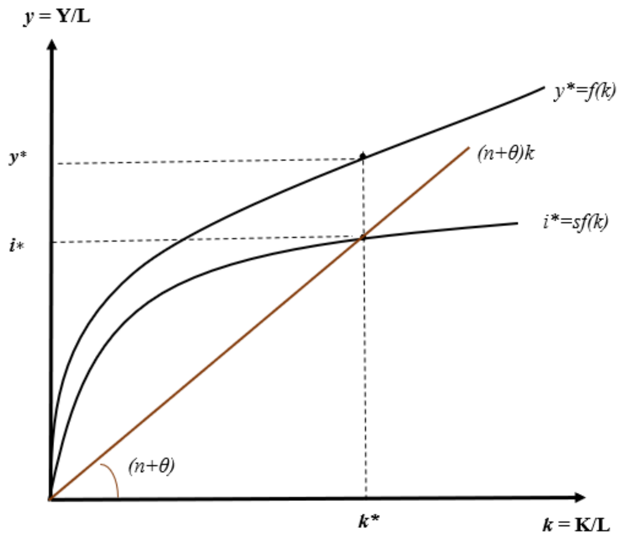

Figure 7. Labor augmenting production function and the technical process

The $i*$ in the above figure stands for the steady state break-even investment value. The investment is defined by the output value and by the rate of savings (s) in the following manner: $i_t = sy_t$. Based on the above figure, the efficient level of capital depends on the development of the labor resources and on the technical change. Now the curves of the production possibilities present how much the firm can optimally produce per given labor input and level of technology. When the growth rate for capital increases the firm can reach the higher production possibilities frontier, since the growth parameter $(n + \theta)$ of the slope steepens.

When also the intermediate inputs are included into the above expression the output y changes into value-added va. With logarithms and time differences the model becomes the following: $\Delta lnva_t = (1{-}\propto)\Delta lnk_t + \Delta lna_t$. Where $va = \frac{VA}{L}$ represents the value-added output per labor input, similarly to other variables in the model. The above notation will be the basis for the model to be estimated. With assumptions of constant returns to scale and competitive markets, the total growth of output can be measured using growth rates of each input, L and K, and the component of technical change. Labor and capital growth rates are weighted with their relative shares (O'Mahony & Timmer 2009, p. F377). This is a traditional approach in growth accounting, but this study questions the relation due to the short-run properties of capital.

Since equation 11 suggests that the output per labor unit can increase through increases in capital per worker, the capital accumulation in the case plant needs to be identified. This is especially important in the short-run analysis, because the capital input has different properties between short-run and long-run production processes. Many studies assume the constant rate of capital over a short-time period since the short-term fluctuations in capital investment are usually not significant. This is supported for example by Koskinen and Vilmunen (2018) and Cooley and Prescott (1994, p. 12) who state that capital fluctuations are negligible during the business cycles. Moreover, there are no rapid adjustments in the capital since investments in the production are planned usually many periods beforehand. This study will discuss this topic and the role of capital in the case plant more in-depth in the next chapter.

The theories and mathematical models for measuring productivity are now covered and the next section will continue with explaining the findings in previous studies and conclusions of the differences in long- and short-run productivity growth generators. This will help answering the research questions and analyzing the test results considering the earlier contributions to the topic.

3.6 Sources of productivity growth

An economy is affected by multiple shocks, which cause fluctuations around the optimal level of output over time (Koskinen & Vilmunen 2018, p. 915). This applies also to companies. Examples are productivity chocks and the changes in demand or market conditions. Despite the wide range of research in the field of productivity, the results of the key drivers of productivity and reasons for its fluctuations are vague. In addition, the results are highly dependent on the level of the measurement. Therefore, the understanding of productivity performance should be considered individually case by case. However, the previous studies, whether they are focused on nation level or firm level productivity analysis, altogether agree that productivity measurement is a crucial part of continuous processes. This section's purpose is to conclude the key findings on how the productivity can be generated at firm level and which factors are the main drivers of productivity growth.

Overall, economists have found declining trend in productivity growth, especially in labor productivity, in recent years (Bournakis & Mallick 2018). This trend is present at both micro- and macro-level. The slowdown of the productivity development can be due to changing production structures or new implemented innovations, to which production adjustment can require a long time. Because of the declining trend in the productivity growth it is becoming more important to focus on the key factors, which generate the biggest part of the productivity gains in a production. The identification of the key drivers and the input dynamics in the case plant's production process will be done later in this study.

The main purpose of the productivity estimation is to identify "the relative importance of different proximate sources of growth" (Schreyer 2001, p. 21) and previous studies in the field have found some interesting underlying factors affecting both output and productivity growth rates. One of the main productivity drivers is the labor input and its role has been widely recognized. For example, Cooley and Prescott (1994) states that labor input fluctuations have contributed up to two thirds of the long-run output growth, while the remaining is attributed to productivity (p. 11). One estimate shows that the contribution of labor productivity to economic growth has been around 2-3% a year (Nordhaus 1972, p. 493). In addition to labor, the importance of capital has support in previous studies as a productivity growth generator. Surprisingly, empirical studies have different conclusions about the role of capital.

Dogramaci (1981) has found that in a long-run capital input is the most important source of growth in output volume, while the technical change is on a second place and labor input is on a third (p. 60). While the long-run capital dynamics play and essential role in output development, the short-run output growth is usually generated by other sources. Also, the importance of each parameter is highly dependent on the industry, structures of the production and the time frame of the study. The conclusions are very vulnerable to any changes in the productivity calculation environment and the driving factors may even be different over short and long run.

Moreover, Maliranta (2003) points out that even though plant would have done new investment and they would use modern technology, plant’s productivity level can still appear low. This situation can occur, for example, if the workers do not know how to use this technology efficiently. (p. 57) Therefore, many studies have focused on the quality of the labor force, such as degree of education, and whether it can result in different productivity levels in firm. No doubt that this kind of qualitative factors generates some of the productivity gains in the long run, but this study will exclude this from the analysis due to lack of suitable data. The separation of labor input into several categories would require more detailed database, which is not available in this case.

To emphasize firm’s processes, Maliranta (2003) notes that micro-level productivity gains are achieved mainly by internal restructuring, implementing new technology or doing changes in labor force (p. 25). This means that at firm-level the biggest productivity growth is achieved through changes inside the organization or in the production, while the external adjustments have more significant impact at the level of an industry. There is also evidence that in a long-run only the most productive firms survive (Aw, Chen & Roberts 1997, p. 20). This further supports the fact that productivity is relevant part of daily business and managers should be able to analyze it and its development with proper tools. It helps the firm to survive in a tougher competition globally. Therefore, one of the purposes of this study is to give a trustworthy overview of the productivity development in Ukraine’s operating plant. If the analysis would have widened to other plants inside the same company the comparison of the relative productivity can be analyzed.

In addition to level of the analysis, the productivity gains may vary over short and long-run. In the long-run productivity development is influenced by economies of scale, while the short-run fluctuations are more heavily influenced by business cycles and capacity utilization. Moreover, there is an empirical evidence that productivity is procyclical (Cooley & Prescott 1994, p. 32). This meaning that during the recessions the growth rate of productivity is expected to slow down. In addition, within the plant fluctuations in output volume can affect the short-run productivity growth negatively (Baily et al. 1992, p. 199). Despite these facts, some early studies in a field of productivity have widely supported phenomenon of short-run increasing returns in labor input (Gordon 1980). Therefore, many studies have found evidence that the long-run productivity tend to follow an upward trend but during shorter period of time the productivity fluctuations can be more random (Gold 1981, p. 106). However, the most recent trend in the productivity growth is diminishing even though the global economy has witnessed a long period or strong economic growth. This is against the previous theories and the link between output growth and productivity growth.

Consequently, a firm's productivity level is sensitive to any changes happening in a production or produced volumes, especially in a short-run. However, also long-term productivity expectations have their impact on the short run output movements (Blanchard, Lorenzoni & L'Huillier 2017, p. 639). Therefore, even though the productivity as a phenomenon can be clearly separated into long- and short-run implications, the short-term production is affected by the long-term expectations and development, and the long-run productivity accumulation is determined by the short-run fluctuations. The analysis in this study focuses on estimating the productivity changes over a short run, covering the last eight years of the production processes. One can expect to find some fluctuations in the productivity levels and based on Gold's (1981) findings it would not be uncommon not to find any positive or negative trend in the productivity development in the case plant (p. 106).

The following table summarizes some elements which can influence on the productivity level in a firm. The factors have been divided into two categories, internal and external sources. The internal sources refer to factors to which firm can influence itself, such as new investments. Because firm can influence on these factors, they are in the main interest of a firm. In addition to the internal factors, firm's productivity can be affected by external shocks, such as changing demand conditions or economic recessions. The key factors influencing short-run productivity development are factors related to workforce, reallocations in production and market conditions through business cycle fluctuations. The rest of the factors listed in table 5 can be highlighted more in the long-run development, since the new investments in capital or research and development do not have a direct effect on technical change. The effects to production will be realized only after longer period.

Table 5. Sources of micro-level productivity growth

Productivity growth							
Internal sources						**External sources**	
Skills and degree of eduaction of the labor force	New technology & capital investments	Reallocations of production inputs	Capacity utilization	Research & development	Scale of production & economies of scale	Market conditions: demand & competition	Business cycles

Some of the aspects listed in table 5 are included in the production function. This study focuses mainly on the labor input, new capital investments and reallocation of the inputs throughout the elasticity of substitution. In addition, the discussion of results reflects the market conditions in Ukraine to discover if the crisis has influenced anyhow to the productivity levels in the manufacturing plant. One important external factor is the exchange rate, which the plant considers as given during each period. Since the case plant has international trade, the fluctuating exchange rate could possibly affect the demand side of the goods manufactured. However, this study disregards the exchange rate from the estimation models. One reason for this is that the case plant manufactures only for the internal customers. Hence the demand can be argued to be rather constant over time –even with poor currency valuations.

So far, this study has discussed about the gains that can be achieved by applying productivity measures. However, there are also many limitations or challenges of which one should be aware of. These challenges can occur in the model specification, availability of the data or wrong interpretation of test results, for example. The next chapter will continue with this topic together with the model specification induced by the case plant's data.

4 Research data and methodology

4.1 Challenges in the productivity measurement

This study has discussed the importance of input factors which may affect productivity level in the manufacturing plant. However, production is a continuous process in which many production components change simultaneously. The production function, which was presented earlier, takes into account only the biggest parts of the production and combines complex production processes in a simplified manner into one equation. Even though the production function approach is widely used in economics, when analyzing the results, one should keep in mind the connection between the actual production and the modelled production. The correctness of the test results depends on how well the production function reflects the production process. Consequently, the total productivity measure can fail to estimate the technological level systematically, because the production function may lack meaningful units of measurement.

The production function has also other drawbacks. The form of the production function affects the calculation results for any given component. That is why it is important to formulate production function correctly, otherwise it won't reflect firm's processes nor productivity in appropriate manner (Wei & Liu 2018, p. 2). In addition, like any other production function or economic model, the Cobb-Douglas approach is a theoretical tool which has well-grounded basis in theory of firm and it assumes simplified market conditions. This appears in the form of strong economic assumptions, such as a perfect competition and profit maximization, which are not very practical. However, they make the estimation process possible.

Furthermore, the close relationship between capital, capacity utilization and costs need to be understood in the analysis. The capacity utilization of the manufacturing plant is a valid concern in the productivity analysis. Some inputs, which are utilized in a production, are partly or fully fixed over time. In a firm it is money and time consuming to adjust the amount of inputs employed at the production, based on transitory fluctuations in demand or capacity. Since firms tend to maximize the profits and continue utilizing inputs at their sustainable long-run level, the productivity can appear low or high at certain time (Maliranta 2003, pp. 56-57). One example being the capital stock, which is not easy or even possible to adjust based on the short-run demand or output fluctuations. Even though the value of the capital stock would stay untouched throughout the business cycles, it is possible that the degree of utilization of this stock varies. In addition, there can be underutilization of the production possibilities if the value of capital is too high. (Morrison 1993, p. 4) Unfortunately, the utilization level is not known and hence, this study assumes full capacity utilization during the examination period.

Like in any empirical study, errors may occur due to measurement errors and poor data availability. Typical examples are the measurement of the output and inputs, of which under- and over evaluation may cause bias in test results (Davis 1955, p. 78). This error can be considered small in this study, because the study will utilize the data of the plant's statement of profits and losses together with more detailed information attained from the plant's business controller. Even though the data is collected in the best possible manners, human errors are possible and may influence the test results. The human errors can be present in the data manipulation procedure of this study, since all the model variables are quantified and converted into the appropriate form by multiple steps. The correctness of the used formulas has been checked multiple times by the author before applying them into practice.

There is also debate of the correct measurement of certain input parameters. One of them being capital, and it has been argued that it is one of the most difficult in input measurement and it is problematic to calculate proper values for the capital consumption and capital assets (Davis 1955, p. 54). Hence, the capital input can be measured in multiple ways. Some studies show that one should sum up all the capital values, such as land, buildings and assets (Davis 1955). Other studies, on the other hand, consider only active capital that has been used in production. This viewpoint in capital measurement has been supported for example by Solow (1957) and he concludes in a clever way that "what belongs in a production function is capital in use, not capital in place" (p. 314).

This study works with respect to this finding and includes only the productive capital into the model. The approach is supported by the OECD manual, in which is suggested that capital input should be calculated as capital services used in the production (Schreyer 2001, p. 51). Once the capital measurement is conducted, another interesting property of capital need to be considered. No matter how the capital is measured, it can be argued whether capital accumulation is significant factor over the short-run business fluctuations (Koskinen & Vilmunen 2018, p. 917). This assumption, and whether the capital accumulation is significant factor determining production in the case plant, will be discussed in the next section.

Even though the theoretical model is quite straightforward, it is very vulnerable to any changes in production or business environment. Morrison (1993) points out one common error type in the productivity analysis. The error occurs because of the substitution effect in the production (Morrison 1993, p. 6). This element will be present also in the empirical part of this study since the substitution effect is assumed to be constant over time to make estimation easier. If the substitution parameter would be allowed to fluctuate over time it would refer to some structural change in production. In short-run, however, the error occurring from constant elasticities can be considered small, since structural changes usually happen over long time periods. Because the substitution parameters are kept constant during the examination period, also the form of the production function is similar from period to another. If the structural changes would be taken into consideration, the productivity estimation becomes more difficult, since the output changes may be generated by both productivity changes and by structural changes. These elements, on the other hand, are difficult to separate empirically.

