KAUNAS UNIVERSITY OF TECHNOLOGY

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NEOCLASSICAL MODEL FOR THE EVALUATION OF FACTORS AFFECTING TECHNOLOGICAL PROGRESS IN MANUFACTURING INDUSTRY

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KAUNO TECHNOLOGIJOS UNIVERSITETAS

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NEOKLASIKINIS TECHNOLOGINĖS PAŽANGOS VEIKSNIŲ APDIRBAMOJOJE PRAMONĖJE VERTINIMO MODELIS

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LIST OF ABBREVIATIONS

ABM Agent-Based Modelling
ACE Agent-Based Computational Economics
CAPM Capital Asset Pricing Model
CCC Cash Conversion Cycle
CML Capital Market Line
DEA Data Envelopment Analysis
DMU Decision Making Unit
EKC Environmental Kuznets Curve
EVA Economic Value Added
FDI Foreign Direct Investment
GDP Gross Domestic Product
NPV Net Present Value
OLS Ordinary Least Squares
R&D Research and Development
SFA Stochastic Frontier Analysis
TE Technological Efficiency
TFP Total Factor Productivity
VAR Vector Autoregression
WACC Weighted Average Cost of Capital

INTRODUCTION

The relevance of research topic

Economic development is a very engaging but also a highly complex and challenging subject. The branch of development economics not only analyzes the growth of the aggregate output, but also evaluates fundamental transformations of the economy including the sectoral structure, demographic and geographic composition while also trying to explain the entire social and institutional fabric (Acemoglu, 2012). This leads to a variety of different approaches for tackling important questions of economic development. Another important aspect of economic growth theories is the ability to assess the evolution of the technological progress and analyze the creation of innovations while measuring their impact on economic growth and social development.

It took some time for the economic growth theory to reach its modern approach. At first, Adam Smith in his book *Wealth of Nations* analyzed the process of economic growth as a strictly endogenous one, while emphasizing the impact of capital accumulation on labor productivity. Still, according to Smith, there is no upper limit to labor productivity. According to Smith, the potential limits of growth could only be the insufficient supply of workers, the scantiness of the nature or the erosion of the motives of accumulation, without even addressing the possibility of the diminishing returns to capital. Later, David Ricardo, while analyzing the issue of economic development, also saw the rate of capital accumulation as an endogenous one, and, according to him, the main ingredient for reaching the stationary state was the limited supply of available land, again, assuming that the set of methods for production are given and constant, thus suggesting constant returns to scale (Kurz, Salvadori, 2003).

Throughout time, the school of economic thought developed and refuted the ideas of the early classical perpetual growth theories. The neoclassical economic growth theory strives to explain the income distribution in a symmetrical way, through the relative scarcities of such production factors as labor, capital and land. The idea of exogenous growth is the starting point in the tradition of the neoclassical growth theory. The most important attribute of the neoclassical growth theory is the assumption of diminishing returns to capital and labor, thus analyzing the structural characteristics of the steady states and their asymptotic stability (Solow, 1999). The Schumpeterian framework tried to further improve the economic growth theory and its understanding by addressing the importance of innovation on the long-term growth (Aghion, Festre, 2017). The presently discussed theory suggests that innovation is a result of investments into research and development, investments into skills of the employed labor capital, search for new markets, etc. These new innovations render the old technologies and skills obsolete. Thus, technological progress becomes endogenous, in contrary to the neoclassical growth theory.

Throughout time, other relevant aspects were incorporated into the analysis of economic growth. In such a way, the concepts of human development and sustainable development were established. Lately, attention was largely shifted towards the role of natural resources and environment, the fundamental aspects of human well-being and the quality of life (Costantini, Monni, 2008). More consideration was being given to the role of economic growth in reducing poverty, increasing the human development levels and achieving higher living standards, while emphasizing that these goals should be achieved in such a way that the generated level of well-being could be transferred and maintained by the future generations in a qualitative way.

Our analysis of literature indicates that, throughout time, the topic of economic growth and development has always been relevant. Frameworks for the analysis of economic growth have also constantly been adapted and developed throughout time so that to reflect the relevant aspects of various societies and their respective problems. The current relevance of the theories of economic growth can be explained through the context of globalization and the fourth industrial revolution, thus emphasizing the importance of the technological progress on economic development.

The manufacturing industry occupies an important part in the analysis of economic development as it is the key sector in many national economies and is involved in the process of the creation of sustainable economic growth (Behun *et al.*, 2018). Manufacturing industries exert significant impact on the economic development in terms of economic, social, environmental and institutional dimensions while also shaping the international trade and global competition, laying foundations for the requirements on more efficient utilization of raw materials and energy. They also influence the qualification structure of the workforce and their skills. Throughout history, there existed various instances when major technological advancements were achieved through innovations created at the industrial level. For these reasons, the activities of manufacturing industries are an important part in the process of economic development. The factors of the manufacturing level and their effect on technological development require detailed analysis.