Especially when measured with TFP tools the empirical results can be misleading. This is because not all the productivity growth is based on the technical change. Other factors behind growth can be the scale effects, adjustment costs, learning by doing, efficiency changes or possible errors in the measurement, among others. (Schreyer 2001, p. 20) It is also difficult to distinguish between these elements and quantify the real productivity gains. Morrison (1993), on the other hand, points out phenomena of “measure of our ignorance”. By this Morrison refers to the situation where the model residual is affected also by other factors than only by the technical change. These parameters can be changes in the production structure, input substitution, or changes in the input costs, for instance. (p. 18) These parameters cannot be separated from the technical change in the estimation and may lead to overestimation of the productivity.

What is beneficial for this study’s purposes, the data availability is good, and the data collection has been made using insider information about the production. This helps to identify the key variables, making possible to focus on the most important factors. Therefore, the errors caused by the data collection should be minimized. The next section will provide further analysis of the data variables and will start with the estimation process.

4.2 Applying theories into practice

Wide range of insights of the productivity measurement and its usefulness has already been provided. This chapter will focus on the empirical analysis and on providing an estimation method to analyze the productivity development in the manufacturing plant in Ukraine, based on the theoretical model presented earlier. The estimation will be conducted for two separate models, of which difference lays in the measurement of the labor input. The econometric tools are widely acknowledged in the productivity measurement and the results gained by these techniques might give new insights for the company managers.

Schreyer (2001) has claimed that the econometric approach is suitable tool for analyzing productivity and its benefits can be highlighted in academically oriented studies (p. 19). Non-parametric and index number methods are more commonly used in the field of accounting, to shed light on productivity performance in a daily business. Econometric techniques, however, provide an alternative approach into this analysis and they can offer new understanding of the plant's performance. Usually the econometric approach is unreachable for managers and hence this study aims to provide supporting and complementing findings alongside the tools that are already being used in the case plant.

The productivity estimation with the case plant's data can be divided into several steps. To analyze the productivity in the case plant one needs to include all relevant input and output factors to the model. After this, one can identify significance of these components alongside the intervening factor, productivity. The analysis in this study will be done with plant's quarterly data and on the actualized values of the production function parameters. This approach is used mainly to smooth the biggest periodic fluctuations due to the qualities of the manufacturing processes. When the examination period is from the beginning of 2011 to June in 2018, total amount of quarters under analysis is 30. In other words, the time index gets values of $t = 1,2, \dots ,30$, where the Q1/2011 is stated as 1. The framework of the productivity analysis process is explained step by step in the following table.

Table 6. The steps in the productivity estimation

The analysis process	
1.	Determine the needed variables and check data availability
2.	Process the data into suitable format
3.	Identify the key properties of the data and check for possible errors
4.	The estimation process and listing the main test results
5.	Analyze the results, and their reliability
6.	The conclusion in terms of productivity development in the case plant

The steps listed in table 6 provide an outline for the analyzing process, which is needed to yield the answers to the research questions. First, based on the findings in the theoretical part, suitable data variables should be identified with respect to the data availability. Once the key variables are collected they need to be manipulated into adequate form. The values will be discounted with an appropriate rate and logarithms and the time differences need to be calculated for each period. This form is defined by the productivity models. When the data set is clear, it is possible to start the estimation process by finding out the best econometric test for the modelling. Finally, the results will be analyzed and their contribution for the study will be identified.

Before going to the estimation process itself, main properties of the key variables will be presented, both in a form of figures and tables. This helps understanding the data properties and can also be helpful when analyzing the test results. The obtained results will be decoded and considered in the light of the research questions. The estimation results should provide answers on how the productivity has developed in the manufacturing plant in Ukraine over the past few years. The test results will be discussed carefully, taking into consideration possible estimation errors and trustworthy of the data. However, following the steps identified in table 6, the next section will start with the data collection.

4.3 Data collection and model selection

This study applies one of the models, the total productivity model, into empirical framework. For the estimation, one needs to define the following parameters: output value for each quarter, labor inputs, capital input and the value of the intermediate inputs, as defined in the theoretical part of this study. This chapter provides closer analysis on how these output and input factors are measured in practice, satisfying the objectives of the productivity estimation. The correct data should be assessed individually to match the production and satisfying its conditions as well as possible.

Firms and individual plants are highly complex and each of them have their unique characteristics. Therefore, it is important to use plant specific and as correct data as possible and to infuse the production function with this information. To decrease the possibility of errors, this study has utilized some plant-specific insights of the production processes and technology available. This information helps identifying the correct input variables needed and in the measurement of these variables. Once one has an understanding of the production processes and the data availability the model variables can be collected in the best possible manner, not only based on the previous theories. The variables used in the productivity analysis will be handled in quantities or in the Ukraine's national unit of value, Hryvnia.

One of the most relevant parameters in the model is the value of output. Output can be measured in different ways, each of them leading to different estimates for productivity (Cobbold 2003, p. 1). In previous studies there have been used mainly two different ways in measuring output volume: gross output and value-added. Both have their positives sides and drawbacks. The main difference between these two measures is that the gross output is a measure of inputs, including capital, labor and all intermediate inputs, where the value-added, on the other hand, does not include intermediate inputs. (Cobbold 2003, p. 1) In other words, value-added can be calculated as gross output minus intermediate inputs (Lieberman & Kang 2008, p. 214; Schreyer 2001, p. 33; Dogramaci 1981, p. 51). The value-added approach is used in this study and the following part concludes some justification for the use of value-added instead of actual sales volume. Despite their differences, Cobbold (2003) states that both ways of measuring the output are valid when estimating productivity growth (p. 1).

The gross output value corresponds directly to the production function and it allows the use of intermediate inputs in the model (Schreyer 2001, p. 23). However, the total value of sales does not indicate the true value what has been produced in the case plant, since it includes the purchased materials and the company overheads. The raw materials, for example, are produced elsewhere and hence should not be considered as part of the case plant's produced output. In addition, since the main interest of this study lays in the estimation of equation 11, the value-added will be utilized in this study. Value-added indicates how much the case plant has generated to output growth with its processes. Moreover, the "value-added based productivity measures reflect an industry capacity to contribute to economy-wide income and final demand" (Schreyer 2001, p. 23). If the output would be measured as periodic sales volumes in each firm and if the productivity equations would be applied to industry or nation level, some of the output value would be calculated twice. This, on the other hand, causes upward bias to the productivity estimates. Once the estimation is conducted with the value-added the estimation becomes straightforward. Based on these findings, for now on the term output refers to the value-added of the case plant.

This study will derive the output variable from the sales volume with the help of periodic inflation rate and the value of the intermediate inputs. The periodic sales will be deducted by the value of the intermediate inputs and the residual will be deflated with corresponding periodic price index. The sales volume, together with value of intermediate inputs, are available in plant's profits and loss statement. The value-added (VA) can be derived from the periodic sales as follows:

$$\textit{Value added} \qquad VA_t = Y_t - X_t$$

Where Y_t is the sales volume and X_t stands for the value of utilized intermediate inputs at period t. Intermediate inputs include components such as the energy usage and the cost of contract work (Baily et al. 1992, p. 205). This study will also include the value of used materials, since it is one of the key components in the manufacturing process. Hence, the value of the intermediate inputs X will be calculated with respect to the following equation: $X_t = S_t + M_t + E_t$. The total value of intermediate inputs is a sum of energy usage E, services S and materials M.

Another key component of the production is the labor input, which refers to either labor force or worked human hours. Usually labor is one of the biggest individual factors in manufacturing and in the case of the case plant labor contributes significant part to the total costs. For the estimation purposes, the labor input includes only the operative labor force, which means that staff and office workers are left out of the scope, since they do not contribute to the manufacturing processes itself. The estimation will be conducted separately for two models. These models are differentiated with respect to labor input. One of the models includes the number of workers and the other the worked labor hours as a proxy for labor input.

Based on the productivity model, the third production function parameter is the capital input. This study considers proxy of capital as a sum of the capital purchases of new machines or other equipment and of the new investments made at the period. These new investments can influence the productivity growth positively and they aim contributing to the technical change by modifying the production system to more innovative direction. The detailed explanation of the methodology of measuring capital stock, together with other data variables, will be found in the appendix 1. As explained, the capital stock will be calculated as a sum of current and previous capital investments. This type of capital valuation has been considered for example by Lieberman and Kang (2008) and Kasahara and Rodrigue (2005) and it can be illustrated as follows:

$$\textit{Real capital stock} \qquad K_t = (1 - \delta_t)K_{t-1} + I_t$$

The above relation states that every new investment adds to the productive capital stock. The appendix 1 provides an explanation on how the capital input is calculated and how it will be applied to the productivity estimation. In this study, the capital input has been collected with respect to the above equation, as periodic depreciation rates of capital. Consequently, the total value of the depreciation, received form the factory controller, includes both old and new investments.

It is possible that errors occur in the data collection if number of operative workers, for example, is not available or it has not been measured systematically over the years. Other key issue related to this topic is the trustworthy of the data and whether it includes only the relevant labor data. Since it is not possible to influence on the incurrence of these problems, the given data set will be considered trustworthy. However, since the preferred data is found from each period, it refers to the systematic measurement procedure in the case plant. Hence, one can move forward to the data manipulation. To analyze the productivity with consistent values the data variables will be converted into base year prices by discounting. The next section covers the main principles of the discount procedure and its importance in empirical analysis.

4.4 Inflation and neutrality of the money

There is an interaction between the productivity adjustments and changing factor prices. To exclude the effect of the latter category from productivity growth estimation one needs to adjust the prices to the base period. In other words, the output and the relevant input variables need to be deflated with the respective rate of depreciation. This methodology makes sure that the effect of the changing input volumes, which are based on the increases in price level, are excluded from the productivity estimation. Otherwise the productivity change may result being too optimistic. Following this procedure, the real increases in the input usage will be estimated as a source of productivity changes.

The relationship between price level and productivity estimates has also been considered in the previous studies and Schreyer (2001) reminds that the use of price indices deflating time series to the base year has a key role in productivity measurement (Schreyer 2001, p. 24).

Like many other elements in productivity analysis, also deflation of the prices can be accomplished in multiple ways. Davis (1955) suggest that price adjustment should be done using base-year prices (Davis 1955). This indicating that for example output quantity should be multiplied with the price which has been present during the base-year. The base year method is supported by Saari (2000) and he points out that production function should be always presented in terms of fixed prices (p. 6). This method, however, ignores possible structural changes in production and it cannot be applied since the quantities of manufactured goods are not systematically reported.

Another way to do the discount is to adjust prices for inflation and for changes in producer price index. So that the interpretation of productivity and output growth is possible, all the output and input values need to be adjusted for inflation (Lieberman & Kang 2008, p. 214) to distinguish between the real increases in output and the increases happening due to annual inflation. Otherwise output values are distorted and the estimation gives too positive image of the production development. Since this study is handling time-series, only the discounting enables unbiased results on development of production. The price discounting method is supported for example by Lieberman and Kang (2008), Morrison (1993) and Fabricant (1981) in their studies.

In this study, all the monetary values will be deflated with respect to quarterly changing price index rates, which fluctuates together with the inflation. An alternative approach would be to convert past values to the current prices using the inflation rate as multiplier. The discounting procedure is based on the assumption that the value of money increases over time, relative to the price development in the country. Therefore, the measured data values at each period can’t be directly compared without price adjustment. The adjustment for the model variables, value-added and capital, will be done with respect to the following relation:

$$P_0 = \frac{P_n}{(1+i)^n}$$

Where P_0 is the price at period zero, P_n is the price at period n $(n > 0)$, and i stands for the interest rate for the asset accumulation. The i is assumed to equal the periodic rate for base inflation or producer price index in Ukraine, depending on the data variable. The procedure yields the real values for each parameter. Since the labor input is not measured as monetary value, the deflation need to be applied only for the output variable and for the capital stock. The deflation to the base period $Q1/2011$ is relatively straightforward. The periodic inflation rates, or producer price rates, have been converted to index numbers, where the base period equals one. In other words, at period 1 the value for the interest rate i equals zero. After the base period the index gets values above one, based on the quarterly rates of the occurred price changes. To understand the importance of the deflation one should deepen the understanding of price development in Ukraine in the past few years.

The inflation in Ukraine has been in double-digit levels since the Ukrainian crisis, which started in 2014. The annual inflation rate is still above the level that is considered normal with the international standards. The rapidly increasing market prices, on the other hand, affects directly to the production costs, through capital and through increased costs of the intermediate inputs. Also the sales prices are adjusted to maintain the profitability of the business process. The following figure (figure 8) shows the development of the annual inflation rate in Ukraine between 2010-2018 to get an overview of the price development. The data has been achieved from the databases of the World Bank (2018) and Statista (2018).

*Figure 8. Inflation rate in Ukraine, 2010-2018**

The above figure illustrates the rapid changes in the annual inflation rate in Ukraine. The inflation rate for 2018 is based on the full-year forecast. In the beginning of the examination period, the inflation has been decreasing and approaching the zero rate. This trend stopped in 2014 due to the Ukrainian crisis and the annual inflation jumped from close to zero to almost 50 per cent during 2013 and 2015. High inflation rates have been reflected to the economy as unstable market conditions and as increasing producer prices. Also, the case plant has been affected by the price shocks.

Together with the inflation, the development of the producer price index (PPI) is an illustrative way to describe the costs of the production. Therefore, in the following graph is illustrated the core inflation and producer price indices in 2011-2017. The base year 2011 equals to 100 in the graph. The data is collected from State Statistics Service of Ukraine (Ukrstat 2018a; Ukrstat 2018b) and modified by the author to the suitable format. During the last seven years the index of core inflation in Ukraine has more than doubled its value. Supporting the previous figure, the most radical changes in the inflation index has occurred in 2014 and 2015, in the beginning of the crisis. The PPI, on the other hand, follows the development of the inflation rate and hence, both variables presented in figure 9 have the same upward trend, corresponding well to each other.

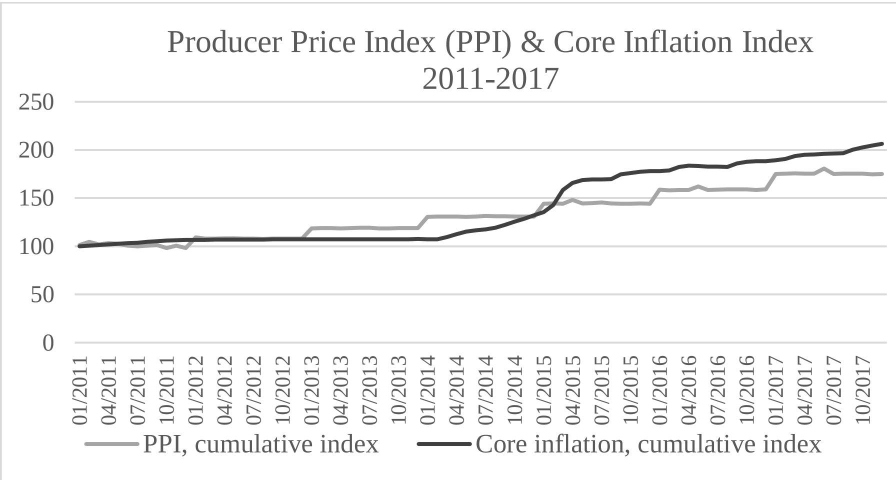

Figure 9. Producer Price and Core Inflation Indices in Ukraine

While the inflation accumulation seems more stable, the producer price index has increased systematically in the beginnig of each year. The variables presented in figure 9 will be used as depreciation rates for output and input factors. While the inflation rate is used to deflate the output, the producer price index will be used for the capital input. This method is supported for example by Cobbold (2003) who states that “in principle, sales and inputs should be deflated by separate price indexes” (p. 21). Since the data variables are valued in a coherent manner due to deflation procedure, the next section will continue by analyzing the deflated model variables and their development over the examination period.

4.5 Profile of the case plant and data description

The study has already pointed out main viewpoints about Ukraine’s business environment. It is not necessary to give detailed description of the market situation to accomplish the objectives of this study, but in order to understand better the estimation results it can be useful to highlight the key elements that may or may have affected the productivity in the manufacturing plant. Ostapchuk, Balmann and Curtiss (2015) show in their study that

Ukraine’s business environment is highly vulnerable to macroeconomic and political conditions (p. 4). This is also shown in figure 10 by the output development in the case plant, which dropped due to the Ukrainian crisis. International crisis and macroeconomic shocks have the biggest impact on economies of which economic structures are not as stable as in developed countries. In addition, Ryzhenkov (2016) shows that resource misallocation and decline of productivity have been present in Ukraine’s manufacturing industry since the beginning of 21st century (p. 1). The declining trend in productivity growth has been reported from multiple countries, but the unstable market conditions may strengthen this trend in Ukraine. When the market prices fluctuate and negative shock on demand are present there is less incentives to make new investments or keep the production sustainable. These findings may have their impact on the case plant’s productivity growth.

Before the productivity estimation, the key data of case plant’s performance will be presented. The following figures 10 and 11 will provide an overview of the key factors’ development in the case plant. Figure 10 shows the output development in the manufacturing plant using quarterly data between January 2011 and June 2018. Output equals to the periodic value-added. To illustrate the importance of price discounting the figure presents both actual added value per quarter and the discounted value-added (VAdefl). Before year 2014 the gap between the nominal and real output volume is minor, but it started to grow rapidly since 2015. This trend has continued since, and in the halfway of 2018 the gap equals more than 50 per cent of the output volume. If the estimation would be done using the nominal sales value, the productivity estimates would be biased upwards because the output seems to be on a higher level than it is in real prices.

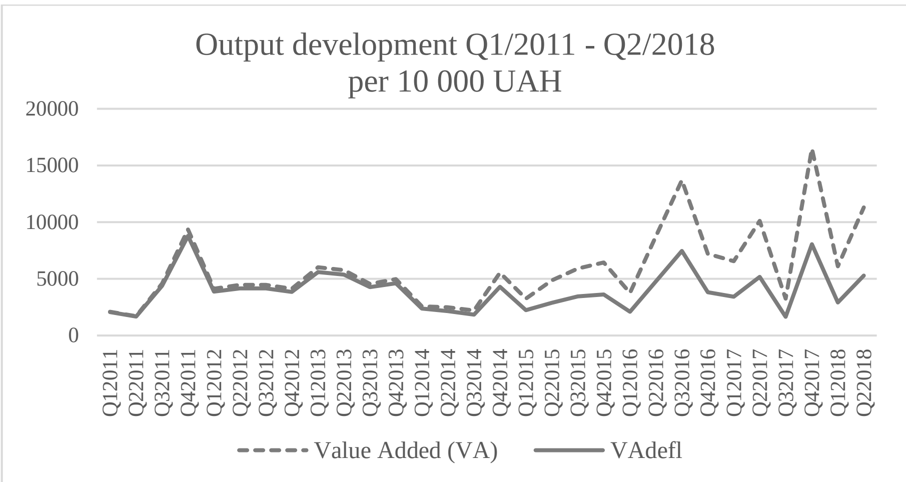

Figure 10. The output development in the case plant in 2011-2018

Few observations can be made of the figure. The output value seems to be highly volatile and there are periodic fluctuations in the output. However, the development of the real output over the entire period of 2011-2018 seems quite stable, without a clear trend upwards nor downwards. The output increased rapidly by the end of 2011, had a minor drop in 2014-2016, and finally started to grow again in 2016, but in a volatile manner. Based on the values between the first period, quarter one in 2011, and the last period, quarter two in 2018, the deflated output has grown by 254%. This indicating that the deflated output in the end of the examination period was more than 2,5 times higher than in the beginning of 2011. One of the objectives of this study is to find, to which extend productivity has generated this growth or has the output growth been based only on increases in input parameters. The big periodic changes may cause some non-linearity difficulties in the productivity estimation, especially if the input variables do not correspond to these changes. The output growth from one period to another gets both negative and positive values. Therefore, the heavy output fluctuations may affect the results and make it a challenge to find a trendline for productivity with econometric tools.

When the production function parameters are converted to the labor augmenting form, as stated in equation 11, the production function parameters $\frac{VA}{L}$ and $\frac{K}{L}$ are informative for the productivity analysis. Since the estimation will be conducted using these labor augmenting parameters, it is justified to illustrate also their development in the case plant. The following figure (figure 11) shows the development of the needed model parameters, the value-added per labor input and the capital per labor input in the case factory between 2011 and 2018. Since this study estimates two models, the variables are calculated based on both workforce and human hours. The deflated parameters are presented as logarithmic indices, where the reference value is one.

Figure 11 offers an important information about the data variables and especially about the development of the value of capital. As illustrated, there has been adjustments in the input variables during 2014 and 2015, since the indices' values has grown during that period. However, the changes are not big nor rapid, since the input variables are semi-fixed especially in a short-run. Even though the firm can hire new people or suspend the current ones, the number of workers is not possible to adjust heavily from period to another due to contract agreements and the interest of maintaining stability in the production. The capital stock per worked hours has fluctuated more heavily than the capital per labor force. This indicates that the reported working hours have been varying in short-run production process.

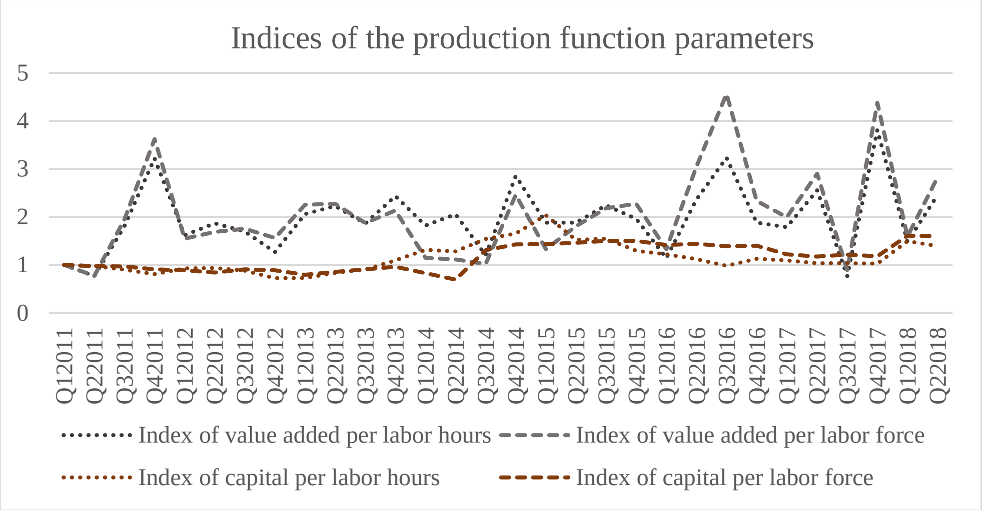

Figure 11. Indices of the model parameters

The value of capital per labor input, especially per worked human hours, has increased momentarily during 2014. This can be explained by the adjustments in the labor input. The capital intensity per labor unit have reached the levels what they were before the crisis. This, together with the fact that number of workers has been increasing in the last couple years, reflects improving market and demand conditions for the plant. The output per labor unit development, on the other hand, tends to fluctuate heavily from one period to another. This creates rapid peaks, both positive and negative, to periodic changes of output per labor unit values. When comparing the value-added per labor hours and value-added per labor force the parameter with labor hours seems more stable than the other data variable. Again, this can be explained by the easier short-run adjustments in labor hours than in the workforce.

One of the important implications of the above figure is that the capital utilizations per labor unit are relatively constant during the examination period. Some studies, such as one conducted by Koskinen and Vilmunen (2018) suggest that in a short-run the capital parameter can be kept constant. This is due to the properties of capital and its difficult short-run adjustments. Furthermore, the capital investments are usually planned many periods beforehand and rapid changes to new investments are not always possible. Therefore, the capital input is not adjusted to the short-term business cycle fluctuations nor momentary demand shocks. Hence, one could deliberate, whether capital is a significant factor determining the short-run output fluctuations in the case plant. This will be further analyzed by the descriptive statistics and by econometric techniques.

To start with the analysis and to further analyze the importance of the capital factor, table 7 lists the main qualities of the key variables. Table lists the name of the variable, the variable description, number of observations (N), minimum and maximum values in the time-series, mean value, and the standard deviation. All the data variables presented in table 7 are in logarithmic form, discounted to year 2011 and converted to periodic differences. Because the time differences are measured as value changes between two periods, the amount of observations decreases from original 30 to 29. The Q1/2011 being the first observation in the data set, the first change rate is reported at the second quarter of 2011. The first data variables of the table, Dln(VA/H) and Dln(VA/L), are the dependent variables and they will be denoted later in the model by $\Delta lnva_t$.

Table 7. Descriptive statistics of the data variables

Descriptive statistics						
Variable	**Explanation**	**N**	**Minimum**	**Maximum**	**Mean**	**Std. Dev**
Dln(VA/H)	Change rate of logarithmic, deflated value added per labor hours	29	-1.2035	1.6053	0.03092	0.58416
Dln(VA/L)	Change rate of logarithmic, deflated value added per labor force	29	-1.1734	1.5869	-0.03573	0.61278
Dln(K/H)	Change rate of logarithmic, deflated capital input per labor hours	29	-0.29298	0.37649	0.01139	0.14047
Dln(K/L)	Change rate of logarithmic, deflated capital input per labor force	29	-0.17772	0.63626	-0.03463	0.13927

The output variable, Dln(VA/L), is the value of periodic changes happening in the volume of value-added per labor force and it gets values between -1,1734 and 1,5869. The similar values for the value-added per labor hours are -1,2035 and 1,6053. Both minimum and maximum values are reported from each data variable and they can be read from the above table. Because each variable is in the form of time differences, the mean value is close to zero. This indicating that all the data variables and their periodic changes tend to fluctuate around this mean value. The last column, standard deviation, define the rate of fluctuation around this mean. The higher the standard deviation, the more distant values variable gets from its average. One can notice that the capital fluctuations are relatively moderate.

Even though figure 11, together with table 7 are very illustrative ways to analyze the capital movements, to avoid making heavy simplifications to the productivity model, the assumption of constant capital should be tested with econometric tools. By doing this, one can make justified decisions about the capital and its incorporation to the model. The capital constancy will be tested with the Chow-test, which can be used to identify structural changes in the data variables. The idea is to test whether capital per labor input has stayed statistically significantly constant over the examination period. If the capital per labor unit value has changed significantly during this period, there has been a structural change in the capital per labor usage and it should be included in the model. In this case, the estimation model will be based on the equation 11. If the null hypothesis of the test cannot be rejected, there has not been a structural change and the capital usage can be assumed constant in our model. The full test results can be found from the appendix 2.

By concluding the remarks of the results, the capital per labor input has stayed constant and the null hypothesis of the 'no structural change' cannot be rejected. This observation is made in both models, with labor force and labor hours. Consequently, one can safely assume capital constant and exclude the capital per labor unit parameter from the estimation model. The observation of the capital intensity result in the fact that it does not need to be included to the specification of the Cobb-Douglas production function and nor to the productivity model. Consequently, the labor input is the only input variable in the model and the parameters $\propto$ and $1-\propto$ are not needed. With these simplifications, the productivity model turns into $VA_t = A_t L_t$, where the output development is defined by the labor input and by the technical parameter. This modification is justified only in a short-run productivity estimation, since long-term influential adjustments in the capital accumulation are possible.

The production function without capital states that the output for every period equal to the labor input multiplied by the technological parameter. Hence, the output growth can be generated by increases in labor input or by positive changes in technology parameter, or both. This is the key relation to the productivity analysis and sets the basis for the estimation considered in this study. The final modification to the productivity model is done by excluding the capital parameter from the equation 11. This can be presented as following:

$$\frac{Y_t}{L_t} = \frac{A_t L_t}{L_t} \qquad \leftrightarrow \qquad y_t = A_t \qquad t = 1, .., 30$$

The above relation states that the output per labor input $y_t = Y_t / L_t$ equals the value of productivity on each period. Based on the logarithmic changes, the change in productivity at period t equals to the change in a parameter of output per labor input. This relationship can be stated as $\Delta ln y_t = \Delta ln A_t$, where the Δ indicates the periodic changes and y_t is the value-added. In other words, any increase (decrease) in output per labor input is due to positive (negative) technical change. This is the ideology behind the productivity analysis in this study and it will be considered in the estimation. The next section will put this model into practice, and continues with the specification of the estimation method, based on the findings in the data set.

5 Estimation results and interpretation

5.1 The estimation process

The object if this section is to find a good econometric model, which performs well for the productivity estimation purposes, given the specified productivity model. The model's estimation is based on the idea that it is possible to explain the changes is one variable with other variables' changes. This means that the model includes one dependent variable, which will be explained, and the other variables in the model are independent variables. With the use of econometric models, the model residual represents all the remaining factors in the production that cannot be controlled by the independent variables. Therefore, the residual of the model should reflect directly to the changes in the productivity parameter. Since the capital parameter is proved to be significantly constant in 2011-2018 and is excluded from the model, the econometric regression is fully based on the value-added per labor unit variable. By manipulating the model residual, one can derive an answer to the research questions with plant-specific data.

One of the most popular estimation tools in time-series estimation and in productivity analysis is the vector autoregressive (VAR) model. This technique represents random process in which different shocks, both technological and non-technological shocks, affect the steady state value of output (Chen et al. 2007, p. 17). These shocks can take any form depending of the data set and the objectives of the study. In this study, the nature of the shocks is determined earlier. Hence, the shock parameters will be determined by the value-added, labor input and the technological parameter.

The next step in the estimation process is to derive an econometric model to yield real values for the productivity parameter. With the capital input incorporated into the model the general model for the estimation purposes would be: $\Delta lnva_t = \propto_1 + b\Delta lnk_t + z_t$ (Gourio 2008, p. 20). As the model specification is being settled and since this study is focusing on the labor augmenting productivity, the above regression turns into $\Delta lnva_t = \propto_1 + z_t$, which is fully identical with the equation 11 when the capital is being constant. This means that the changes of value-added per labor unit are explained by the constant term $\propto_1$ and by the residual z_t. Here the z_t refers to the productivity parameter. Since the productivity shock term is not known, one needs to define that the periodic change in productivity is catch by the following expression (Koskinen & Vilmunen 2018; Solow 1957, p. 313):

$$\Delta A_t = \frac{A_t}{A_{t-1}} = exp\ z_t \qquad (12)$$

Equation 12 states that the real periodic changes in the productivity parameter equals to the expression of $exp\ z_t$. [7] This yielding the productivity parameter within our interests. The above relation denotes that the periodic change in the productivity parameter equals to exponent form of the variable z_t, which is originally defined in logarithms. The logarithmic form for the productivity term stems from the productivity equations' properties. The above equation can be alternatively presented as $\Delta a_t = lna_t - lna_{t-1} = z_t$, which is yield by taking natural logarithms both side of the equation. This relation states that the periodic change in the logarithmic productivity change can be expressed with help of the parameter z_t. Therefore, the objective is to identify this parameter z_t as accurately as possible, since it reveals the productivity development in the case plant.

To continue with the estimation, multiple studies have considered the variable z_t to reflect the first-order autoregressive process (AR(1)) on each period. The autoregressive process refers to the process where the past values, z_{t-n}, have an influence on the current values of the parameter z_t. More precisely, in the AR(1) process the current values of the parameter are effected by its values in the previous period $t-1$. The assumption of the series' autoregressive property is common and realistic approach in the economic estimation when handling time-series and estimating productivity from period to another (Gourio 2008, p. 2). Consequently, the productivity term z_t is catch with the help of the properties of the first-order autoregressive process. This kind of autoregressive process can be stated as (Koskinen & Vilmunen 2018, p. 917; Kasahara & Rodrique 2005, p. 12; Gourio 2008, p. 5):

$$z_t = \propto_1 + \rho z_{t-1} + \varepsilon_t \qquad (13)$$

Where $\varepsilon_t \sim N(0, \sigma^2)$. The residual term ε_t is assumed to be normally distributed, with mean value of zero and a constant standard deviation. Moreover, the residual term ε_t, based on the model specification, is stationary and independent of the model variable z_t. The values for z_t and z_{t-1} are known, since they reflect the values in model parameter, logarithmic value-added per worker or worked hour. Now the ε_t reflects the logarithmic productivity shock at period t and hence is in our interests. The absolute value of the parameter ρ is assumed to be less than one, which means that the process is stationary. Therefore, the time-

[7] Here the notation can be expressed as $exp\ z_t = e^{z_t}$, where the e equals approximately to 2.718281828.

series can be considered stable over time and the effect of the previous shock term is not permanent. Equation 13 defines a process, where the current value of the data variable is dependent on its own previous value and the stochastic innovation parameter ε_t.

Since the equation 13 describes an autoregressive process, it assumes that the parameter z_t is integrated degree of one. This indicating that it is has a unit root and is not a stationary over time. Naturally, if the z_t has unit root also its lagged value z_{t-1} has a unit root, since they correspond to values in the same parameter, but on separate periods. If these two non-stationary parameters are cointegrated their linear combination ε_t, like presented in equation 13, is stationary. In this case, the linear combination is a residual and it follows the normal distribution. Consequently, since the residual term reflects the productivity shocks, one of the simplified assumptions in the model is that the productivity is fully stationary over time (Gourio 2008, p. 2). This assumption, on the other hand, may not hold especially in the long run but it is needed to derive rational estimates for the productivity.

The reason why the relations stated in the above equations appear helpful in the estimation process is that they can reveal the actual values of the productivity growth development. Since the real change in productivity is defined in the exponential form as shown in equation 12, one can derive the actual development process for productivity by taking exponents of the logarithmic residual. This will be done with respect to the estimation results. Equations 12 and 13 and their relationship is fully derived and justified in the appendix 3.

Since the process of z_t is known, one can continue with defining that $z_t = \Delta lnva_t$ in this study. In other words, z_t is a process of logarithmic value-added per labor unit, which is in a form of logarithmic time differences. Using this information together with equation 13, one can obtain the final model for the estimation. The model can be stated as follows:

$$\Delta lnva_t = \propto + \rho \Delta lnva_{t-1} + \varepsilon_t \qquad t = 2, .., 30 \qquad (14)$$

Equation 14 will be the final regression which it is used for estimating the productivity parameter. It follows the first-order autoregressive process, as defined. The parameter $\propto$ is the model coefficient and ε_t is the logarithmic change rate for the productivity in the case plant. Based on equation 14, the current value of value-added per labor input is generated by the previous period's value-added per labor input and by the technical change. In other words, any increases or decreases in output-input ratio $\Delta lnva_t$, which cannot be explained by the previous input usage, has occurred via productivity growth. The estimation of equation 14 reveals the productivity growth fluctuations in the manufacturing plant.

The AR(1) process, which is used in the estimation, represents a time-series model. The values of the chosen variables are dependent on time and they may fluctuate over time. Therefore, before estimating the regression 14, few tests will be conducted to make sure the model variables and hence the residual behaves well. Only this guarantees valid estimation results and a solid interpretation. The autocorrelation and the existence of a unit root in the data variables are the main qualities being present when handling time-series. Traditionally, the stationarity of the test variables is one of the most key assumptions in the econometric analysis. This indicates that the variable does not have a unit root and the series stay stable over time. However, if the variable follows a non-stationary process it needs to be differentiated with respect to time to yield time differences. This forces the variable to fluctuate around its average value and hence guarantees a stable process. The amount of needed time differences depends on the power of integration of the variable. When time series becomes stationary with one time differentiation, it indicates that the time-series follows a I(1) process. In this case the time series has a unit root and is integrated of order one. If, on the other hand, the time series would be integrated order of two and follow a I(2) process, it need to be differentiated twice in order to make it stationary over time.

Despite the common approach and assume parameters stationary in the econometric analysis, due to the properties of the AR(1) model, the model variable needs to have a unit root. This is based on the assumption of the cointegration of the data variable. When two model parameters, in this case $lnva_t$ and $lnva_{t-1}$, are cointegrated, their linear combination, the residual ε_t, appears as white noise and it represents a stationary I(0) process. The testing for the time-series properties is one of the required steps in the estimation process and only it guarantees reliable estimation results.

Consequently, the last step before the productivity estimation is to examine the time-series' properties and to check the existence of a unit root in the key variable $lnva_t$. The stationarity and the existence of a unit root can be tested with econometric tools, using the Augmented Dickey-Fuller (ADF) test. The general form for the unit root test in the first-order process, without trend nor constant, can be stated as (Maddala & Wu 1999, p. 633):

$$\Delta y_t = \varphi y_{t-1} - \propto_1 \Delta y_{t-1} + \epsilon_t$$

Where the error term ϵ_t is stationary and $\varphi = \theta - 1$. Since we are estimating the first-order autoregressive process, it is enough to analyze the stationarity using only one-period lagged values. This is indicated by the lagged value y_{t-1}. The above regression states that the current changes in the test variable are explained by its previous values, both in a form of cumulative values and of periodic changes. In the above regression, the dependent variable y_t equals the value-added per labor unit. The hypotheses for the ADF test are the following:

H_0: $\theta = 1$; $y_t \sim I(1)$*: time series is non-stationary, unit root exists*

H_1: $|\theta| < 1$; $y_t \sim I(0)$*: time series is stationary, no unit root*

If the null hypothesis is rejected, the time series does not have a unit root and the series is stationary. In order to reject the null hypothesis, the φ term in the test regression needs to be statistically significantly different from value zero. This follows the fact $\varphi = \theta - 1$ and under the null hypothesis, when $\theta = 1$, the $\varphi = 0$. Otherwise the time series follows a trend and has a unit root. The test results, listed in the appendix 4, suggest that the key variables value-added per labor hours and per worker have a unit root and are non-stationary. Therefore, they are integrated with degree of one, follow the I(1) process, and they can be used for estimating the autoregressive model.

This section has derived a model for the short-run productivity growth estimation in the case manufacturing plant. The data variables are fully defined, along with the model parameters and the justification for the estimation method. The next step includes the econometric estimation of the productivity model. The objective is clear: to define the productivity growth development and the average productivity rate in the case factory. To make any conclusions about the topic, the next section will provide an overview of the main test results and analyze their contribution to the research problems.

5.2 Test results and the productivity performance of the case plant

Productivity models, which stem from the production function, have been derived and the regressions induced with the data variables can be analysed. The estimation process will follow the specified principles and hence the equation 14 can be estimated as an autoregressive process using econometric techniques. The regression will be estimated with ordinary least squares (OLS), which is one of the most popular methods in the productivity estimation. Once the test results have been obtained, one can analyse the dynamics of the model variable and the productivity parameter.

The regression, presented in equation 14, has been estimated and the summary of the test results is listed in table 8. The full description of the obtained test results is provided in the appendix 5. In table 8, the model L refers to model with labor force and H to model with labor hours. The partial goodness of fit R^2 tells how much the model variables explain changes in the dependent variable, or equivalently, what is their contribution to the output per labor unit changes at current period. The remaining movements in the output per labor input $\Delta lnva_t$ are assumed to be generated by the changes in productivity. Since the estimated values for the model parameters may be biased due to a unit root in the error term, one needs to test the existence of the unit root with the help of ADF test. If the models' residuals are stationary and the unit root is not found, the test values can be trusted and they can be analyzed. The ADF test results are listed in detail in the appendix 6 and the conclusion of the results is that the models' residuals behave correctly and the null hypothesis of the existence of a unit root can be rejected in both models. Hence, the test results are trustworthy.

Table 8. Summary of the test results

		Model	
Variable		**L**	**H**
Constant	Coefficient	0.0356	0.0501
	t-prob	(0.5857)	(0.4626)
	Partial R^2	0.0116	0.0209
$\boldsymbol{\Delta lnva_{t-1}}$	Coefficient	-0.5664	-0.6223
	t-prob	(0.0019)***	(0.0005)***
	Partial R^2	0.3147	0.3755
Residual $\boldsymbol{\varepsilon_t}$	Partial R^2	0.6853	0.6245

In table 8, the *t-prob* represents the value for the t-test for each variable. This value indicates whether the coefficient of the parameter is significantly different from zero and denotes whether the parameter should be included to the model. If the coefficient is statistically different from the zero, the null hypothesis of the t-test is rejected, and the parameter contributes to the model specification. Based on this knowledge and on the test results, one can conclude that the lagged variable $\Delta lnva_{t-1}$ is extremely significant at one per cent level in both models, while the constant term is not significant parameter in the models in any of the significance levels.[8] Consequently, the t-test's null hypothesis of the coefficient being equal to zero can be rejected and the independent variable captures well the changes happening in the dependent variable.

In the workforce model (L), the lagged value of value-added per worker explains relatively well the current output changes with a partial explanation rate of 0.3147. This means that

[8] In table 8, three stars *** indicate significance at 1% level. The significance at 5% level would be indicated by **.

the one periodic lagged value explains more than 30 per cent of the current changes in the value-added per worker. Another interesting observation is that the lagged value and the current value of the model parameter correlate negatively. When the current value increases with one, based on the test results, the previous value has decreased by -0.5664. This seems rational, since the periodic fluctuations in the variable were noticeable in the data set. The constant term, on the other hand, is not a significant parameter explaining changes in the dependent variable and it should not be included into the models. This can also be noticed from the fact that the constant term explains only one per cent of the changes in value-added per worked.

The constant terms 0,0356 and 0,0501 represent the estimated parameters for the average output per labor unit growth. This indicates that the quarterly output per labor has increased by 3,5% or by 5,0%. However, based on the t-test, these growth trends are not significant and can be disregarded. The models' constant terms do not explain the changes occurring in the model variable $\Delta lnva_t$ and consequently, it is reflected to the models' residuals. Based on the assumptions for the model regression (equation 14) the residual should be white noise. However, the residuals include some bias, and this is shown in their high degree of explanation. Hence, the interpretation of the residuals is problematic.

The value of the parameter rhoo guarantees the stationarity of the process only if $-1 < \rho < 1$, or equivalently if its absolute value is less than one. Table 8 has listed this value, and since the $\rho = -0{,}5664$ in the workforce model it fulfills the required condition and the process is stationary over time. In other words, the shock parameter loses its impact on the model parameter eventually. Moreover, the autocorrelation varies between positive and negative values for different time lags, since the ρ is negative. Any occurred productivity shock influences the current growth in the value-added per worker, but with diminishing returns. Given the estimation results, the productivity model per worker looks as follows:

$$\Delta\widehat{lnva}_t = 0{,}0356 - 0{,}5664 * \Delta lnva_{t-1} + \varepsilon_t$$

However, the constant term is not statistically significant and can be left out of the model. Since this study has specified the productivity as a model residual, one can calculate the importance of the productivity parameter based on the test results. As the lagged value $\Delta lnva_{t-1}$ explains dependent variable by more than 30 per cent, and since the coefficient term is not statistically significant, the remaining part of 68,53 per cent in the growth of dependent variable is due to technical change and productivity. This indicates that the output per worker fluctuates up to 69 per cent by some other factors than by previous values in the output-labor parameter. In other words, labor augmenting productivity parameter explains more than half of the actual periodic changes in the logarithmic value-added per worker. Based on the model specification, the residual term should appear as a white noise. Hence, the interpretation of this parameter should be done cautiously.

In the labor hour model, the results look similar than in the case of workforce. The lagged value of value-added per labor hours explains a bit better the overall changes in the dependent variable than in the case of workforce. Even though, the role of the technical process has been significant and the productivity parameter explains around 62 per cent of the total output per labor hour changes during the examination period. The labor hour model, based on the estimation results, can be now stated as:

$$\Delta\widehat{lnva}_t = 0{,}0501 - 0{,}6223 * \Delta lnva_{t-1} + \varepsilon_t$$

Also the labor hour model is stationary over time, since the absolute value of ρ is less than one, being equal to 0,6223. The effect of a productivity shock in the previous period is not fully reflected to the current period and the shock loses its strength over time. Considering this, the estimation results in both models are coherent. The periodic productivity change explains the variations in the model as much as 62,45 per cent, which is around two thirds of the total fluctuations. One could claim that the productivity plays an important part in the production process in both models. On the other hand, the estimation results may imply also that the production process includes uncertainty from period to another, which make both the value-added and productivity parameter unstable. In addition, the residual reflects also all the non-controlled variables in the production. Hence, the real contribution of the productivity parameter itself may be smaller than suggested in table 8.

The estimated productivity coefficients reflect both the productivity itself and the effect of all the other variables influencing production, which are not controlled in the model. Therefore, the given estimates are not a perfect reflection of the productivity process in the firm but can be considered the best possible approximate of the technical change and Solow residual. Even though the overall contribution of the labor augmenting productivity has been important to the output development, the finding does not tell anything about the qualities of the productivity growth or how it has developed over the examination period. This study will continue by providing further analysis on the periodic productivity changes and their development over the past eight years.

After the model estimation, one can start with the manipulation of the residual term to yield real series for the productivity changes. Since the estimation models are defined in logarithmic differences, also the residual term reflects these periodic changes. To understand the productivity development in the case factory, one needs to set the value for the base period as $lnA\left(\frac{Q1}{2011}\right) = a\left(\frac{Q1}{2011}\right) = 0.000$ and calculate the cumulative values for both productivity growth measures. The procedure follows the fact that $a(t+1) = a(t) + \Delta a(t+1)/a(t)$. As a result, the productivity at period Q2/2011 is zero plus the corresponding periodic change from period 1 to period 2. More detailed description of the data manipulation and the data series are presented in the appendix 7.

The following figure presents the cumulative values of the models' residuals. In addition to the actual series of the residual, the figure shows the trendline for the productivity growth in a form of a smoothing function. The author has used the Hodrick-Prescott (HP) filter to estimate the smoothed trend for the productivity growth and the HP filter series are presented by lines in figure 12. The HP filter is based on the moving average values of the original series, providing a symmetric trendline. The filter is widely used in macroeconomic estimation. The use of smoothing function is very illustrative and shows a clear trend in the productivity levels in the case plant.

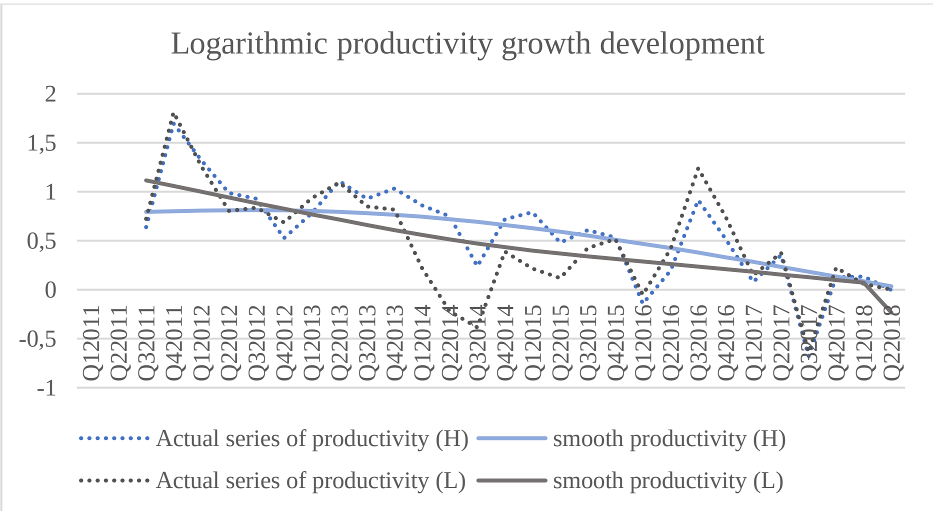

Figure 12. Cumulative productivity growth development in the case factory

Figure 12 shows that there have been clear productivity fluctuations over the examination period in both models. The actual values follow a random walk with drift and the models' residuals fluctuate both sides of the value zero. Especially in the last couple years the productivity growth has varied from period to another without a clear trend. This is mostly explained by the high volatility in case plant's value-added and simultaneous minor adjustments in the labor input. The heavy fluctuation of the productivity growth refers to unstable production processes, where the productivity is not on a sustainable level nor adjusted systematically based on the production volumes. On the other hand, when looking at the trendlines, or the drift, given by the HP filter one can notice that the growth in productivities has slowed down almost systematically between 2011 and 2018.

The decrease in the productivity growth has started few periods earlier in the workforce model than in the labor hour model. The productivity growth level, which is based on the hours worked, sustained its strong growth till year 2014. The trendlines for productivity in both models are clearly downwards sloping. Consequently, the test results suggest that the labor augmenting productivity growth and the technical process have been decreasing, contributing negatively to the output growth.

Figure 12 illustrates the productivity growth accumulation and hence, the following observations can be made. The average productivity growth accumulation in the labor force model has been 1,61.[9] This indicates that even though the trend for the productivity growth development has been heavily downward sloping, on average, the productivity growth has supported the output growth. However, the most recent value for the cumulative productivity growth per worked has been 0,79, which is clearly less than one and therefore contributed negatively to the output per worker development. Moreover, the relationship between the average growth rate and the latest growth suggests that the productivity has developed rapidly to the negative direction.

Similar situation is present in the labor hour model. The average value for the productivity growth accumulation during the entire period of 2011-2018 has been around 1,75, whereas the most recent productivity level has been only 1,04. When comparing these two models, one can conclude that the performance of the labor hour model has been more favorable than the workforce model. This phenomenon is logical, since the labor hours are easier to adjust to rapid and momentary market conditions or to output changes than the number of workers. The results suggest that the case manufacturing plant has increased or decreased the labor hours relative to short-run production fluctuations, whereas the decisions about workforce are based on the longer-term production development. This clarifies why the trendline of the labor hour productivity has been on a higher level than in the other model.

[9] The average logarithmic change rate for productivity in the workforce model is 0,478 and in the labor hour model 0,559 In non-logarithmic form: exp(0,478)=1,61 and exp(0,559)=1,75.

For further assessment of the periodic changes in the productivities, figure 13 provides the time-series of the periodic changes occurring in the smoothing functions' values. The HP filter values for the productivities have been converted to periodic time differences to illustrate the changes happening in the productivity. These growth rates have been illustrated by the curves, while the two straight lines indicate the average change in the logarithmic productivity. When the periodic change rates are analyzed and compared to the average level, one can notice the fluctuation in the productivity together with the recent trends in its development. The average level of the logarithmic productivity change in the workforce model has been around -0,04, while the periodic changes in the smoothing function gets values between -0,06 and -0,02. In a similar manner, the model based on the labor hours indicates that the average periodic change in the productivity growth has been -0,027 and it is straightforward with the results in the labor force model. In both models the periodic changes in the productivity growth have been minor, but the productivities have developed evidently in different manners.

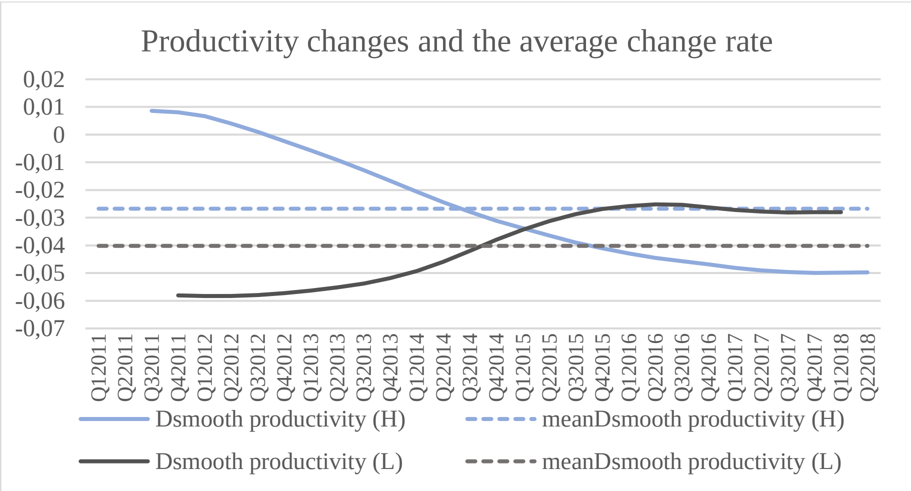

Figure 13. Periodic changes in the productivity measures in Q1/2011-Q2/2018

Figure 13 illustrates the quarterly changes in the logarithmic productivities and the average values for the productivity change during 2011-2018. In the workforce model, the periodic productivity change has been in fact upward sloping from 2011 till 2016, after which the periodic productivity growth rate development has slowed down and stayed quite stable. This indicates that the productivity change rate has actually improved in the workforce model, while the productivity growth has been systematically decreasing in the labor hour model. However, since the average value of the logarithmic productivity change is negative in both models, the effect of the periodic productivity on the output growth has been negative during the examination period. The support for this relationship was stated earlier by the logarithmic productivity equations or for example by equation 14. Since the residual term ε_t is below zero, its contribution to the quarterly growth in value-added is negative.

Since the above figures 12 and 13 present the productivity in logarithms, the actual average change rate for the periodic productivity equals $\Delta A(t) = \exp(-0{,}04018) = 0{,}960616$ in the workforce model. This is stated by equation 12. With the same methodology, the labor hour model provides an estimate for the periodic change rate for productivity and it equals to $\exp(-0{,}027) = 0{,}97$. If the models have been specified correctly, the real output changes should follow the changes in the productivity rate multiplied by the changes in the labor input. The non-logarithmic value for the average productivity growth is less than one and consequently, the contribution of the productivity growth is negative to the overall output growth dynamics. This observation is based on the following relation, which is consistent with the theory of the Cobb-Douglas production function when the capital is constant. By using the estimates given by the workforce model, one can conclude the following dynamics happening in our productivity model:

$$\frac{\Delta VA_t}{\Delta L_t} = \Delta A \quad \leftrightarrow \quad \frac{\Delta VA_t}{\Delta L_t} = 0{,}96 \quad \leftrightarrow \quad \Delta VA_t = 0{,}96 * \Delta L_t$$

The same analysis can be made for the estimates in the labor hour model, using the fact that $\Delta A(t) = 0{,}97$. The above relation states that the productivity change has in fact contributed negatively on the periodic value-added development in the case plant. Since the average quarterly change rate in the productivity parameter is less than one, it diminishes the impact of any positive change in the labor unit usage on the output development. If the productivity change would equal one, there would not be any technical process between the two periods, and the increase in the input variable is reflected fully to the growth in output. Positive technical process would be present in the production only if the productivity parameter is above one, $\Delta A(t) > 1$.

The estimation results suggest that the productivity has decreased especially in 2015 and in 2016, most likely due to decreasing output volume and production adjustments because of the crisis. The crisis represents a negative external shock, which may have reflected to the production process and hence to the productivity development. The downtrend in the productivity levels suggest that the manufacturing plant has not been able to retain its resource efficiency. Consequently, more inputs are needed to maintain the same volume in the output production. This supports the findings in previous studies, which have reported slowdown in productivity growth in recent years.

The decreasing productivity levels means that the case plant has not sustained the efficient input-output combinations. On the other hand, the smaller productivity growth can be due to minor adjustments in the input variables, when the output volume was being decreased. This conclusion is based on the basic definition of productivity, presented in equation 4, where the productivity equals to the ratio of output per value of inputs. The results, and especially the observation of the decreasing productivity levels, reflect some underlaying problems in the production to which managers should pay attention. If the productivity development continues as it is, and has been in last couple years, the production process is not sustainable and it wastes resources in the long run. Furthermore, declining productivity growth leads to smaller long-term profitability of the business process.

One of the underlying factors behind the productivity development can be the production's increasing material costs, such as the steel price. This has a direct negative effect on the productivity levels if the price increases in the material costs are bigger than the average producer price index, which has been considered in the estimation through the deflator. On the other hand, if the situation would be reversed and the average producer price index is bigger than the realized material costs at the plant, this would be reflected to the productivity levels as an increase and too optimistic productivity growth estimates. The real difference between the discount rate and the realized price changes in the production would require further studies of the cost categories and their development. This study will not provide any further analysis of the topic, but these relations are important to understand when interpreting the productivity development. The estimated productivity changes can be biased even though the possibility of errors has decreased to minimum.

In addition to the uncaptured price changes, when analyzing the total productivity, any increase or decrease in the productivity level does not necessarily represent productivity changes. For example, the qualitative stability of each input through time has been overlooked in the analysis. Because the productivity measure considers only one key input factor in the model, the productivity shifts can be generated by structural changes occurring in the production. For example, the decreasing trend in the labor augmenting productivity can be due to the actual productivity loss or due to substitution effects. The substitution effects take place if part of the machine hours has been replaced with humans, for instance. However, these factors are not observable, nor the degree of utilization of these inputs. The possibility of the structural change was ruled out and this error should be minor in the estimation results.

Furthermore, the reported productivity values may reflect changes in other internal or external factors which are not captured by the model. Therefore, it was important to econometrically justify the assumption of the constant capital. If the capital input would have been left out of the model without checking its development in the case plant, it could have increased the possibility of bias in the test results. Consequently, the productivity levels and productivity changes presented in figures 12 and 13 represents the best available knowledge of the productivity situation in the case plant. Even though the model and data set are defined based on the best acknowledge, supported by both theory and empirical observations, errors may occur in any empirical study. The next section discusses the main points about the models' performance. Furthermore, the following section focuses on the possible challenges in the trustworthiness of the productivity estimates.

5.3 Performance of the model

Based on the productivity models' test results, the models perform quite well and offer plausible estimates for the productivity changes during the examination period. Despite this, the biggest challenge in the model estimation is the heavy fluctuations in the output volume. When the output's periodic changes are big, the model parameters cannot explain all the occurring changes and the performance of the explanatory variables lack confidence. Consequently, the independent variables do not explain even half of the total fluctuations in the output. Moreover, the constant term is not significant in the model. Most likely, if the output development would be more stable over the periods and if it could be forecasted better, the coefficient of determination of the models would increase.

The residuals' relationship with the actual productivity rates has already been pointed out. The residual reflects the productivity process and the technical change, but it also includes all the other shock variables that are not included in the model, but which effects somehow on the output development. Therefore, the model specification and decision of the correct parameters cannot be highlighted enough. If the data is wrong or does not reflect the wanted production process, it will be reflected to the model's residual term. As a result, the productivity rates can be biased. This is called omitted variable bias and it occurs when the estimated model does not include all the relevant variables as independent variables. Usually the omitted variable bias leads to over- over underestimation the significance of one or more variables. The possibility of this kind of bias is reduced by models' strong link to the previous theoretical models and by plant-specific knowledge, but even still the correctness of the productivity parameter should be questioned.

Despite the challenging data set, the econometric results are trustworthy and the models' residuals behave well. Neither of the residuals include a unit root and their values follow the normal distribution, as assumed in the model specification. In addition, the residual is independent of the model variable. However, as stated earlier, the residual values include most probably also some other aspects and variable dynamics than just the productivity parameters. Due to the non-linearities in the data set, the use of more advanced econometric techniques would be appropriate to catch the real productivity changes. The productivity development reported in this study lacks confidence and they should be regarded as a guiding evidence, not exclusive.

Another important aspect in the econometric analysis is the problem of endogeneity of the independent model variable. This problem has been noted widely in the previous studies and it means that the estimation results may be biased if the independent parameters are defined party inside the model and hence are not fully exogenous. The issue of endogeneity would be a valid concern if this study would have estimated the basic form of the Cobb-Douglas production function, as presented in equation 8. In this case, the output value affects the input usage and the estimation results will be biased due to correlation between the model variables. However, since the estimation model in this study was specified in a different form and because the estimation is based on the first-order autoregressive process, the independent variable is explained by the variable's value in the previous period. Consequently, the lagged value is exogenous and the present value of the model parameter cannot affect the former values.

In traditional econometric approaches, when the analysis is conducted to a wider context, it would be appropriate to exclude outliers from the data. This means excluding the smallest and biggest values from the data set and from the regression. As a result, the estimation model could be easier to estimate, and the goodness of fit could increase. However, the approach in this study wanted to maintain highly practical and conduct the analysis with respect to needs of a single firm. In addition, the time series is available only from a short period of time. The exclusion of the outliers would result in discontinuous time series and would make the results more difficult to analyze. Based on these reasons, it is justified to use all the actual values available, without unnecessary data manipulation –even though it leads to non-linearities of the series.

There is also a possibility that the study has failed to identify the correct production function. If the form of the production function is incorrect, the estimation results can be biased. One could make sure that this kind of error does not occur by testing alternative models, which are based on different production function identifications. If there is no improvement in the test results, one can assume that the Cobb-Douglas production function is appropriate for the productivity measurement of the case plant. The reason why Cobb-Douglas production function was chosen as a status quo is because it has a strong support in the previous studies with similar estimation purposes. In addition, the Cobb-Douglas production function is flexible and allows estimation for one or multiple input parameters. Furthermore, the model performs well in the econometric estimation and can be considered a proper model for the productivity analysis.

Despite the problems in the models' performance, the results describe the development of the production process in a best possible manner. Even though the error term may include other elements too than just the Solow's residual, it offers an illustrative information of the drift in the production. This study will continue with the assessment of the test results and will discuss the contribution of the results.

5.4 Contribution of the results and discussion

Labor, being one of the most important production factors, defines a great deal of the case plant's short-run productivity fluctuations. Based on the findings in the previous studies and the results of the empirical part of the study, the labor input is relatively easy to measure and its interpretation is straightforward over time. Therefore, the labor augmenting productivities and their development are one of the key elements the firm should follow, since it contributes to the output development and to cost efficiency of the production operations. Based on the findings, both labor force and labor hours are valid proxies for the labor input. These two labor unit measures may result in different productivity estimates, but during the examination period they have followed a similar trendline. Since the labor hours are relatively flexible production factor, one could argue that the labor hours are more comprehensive to catch the short-term production fluctuations, while the workforce is more valid over the longer period of time.

The estimation results suggest that the production process in the manufacturing plant in terms of productivity is not sustainable at its current level. The trend of productivity growth is downward sloping and it indicates that the resources are not utilized efficiently, at least compared to the entire productivity development history in the plant. Furthermore, the quarterly productivity development has been weak. The test results show that there has been a structural change in the productivity growth development. The periodic productivity growth was on its highest levels during 2011 and 2012 in the labor hour model, while in the workforce model the highest growth rates were reported in the end of the examination period. Even though productivity is still an important factor in the production it is losing its significance.

The productivity accumulation has been on its highest levels in the beginning of the examination period, which indicates that in the beginning of the examination period occurred a positive productivity shock. The productivity development has had a favorable contribution to the output development especially on the first half of the examination period. However, the productivity shock follows a stationary process and the effect of the productivity shock disappears over the time. The findings suggest that the production has achieved a higher frontier for production possibilities in the beginning of the examination period, but due to the recent regress in productivity, the production is moving towards the original state with less efficient output-input combinations. It is difficult to analyze the full dynamics of the production because it is affected simultaneously by multiple shocks. The productivity levels reached in 2011 may not be feasible with current production properties. After all, the productivity is an abstract phenomenon and its realized impact on output changes can only be estimated approximately.

In a graphical form the estimation results can be presented as illustrated in figure 14. Any positive shock in productivity and technological possibilities shifts the production function upwards from period 1 to period 2. This has happened in the beginning of the examination period. However, since the results suggest slowdown in the productivity development, the productivity shock loses its strength over time. This indicates that the production process slowly returns to the lower level at period 3 and towards the original state (l_1, va_1). The positive gains from the productivity shock will disappear. The negative shift in the production function has already started, based on the estimation results. The following figure presents the production function dynamics with constant capital, as considered in this study. The x-axis illustrates the labor input usage and the y-axis the produced value-added.

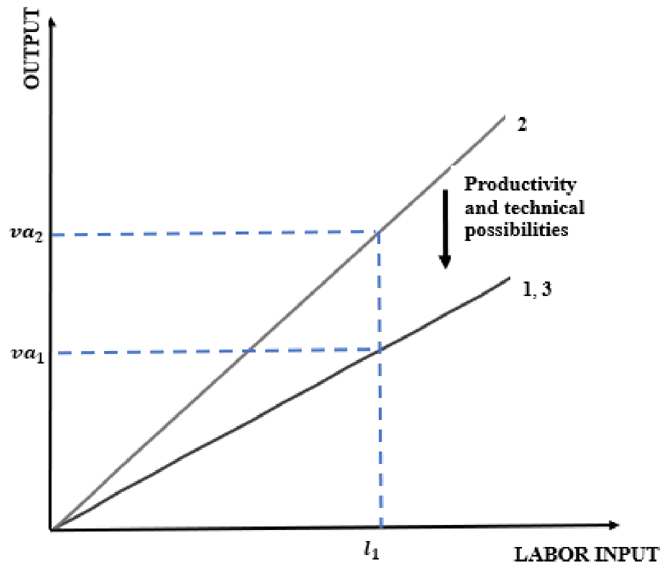

Figure 14. Figure illustration of the productivity development in the case plant

Similar productivity growth trends have been reported at macro-level both from developed and developing countries. This indicating that the results found in this study are not unique and they follow the same development pattern that is supported by multiple previous studies. However, the specific reasons for this development are not fully identified and they remain unsolved also in this study. Any further analysis about the underlying factors would require more comprehensive data of both internal and external factors.

This study has emphasized the role of labor in the production. However, the empirical part has disregarder any changes in elasticities of substitution between the input parameters and possible changes in the production processes. The deeper understanding of the causing factors of productivity development would require in-depth analysis of the underlying factors. This research, however, has focused only on the key parameters of the production to find a valid measurement tool with systematic contribution over time. The labor input has played an important role in the case plant's production and its contribution cannot be easily substituted by other input parameters. Consequently, when the value-added has been calculated respective to the labor unit, the results provide important observations of the productivity levels.

The results of this productivity analysis are beneficial for the case company in many ways. First, this study has provided a deep understanding of the resource development over the past eight years, excluding the effects of inflation. Furthermore, this study has identified the key parameters, which should be included into the analysis and which of them are relevant to take into consideration in the case plant's productivity assessment. These results are obtained under some specific circumstances and they may vary based on the time frame and reorganizations in the production. Despite these facts, the estimation results contribute to the understanding of the productivity growth dynamics in the case plant. The results are also a good way to indicate the recent development in the production and its cost efficiency to the management. Furthermore, the productivity model can be used alongside other productivity measures to analyze the sustainability of the production process.

Data constraints remain a valid issue in the empirical part of the study. The data set is narrow and includes only 30 periods. Trustworthy conclusions and comprehensive interpretation of the empirical results is a challenge. Furthermore, it is not reasonable to generalize the findings to any other context. If the empirical part of the study would have utilized a panel data, which includes observations from several manufacturing plants, the conclusions would be most likely clearer. In order to make any further remarks of the micro-level productivity growth dynamics, more data is needed. Moreover, application of the productivity model to the case manufacturing plant remains a challenge and more reliable results would require more complicated econometric techniques.

Even though this study has emphasized the role of productivity growth and its importance, not all benefits can be measured in money. Hence, attaining a high productivity level should not be a pure goal for the company. Productivity is a measure of value, but it ignores all the other values a firm may have. This kind of qualitative aspects were left out of the study, but they have had attention in the previous studies. However, assessment of the qualitative aspects is time consuming and not beneficial for the daily management nor for the purposes of this study.

The empirical evidence of the decreasing productivity rates together with the unstable market and price conditions in Ukraine keeps the case plant’s situation interesting. The production will most likely continue fluctuating from period to another and the risk of the increasing price levels is a valid concern. These resulting to the importance of the managerial attention on the plant’s processes. If the market conditions will not be improved and if there is a strict relationship between the output development and the productivity, as shown by the theory and empirical findings, the productivity growth rate is not expected to increase in the near future. The needed actions to support the productivity growth in the manufacturing process will be considered by the company.

6 Conclusions

Productivity growth and favorable technical change are critical factors in improving the output growth and in developing the resource efficiency, both at nation and firm level. This study has identified the main components influencing the productivity growth especially in a short-run production process. Furthermore, this study has conducted a micro-level estimation for the productivity development in the manufacturing plant in Ukraine. The theory has proved that the econometric techniques are well suited for the productivity analysis' purposes, but the estimation is not always straightforward. In addition, the data set and the length of the examination period have a strong influence on the test results and productivity growth's trendline. Hence, the productivity model should always be assessed based on the specific data and a study's purposes. The findings in this study supports the previous literature that in a short-run the productivity growth tends to fluctuate from period to another. Moreover, this study found a negative trendline for this productivity fluctuation. This fact was highlighted in the empirical part of the study.

The productivity analysis provides a highly interesting framework to assess the micro-level business processes. Even though the traditional approach is to apply productivity analysis to industry or national level, this study has shown that the basic principles behind the productivity growth are the same at micro-level. After all, all the economic growth starts from a micro-level performance and firms' capabilities to increase their productivity levels. Therefore, it is important for a firm to analyze and maintain its productivity levels to support the profitability of the business and economic growth. Furthermore, a correct productivity measurement supports the efficient resource utilization and cost minimization. Productivity growth is in the interest of a single firm and of an entire economy.

In the first part of this study, three research questions were determined. The answers to these questions will be provided based on both the existing literature and the results of the case study. One of the questions focused on determining the productivity tools and the problem was defined as follows:

How can productivity growth be measured at firm level?

There are multiple approaches to the productivity measurement at firm level. However, in economics, the most common approach in the productivity analysis is to use production function in the empirical estimation. This method has been applied widely both at micro-and macro-level estimations. When the production function is well defined, one can derive the productivity growth as a model residual, with respect to the specification given by the production function. This study has considered a specific form of the CES production function, the Cobb-Douglas production function, in the empirical estimation.

The Cobb-Douglas production function is flexible and it can be modified to satisfy the needs of the analysis, considering the properties of the data set. Consequently, the production function enables measuring productivity based on one input parameter or based on multiple production components. The former is rather simple to calculate, whereas the latter is usually more comprehensive and gives more realistic estimates for the productivity since it reduces bias of omitted variables. This study considered the properties of the Solow growth model and the estimation was based on a total productivity model, in which multiple production parameters are incorporated to the production function. Since the capital input is proven constant during the examination period in the case plant, the model is formed subject to the value-added and the labor input. As a result, the main interest lays in the human capital of the production. The human capital was separated to the number of operative workforce and the hours worked in the production. This approach was argued to be the most suitable in the Ukraine's manufacturing plant, considering the data properties and the short time period.

When analyzing the productivity over multiple years, one of the most important steps in the productivity estimation is discounting of the data variables. This study has deflated all the relevant model variables to the base period, to the first quarter of 2011. Only this approach guarantees proper estimates for the productivity development and excludes the effect of the inflation, which has been unstable in Ukraine. When all the relevant elements are incorporated into the specified productivity model, it becomes possible to analyze the dynamics of the productivity growth in the case plant. Hence, by econometric techniques, this study has found an answer to the other main topic:

How has the case manufacturing plant's productivity growth developed in 2011-2018?

The data set, achieved from the case plant, has many interesting properties. The output, being equal to the value-added, is highly volatile and the fluctuations from period to other causes non-linearities to the time series. Moreover, there has not been a structural change in the capital intensity between 2011 and 2018 and hence, the capital input is kept constant in the model dynamics. Since the value-added per labor unit is the dependent variable in the model, based on the theories and on the case-specific data properties, the labor is only significant input factor contributing to the output development. Consequently, this study has applied the labor augmenting production function to the productivity estimation.

Given these data properties and the specified production function, the estimation results of the productivity models suggest that the trend for the productivity growth accumulation is downward sloping in the case plant. The trend has been present in both models, even though the productivity level in the labor hour model remained on a higher level longer than when using the labor force as a proxy for the labor input. This can be explained by the fact that the human hours are relatively easy to adjust to short-run changes in the production, while the decisions about the labor force adjustments are not justified without a longer-term transition in the market conditions or production processes. The peak in the productivity growth occurred during 2011, after which the productivity has been declining systematically. This indicates that the productivity level has decreased in the case plant and one could argue the manufacturing plant is wasting its production resources compared to the beginning of the examination period.

Although labor force and labor hours are both valid proxies for labor input, they may result in contradicting conclusions. The estimation results suggest that a positive productivity shock has occurred in the case plant in the beginning of the examination period, but its favorable impact on the output dynamics has vanished by 2018. The stationary property of the productivity parameter was strongly supported by the test results. However, maybe surprisingly, the estimation results do not indicate any unusual drop in the productivity level during the Ukrainian crisis.

Once the productivity fluctuations in the case plant are known, it is possible to investigate the relationship between the productivity growth and output growth. The main objective of this study was to define whether there has been a favorable productivity growth during the examination period and whether this productivity development has supported the output growth in the case plant. The main research problem was specified as:

Has productivity contributed to output growth in the case plant between 2011-2018?

Both productivity models indicate that the productivity development has been an important factor in defining the production processes during the examination period. While in 2011 and 2012 the productivity growth was rapid due to a positive productivity shock, the most recent evidence suggests that the productivity growth accumulation has in fact contributed negatively on the output development. On average, the productivity growth development and the technical change have generated two thirds of the production fluctuations in the manufacturing plant. However, the decelerating growth rate of productivity in the manufacturing processes comes with the cost of profitability and resource efficiency, especially if the trend continues as it is.

When analyzing the quarterly productivity growth rates, the productivity has not performed well. The average quarterly change in the productivity parameter has been less than one during the last eight years. Consequently, the periodic productivity has in fact contributed negatively on the quarterly output growth development. While in the labor hour model the periodic change in the productivity parameter has decreased systematically, the productivity change in the workforce model improved momentarily. Nevertheless, both models' average productivity growth has been moderate. The periodic productivity growth rates suggest different results for the two models.

To conclude, the productivity growth accumulation has contributed positively to the output growth between the entire period of 2011-2018, but in an evidently diminishing manner. The periodic growth rate has, on the other hand, attributed negatively on the periodic output growth. Even though the results are plausible, some caution is needed when analyzing the results. The productivity parameter is only the best achievable estimate with applied models. Moreover, the estimated productivity parameter does not fully correspond to the theoretical Solow residual.

Despite the models' problems, the estimated drifts for the productivity changes are consistent with the findings in the previous studies. Multiple studies have reported declining trend in productivity, both in developed and developing countries. Hence, the results in this study reinforce these findings by concluding that the micro-level productivity development has not been sustainable in the case plant. The productivity gains are diminishing and the impact on the output growth is turning negative. This evidence is beneficial for the company managers since the results indicate possible inefficiencies in the production to which managers can act on. If the productivity development continues to follow its trendline, the resource efficiency in the case plant suffers.

For further research about the topic, it would be interesting to analyze the within company productivity performance in different international locations. One could also broaden the productivity model to the long-run context and include multiple shock parameters, such as interest rate or impact of R&D, into the model. With advanced econometric techniques it would become possible to research the possibility of non-stationarity properties of the productivity shocks. Furthermore, on a wider context, it would be feasible to investigate whether the different interest levels between the major economical areas have boosted or slowed down the overall economic growth and the productivity development. Theoretically, the lower interest rates should lead to a stronger demand and eventually to the higher output. There are multiple intriguing perspectives when analyzing the productivity growth and the scientific contribution on the topic will most likely stay strong.

Even though the gains of a micro-level productivity growth measurement may not seem obvious, the micro-level production processes and the short-term fluctuations determine economy’s productivity development in the long run. Productivity, on the other hand, is a key element in production’s efficiency assessment and it has a direct link to a firm’s profits and nations’ welfare. Based on the discussion in this study, one can conclude that “the productivity isn’t everything, but in a long run it’s almost everything” (Krugman 1997, pp. 11-12), and it should be analyzed comprehensively even in the micro units of an economy.

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Appendices

Appendix 1. Data details

Value-added (VA) In this study, the output equals value-added, which is the case plant's periodic sales volume, deducted by the value of intermediate inputs: $VA = Y - X$. The volumes have been deflated to base period, beginning of 2011, with corresponding inflation index, shown in the figure 10. Deflation has been accomplished with respect to the following formula, using decimal form of inflation index:

$$deflated\ value = \frac{Nominal\ value\ (Y_t)}{Price\ index\ at\ time\ t}$$

After the deflation, the value-added has been converted to logarithmic form ($lnVA_t = va_t$) and differentiated with respect to time. In mathematical form this means the following: $\Delta va_t = va_t - va_{t-1}$. As a result, we get the periodic changes of output volume, which can be used in the estimation process.

Intermediate inputs (X) The value of the intermediate inputs is needed in order to calculate the value-added. The intermediate inputs, as considered in this study, contains three cost categories: energy, services and materials. The relation can be presented as following: $\mathrm{X_t} = \mathrm{X_t^S} + \mathrm{X_t^M} + \mathrm{X_t^E}$. Energy (E) includes for example the use of electricity, water and gas. Services (S) is measured as maintenance of equipment used for production and other services that might occur. Materials (M) include all the other variables, such as new tools purchased for the production's purposes.

Labor input (L) This labor input includes the number of all the operative workers on each period. This means that labor input considers only productive workers, who work in the production, not in the office. Unlike the value-added and intermediate inputs, the labor does not need to be deflated. Therefore, the actual values of labor can be converted to logarithmic form ($lnL_t = l_t$) and time differences can be taken for each period.

Labor input (H) The other labor input, worked hours, informs the actual human hours worked at the production. Since the value is not found in the plant's income statement, the hours have been asked directly from the business controller. Otherwise the procedure is similar to other labor input presented above, and it does not need to be deflated. Only logarithms and periodic time differences need to be taken to yield variable, which is used in the estimation.

Capital input (K) This study has included to capital stock the depreciation rates of the machines and other equipment used in the production, together with the investment rate per period. As presented in the text, the productive capital stock is:

$$K_t = (1 - \delta_t)K_{t-1} + I_t$$

The depreciation rate has been given by the controller of the manufacturing plant. The capital stock has been deflated using producer price index (PPI) and transformed to logarithmic form and differentiated with respect to time to get the periodic changes in capital stock.

Appendix 2. Chow test for capital

The Chow test for structural change can be used to identify whether the capital per labor can be assumed constant over the examination period. The hypothesis for the Chow test are the following:

H_0: *no structural change*

H_1: *structural change*

The test results are shown in the tables i and ii.

Table i. Results for Chow-test, labor force

```
EQ( 3) Modelling LN(VA/L)defl by OLS
       The dataset is: C:\
       The estimation sample is: 1 - 30

                  Coefficient  Std.Error     HACSE  t-HACSE  t-prob Part.R^2
Constant              4.58770      1.690     1.280     3.59  0.0013   0.3147
ln(K/L)              0.132641     0.1745    0.1294     1.03  0.3141   0.0362

sigma                0.388087  RSS              4.21711879
R^2                 0.0202263  F(1,28) =      0.578 [0.453]
Adj.R^2            -0.0147657  log-likelihood     -13.1375
no. of observations        30  no. of parameters         2
mean(Y)               5.87177  se(Y)              0.385253

AR 1-2 test:      F(2,26)   =  0.97240 [0.3915]
ARCH 1-1 test:    F(1,28)   =  0.92458 [0.3445]
Normality test:   Chi^2(2)  =   2.3378 [0.3107]
Hetero test:      F(2,27)   =  0.22023 [0.8038]
Hetero-X test:    F(2,27)   =  0.22023 [0.8038]
RESET23 test:     F(2,26)   =  0.47923 [0.6246]

Test for excluding: ln(K/L)
Subset F(1,28)   =  0.57803 [0.4534]
Subset F(1,28)   =   1.0509 [0.3141]   (using HACSE)
```

Table ii. Results for Chow-test, labor hours

```
EQ( 4) Modelling ln(VA/H) by OLS
       The dataset is: C:\
       The estimation sample is: 1 - 30

                  Coefficient  Std.Error     HACSE  t-HACSE  t-prob Part.R^2
Constant              5.68974     0.9043    0.5235     10.9  0.0000   0.8084
LN(K/H)             0.0579084     0.2868    0.1557    0.372  0.7127   0.0049

sigma                0.391787  RSS              4.29791734
R^2                0.00145414  F(1,28) =    0.04078 [0.841]
Adj.R^2            -0.0342082  log-likelihood     -13.4222
no. of observations        30  no. of parameters         2
mean(Y)               5.87177  se(Y)              0.385253

AR 1-2 test:      F(2,26)   =  0.78895 [0.4649]
ARCH 1-1 test:    F(1,28)   =   1.6324 [0.2119]
Normality test:   Chi^2(2)  =   1.9542 [0.3764]
Hetero test:      F(2,27)   =  0.89133 [0.4218]
Hetero-X test:    F(2,27)   =  0.89133 [0.4218]
RESET23 test:     F(2,26)   = 0.030671 [0.9698]

Test for excluding: LN(K/H)
Subset F(1,28)   = 0.040775 [0.8414]
Subset F(1,28)   =  0.13841 [0.7127]   (using HACSE)
```

In neither of the exclusion tests the null hypothesis cannot be rejected, based on the F-test values 0,4534 (in the workforce model) and 0,8414 (in the labor hour model). The parameter coefficient is not statistically significantly different from zero. Consequently, there has not been structural change in the capital usage and it can be left out in both models.

Appendix 3. The model derivation

$$\Delta A_t = \frac{A_t}{A_{t-1}} = exp\ z_t \qquad |\ \textit{taking natural logarithms}$$

$$\Delta a_t = lna_t - lna_{t-1} = z_t$$

Where the z_t follows the AR(1) process as:

$$z_t = \propto_1 + \rho z_{t-1} + \varepsilon_t$$

One can merge these equations together, to yield:

$$lna_t - lna_{t-1} = \propto_1 + \rho z_{t-1} + \varepsilon_t \qquad |\ \textit{because}\ \ z_t = lna_t - lna_{t-1} = lnva_t - lnva_{t-1}$$ [10]

$$lna_t - lna_{t-1} = \propto_1 + \rho[lna_{t-1} - lna_{t-2}] + \varepsilon_t$$

$$\Delta va_t = \propto_1 + \rho \Delta va_{t-1} + \varepsilon_t$$

The term Δva_t is known based on the data set. With the help of $\propto_1$ and ρ one can calculate the process for productivity, when the first value of the logarithmic productivity change is known. Because now the productivity process is expressed with logarithms, one can take exp(.) function to yield the original productivity growth ΔA_t.

[10] Since $\Delta va = \Delta a$, based on the Cobb-Douglas production function with constant capital

Appendix 4. ADF test results for the model variables

The Augmented Dickey-Fuller (ADF) test is used to analyze whether the model variables have a unit root or not. The test regression (without constant, without trend) is the following: $\Delta y_t = \varphi y_{t-1} - \propto_1 \Delta y_{t-1} + \epsilon_t$. Where the $\varphi = \theta - 1$.The hypothesis in the test can be stated as: H_0: $\theta = 1$, *time series is non-stationary, unit root exists;* H_1: $|\theta| < 1$, *time series is stationary, no unit root.*

First, one needs to identify whether ln(VA/L) is stationary. As shown in the following test result tables, the null hypothesis of a unit root cannot be rejected, and the logarithmic value-added per worker is non-stationary. This finding is consistent with the assumptions of the AR(1) process, which is used for productivity estimation.

Table iii. ADF test results for value-added per labor force

```
Augmented Dickey-Fuller test for lnVA/L; regression of DlnVA/L on:

                Coefficient    Std.Error      t-value
lnVA/L_1          0.0039010    0.0083374      0.46789
DlnVA/L_1          -0.56787      0.16435      -3.4553

sigma = 0.534417  DW = 2.181  DW-lnVA/L = 2.21  ADF-lnVA/L = 0.4679
Critical values used in ADF test: 5%=-1.954, 1%=-2.649
RSS = 7.425653411 for 2 variables and 28 observations
```

The test value 0,46789 > critical value -1,954. The value-added per labor force has a unit root and is non-stationary series. Since the original variable is non-stationary, one needs to test whether its first difference is stationary. Now the test variable is $\Delta \ln(\frac{VA}{L})$. Like shown in the following test result table (table iv), the variable is stationary, since the null hypothesis is rejected. Consequently, the model variable is non-stationary and follows a I(1) process.

Table iv. ADF test results for differentiated value-added per labor force

```
Augmented Dickey-Fuller test for DlnVA/L; regression of DDlnVA/L on:

                Coefficient    Std.Error      t-value
DlnVA/L_1           -1.9581      0.33135      -5.9094
DDlnVA/L_1          0.27324      0.19341       1.4127

sigma = 0.504703  DW = 2.123  DW-DlnVA/L = 3.193  ADF-DlnVA/L = -5.909**
Critical values used in ADF test: 5%=-1.954, 1%=-2.652
RSS = 6.36813014 for 2 variables and 27 observations
```

The test value -5,9094 < critical value -2,656. The value-added is stationary on 1% level. In a similar way one can test the unit root of the model variable ln(VA/H). The conclusion is same than in the case of labor force model: the value-added per labor hours follows a I(1) process. The test results are presented in the table v.

Table v. ADF test results for value-added per labor hours

```
Augmented Dickey-Fuller test for ln(VA/H); regression of Dln(VA/H) on:

                  Coefficient    Std.Error      t-value
ln(VA/H)_1          0.0023995     0.015500      0.15481
Dln(VA/H)_1          -0.60369      0.15400      -3.9201

sigma = 0.475459  DW = 2.485  DW-ln(VA/Hdefl) = 2.854  ADF-ln(VA/Hdefl) = 0.1548
Critical values used in ADF test: 5%=-1.954, 1%=-2.652
RSS = 5.651537665 for 2 variables and 27 observations

Augmented Dickey-Fuller test for Dln(VA/H); regression of DDln(VA/H) on:

                  Coefficient    Std.Error      t-value
Dln(VA/H)_1           -2.1621      0.32904      -6.5709
DDln(VA/H)_1          0.35579      0.18795       1.8930

sigma = 0.44487  DW = 2.078  DW-Dln(VA/H) = 3.31  ADF-Dln(VA/H) = -6.571**
Critical values used in ADF test: 5%=-1.954, 1%=-2.652
RSS = 4.94773173 for 2 variables and 27 observations
```

Appendix 5. The estimation results

This section provides the full test results for the productivity models. The existence of a unit root in the model residual will be tested in the appendix 6. The results of the models are the following:

Table vi. The test results of the AR(1) models

```
EQ( 1) Modelling DlnVA/L by OLS
       The dataset is: C:\
       The estimation sample is: 3 - 30

                  Coefficient  Std.Error  t-value  t-prob Part.R^2
DlnVA/L_1           -0.566356     0.1639    -3.46  0.0019   0.3147
Constant            0.0556858     0.1009    0.552  0.5856   0.0116

sigma                0.533545  RSS               7.40141493
R^2                  0.314656  F(1,26) =     11.94 [0.002]**
Adj.R^2              0.288297  log-likelihood      -21.1028
no. of observations        28  no. of parameters          2
mean(DlnVA/L)        0.046258  se(DlnVA/L)         0.632443

AR 1-2 test:      F(2,24)    =  0.94980 [0.4009]
ARCH 1-1 test:    F(1,26)    =   1.4022 [0.2471]
Normality test:   Chi^2(2)   =  0.93858 [0.6254]
Hetero test:      F(2,25)    =  0.31386 [0.7335]
Hetero-X test:    F(2,25)    =  0.31386 [0.7335]
RESET23 test:     F(2,24)    =  0.69850 [0.5072]
```

```
EQ( 2) Modelling Dln(VA/H) by OLS
       The dataset is: C:\
       The estimation sample is: 3 - 30

                  Coefficient  Std.Error      HACSE  t-HACSE  t-prob Part.R^2
Dln(VA/H)_1         -0.622313     0.1553     0.1574    -3.95  0.0005   0.3755
Constant            0.0500763    0.09130    0.06716    0.746  0.4626   0.0209

sigma                0.482983  RSS               6.06509267
R^2                  0.381656  F(1,26) =     16.05 [0.000]**
Adj.R^2              0.357873  log-likelihood      -18.3151
no. of observations        28  no. of parameters          2
mean(Dln(VA/H))     0.0413049  se(Dln(VA/H))       0.602729

AR 1-2 test:      F(2,24)    =   1.4370 [0.2574]
ARCH 1-1 test:    F(1,26)    =   1.0398 [0.3173]
Normality test:   Chi^2(2)   =  0.68258 [0.7109]
Hetero test:      F(2,25)    =  0.17861 [0.8375]
Hetero-X test:    F(2,25)    =  0.17861 [0.8375]
RESET23 test:     F(2,24)    =   2.0776 [0.1472]
```

When the variable va_t is explained with its first lagged value, one obtains the above results. The lag value of value-added per labor unit explains 31,47 per cent of the total fluctuations in the labor force model, while in the labor hour model it explains almost 38 per cent. In the labor force model, the constant term explains a bit over one per cent (which is not statistically significant), and the model residual explains the rest of the model variations. This residual is the productivity parameter in a form of logarithmic differences. The constant term is not significant either in the labor hour model, since it explains only two per cent of the fluctuation sin the dependent variable. The lagged value of value-added is statistically significant on 1% level. This can be seen from the value of ‘t-prob’ in the table. Consequently, the productivity parameter explains up to 1-0,3755= 0,6245 (62,45%) of the changes.

The model residuals follow the normal distribution. The assumption of normal distribution was one of the most important assumptions in the model and regarding the distribution of the residual there is no error occurring. This can be read from the chi square test values and with the null hypothesis of ‘follows the normal distribution’, the null hypothesis cannot be rejected. For further illustration, the following figure plots the residuals from both models against the normal distribution.

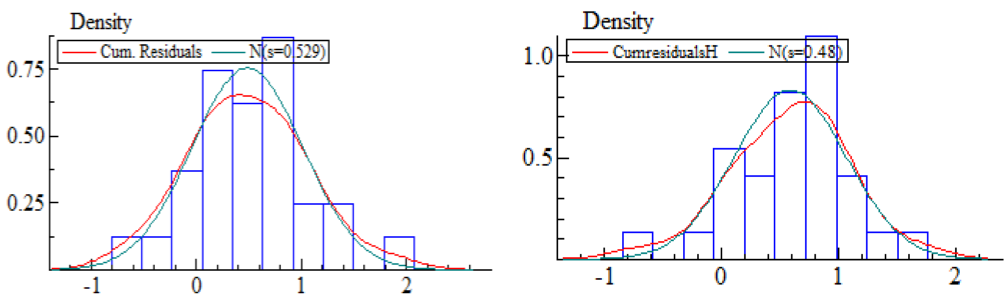

Figure vii. The distribution of models’ residuals against the normal distribution

Appendix 6. Testing for residuals' unit root

To the model perform well, the linear combination, or residual, of the non-stationary variables need to be stationary. Therefore, the unit root of the residual need to be tested with Augmented Dickey Fuller test. The test regression (without constant, without trend) is the following: $\Delta y_t = \varphi y_{t-1} - \propto_1 \Delta y_{t-1} + \epsilon_t$. Where the $\varphi = \theta - 1$. The hypothesis in the test are the following: H_0: $\theta = 1$, *time series is non-stationary, unit root exists;* H_1: $|\theta| < 1$, *time series is stationary, no unit root.*

Table vii. ADF test results for model residua (labor force)

```
Augmented Dickey-Fuller test for residuals; regression of Dresiduals on:

                 Coefficient    Std.Error      t-value
residuals_1          -1.5441      0.25421      -6.0741
Dresiduals_1         0.25759      0.16590       1.5526

sigma = 0.446362  DW = 2.03  DW-residuals = 2.393  ADF-residuals = -6.074**
Critical values used in ADF test: 5%=-1.955, 1%=-2.656
RSS = 4.781737032 for 2 variables and 26 observations
```

The test value -3,9154 < critical value -2,66. The model residual is stationary on 1% level. However, this test result only indicates that the residual is I(1) process, to find out whether non-differentiated residuals have a unit root, one needs to conduct ADF test for the cumulative values of the residual. This is listed below.

Table viii. The ADF test for cumulative residuals (labor force)

```
Augmented Dickey-Fuller test for Cum. Residuals; regression of DCum. Residuals on:

                    Coefficient    Std.Error      t-value
Cum. Residuals_1       -0.29581      0.11803      -2.5063
DCum. Residuals_1      -0.11426      0.16808     -0.67979

sigma = 0.41686  DW = 2.117  DW-Cum. Residuals = 0.9065  ADF-Cum. Residuals = -2.506*
Critical values used in ADF test: 5%=-1.955, 1%=-2.656
RSS = 4.170525973 for 2 variables and 26 observations
```

The test value is -2,5063 and it is smaller than the critical value -1,955. Consequently, the cumulative residuals does not have a unit root (on 5% significance level) and it is a I(0) process. Consequently, the AR(1) model performs well, since the residual does not have a unit root. The same conclusions can be made of the other model, where the labor input equals to worked human hours. The test results of ADF test are listed in the following tables (tables ix and x), and one can conclude that the productivity does not have a unit root and hence it follows a I(0) process and is stationary over time.

Table ix. ADF test results for model residua (labor hours)

```
Augmented Dickey-Fuller test for residualsH; regression of DresidualsH on:

                 Coefficient    Std.Error      t-value
residualsH_1         -1.6700      0.24840      -6.7230
DresidualsH_1        0.28665      0.15768       1.8180

sigma = 0.380077  DW = 2.171  DW-residualsH = 2.661  ADF-residualsH = -6.723**
Critical values used in ADF test: 5%=-1.955, 1%=-2.656
RSS = 3.467003163 for 2 variables and 26 observations
```

Table x. The ADF test for cumulative residuals (labor hours)

```
Augmented Dickey-Fuller test for CumresidualsH; regression of DCumresidualsH on:

                   Coefficient    Std.Error      t-value
CumresidualsH_1       -0.19756     0.098716      -2.0013
DCumresidualsH_1      -0.23268      0.16459      -1.4137

sigma = 0.375315  DW = 2.309  DW-CumresidualsH = 0.852  ADF-CumresidualsH = -2.001*
Critical values used in ADF test: 5%=-1.955, 1%=-2.656
RSS = 3.38066374 for 2 variables and 26 observations
```

Appendix 7. Estimated productivity changes and cumulative values

The following table lists the values for periodic change for logarithmic productivity, changes for the non-logarithmic productivity and finally the cumulative values for the productivity. The cumulative values are calculated based on the value changes, giving the fact that the value for base year productivities is equal to zero. Due to the model setting, the series gets its first value on third period, and hence the base value is set on Q2/2011.

The calculations are based on the fact $\Delta A = \exp(\Delta a)$.

The smoothed trendline values are attained by the Hordick-Prescott filter. The HP filter has been calculated with value 1600 for lambra, which is a correct value for the smoothing parameter when analyzing quarterly data.

Table xi. The actual series for productivity changes and cumulative values

Productivity model with labor force

Period	Δa	*a(t)*	*smooth a(t)*	*Dsmooth a(t)*	*mean Dsmooth a(t)*	*mean At)*
Q12011					-0,040	0,961
Q22011					-0,040	0,961
Q32011	0,723	0,723	1,116		-0,040	0,961
Q42011	1,088	1,811	1,058	-0,058	-0,040	0,961
Q12012	-0,554	1,257	1,000	-0,058	-0,040	0,961
Q22012	-0,452	0,805	0,941	-0,058	-0,040	0,961
Q32012	0,033	0,838	0,883	-0,058	-0,040	0,961
Q42012	-0,151	0,687	0,826	-0,057	-0,040	0,961
Q12013	0,247	0,934	0,770	-0,056	-0,040	0,961
Q22013	0,162	1,095	0,715	-0,055	-0,040	0,961
Q32013	-0,245	0,851	0,661	-0,054	-0,040	0,961
Q42013	-0,035	0,816	0,609	-0,052	-0,040	0,961
Q12014	-0,600	0,216	0,560	-0,049	-0,040	0,961
Q22014	-0,439	-0,223	0,514	-0,046	-0,040	0,961
Q32014	-0,162	-0,384	0,472	-0,042	-0,040	0,961
Q42014	0,775	0,391	0,434	-0,038	-0,040	0,961
Q12015	-0,176	0,215	0,400	-0,034	-0,040	0,961
Q22015	-0,096	0,119	0,368	-0,031	-0,040	0,961
Q32015	0,307	0,425	0,340	-0,029	-0,040	0,961
Q42015	0,093	0,518	0,313	-0,027	-0,040	0,961
Q12016	-0,571	-0,053	0,287	-0,026	-0,040	0,961
Q22016	0,471	0,418	0,262	-0,025	-0,040	0,961
Q32016	0,820	1,239	0,237	-0,025	-0,040	0,961
Q42016	-0,497	0,742	0,210	-0,026	-0,040	0,961
Q12017	-0,593	0,149	0,183	-0,027	-0,040	0,961
Q22017	0,228	0,377	0,155	-0,028	-0,040	0,961
Q32017	-1,018	-0,640	0,127	-0,028	-0,040	0,961
Q42017	0,867	0,227	0,099	-0,028	-0,040	0,961
Q12018	-0,168	0,058	0,071	-0,028	-0,040	0,961
Q22018	-0,058	0,000	-0,233	-0,028	-0,040	0,961

Productivity model with labor hours

Period	Δa	*a(t)*	*smooth a(t)*	*Dsmooth a(t)*	*mean Dsmooth a(t)*	*mean At)*
Q12011					-0,027	0,974
Q22011					-0,027	0,974
Q32011	0,638	0,638	0,793		-0,027	0,974
Q42011	1,058	1,696	0,801	0,008	-0,027	0,974
Q12012	-0,376	1,320	0,808	0,007	-0,027	0,974
Q22012	-0,334	0,986	0,812	0,004	-0,027	0,974
Q32012	-0,058	0,927	0,813	0,001	-0,027	0,974
Q42012	-0,401	0,526	0,810	-0,002	-0,027	0,974
Q12013	0,255	0,781	0,804	-0,006	-0,027	0,974
Q22013	0,328	1,109	0,795	-0,009	-0,027	0,974
Q32013	-0,180	0,929	0,782	-0,013	-0,027	0,974
Q42013	0,105	1,034	0,766	-0,017	-0,027	0,974
Q12014	-0,174	0,860	0,745	-0,021	-0,027	0,974
Q22014	-0,111	0,749	0,721	-0,024	-0,027	0,974
Q32014	-0,511	0,238	0,693	-0,028	-0,027	0,974
Q42014	0,482	0,720	0,662	-0,031	-0,027	0,974
Q12015	0,073	0,792	0,628	-0,034	-0,027	0,974
Q22015	-0,311	0,481	0,591	-0,036	-0,027	0,974
Q32015	0,126	0,607	0,552	-0,039	-0,027	0,974
Q42015	-0,073	0,534	0,511	-0,041	-0,027	0,974
Q12016	-0,677	-0,143	0,468	-0,043	-0,027	0,974
Q22016	0,340	0,198	0,424	-0,044	-0,027	0,974
Q32016	0,717	0,915	0,378	-0,046	-0,027	0,974
Q42016	-0,398	0,517	0,331	-0,047	-0,027	0,974
Q12017	-0,438	0,078	0,283	-0,048	-0,027	0,974
Q22017	0,275	0,353	0,234	-0,049	-0,027	0,974
Q32017	-1,032	-0,678	0,185	-0,050	-0,027	0,974
Q42017	0,806	0,128	0,135	-0,050	-0,027	0,974
Q12018	0,005	0,133	0,085	-0,050	-0,027	0,974
Q22018	-0,135	-0,002	0,035	-0,050	-0,027	0,974