Scientific problem and the extent of its investigation

With a vast variety of economic development theories and models, each of them has their own unique advantages and disadvantages. Classical economic theories are outdated by today's standards as they are a product of their specific time period. Their ideas were limited by the conditions of the predominantly agrarian economy; hence, in the classical theories, significant changes in the methods of production were not yet witnessed (Harris, 2007). Analysis of the classical economic development theories underestimated the far-reaching character of technological progress as a factor influencing the conditions of productivity both in agriculture and in the manufacturing industry.

The neoclassical growth theories inherently have their own shortcomings which could be improved upon. For example, in the Solow's neoclassical growth model, the variable of technological progress is handled as an exogenous variable; thus, the measure is recognized as growing at a constant rate (Jones, Vollrath, 2013), which might be inaccurate while exploring the determinants of long-term economic growth (Barro, Sala-i-Martin, 2004). Neoclassical growth models also suggest that differences in investment rates lead to either convergence or divergence of economic growth between markets, although the exact reasons for inequalities are not analyzed by the theory (Weil, 2013). Finally, the reasons of economic growth and development are explained through factors on the supply side, while any differences pertaining to the variables on the demand side are left unaccounted for (Landreth, Colander, 2001).

Although the theories of endogenous growth are an improvement on the economic development analysis framework proposed in the neoclassical growth theories, they still receive certain criticism. These critiques are related to the modelling of uncertainty in individual decision making, restriction of analysis on the steady state equilibria, and lack of inherent time reversibility (Alcouffe, Kuhn, 2004). The theories of endogenous growth also eliminate the assumption of perfect competition from the analysis of economic growth and replace it with imperfect competition and increasing returns to scale, which allows for the generation of new ideas and creation of innovations where knowledge is assumed to be a public good shared between companies operating in a market (Cavusoglu, Tebaldi, 2006).

Even the increasingly relevant and attention-grabbing theories of sustainable growth receive fair share of criticism. The currently developed sustainable growth theories are regarded as being oriented towards specific issues of various different sectors, and they cover only a short-term plan of action (Gaziulusoy, 2015). Methodologies for the analysis of economic and ecological interactions require fundamentally more unified approaches associated with new measures of sustainable development (Moffatt, 2000).

Thus, analysis of literature indicates that every theory of economic growth reconciles with a unique set of limitations in order to analyze the economic development from a distinctive perspective. In the case of the most popular theories of economic growth, the variable of technological progress is either analyzed as an exogenous variable, or else any factors influencing changes in the technological progress are not evaluated in detail. This limits the understanding of changes whichever the measure of technological progress incurs throughout time, thus hampering analysis of economic development. This research is dedicated to eliminating the above described limitations by improving analysis of technological progress in the context of manufacturing industries.

The objects of this research are the sectors operating in the manufacturing industry and the value changes of the dynamic technological progress of these sectors.

The aim of this research

To construct a model for the evaluation of factors affecting technological progress in the manufacturing industry which represents how changes in factors influence variations of the values of technological progress.

Research objectives

1. To distinguish the most appropriate methods for the evaluation of technological progress.
2. To verify factors which exert the largest impact on the growth of manufacturing industries and the changes in the measures of technological progress.
3. To form a methodology for the estimation of the measures of technological progress.

4. To create a model which includes the estimation of technological progress measure values, the examination of the presence of the technological progress spillover effect in the case of manufacturing industries and the determination of the functional forms of the measure of technological progress.
5. To examine the practical applicability of the constructed model in the case of the Lithuanian manufacturing industry by carrying out sensitivity analysis.

Research methods

The method of systematic analysis of academic literature was used in order to single out the factors which can potentially influence changes in the technological progress values, assess the main shortcomings of the currently most popular theories of technological progress evaluation and define the most accurate methods for the value estimation of technological progress.

For the estimation of the technological progress measure values, the time series regression method was used; it built on the basis of the Solow's neoclassical growth theory. In order to evaluate whether the effect of the intersectoral technological progress spillover takes place, the Granger causality test was employed. For the formation of functions which we use to estimate the effect of various factors on the fluctuations of the measure of technological progress, the vector autoregression method was utilized. Sensitivity analysis on the technological progress values was performed by using the agent-based modelling methodology.

Statistical analysis was carried out, and all previously mentioned econometric methods were implemented with the help of scripts written in *R* programming language. Tables and graphs presented in our research paper were prepared and formatted with the help of the *Microsoft Excel* software.

Scientific novelty, theoretical significance and practical application of dissertation

The evaluation model in the presented research was built on the basis of the neoclassical growth theories. This dissertation strives to improve the evaluation of the values of technological progress as presented in the Solow's neoclassical growth theory by incorporating the total factor productivity measure as an endogenous variable. This enables the assessment not only of the effect of technological progress on the total output growth, but also the identification of how different variables influence changes in the measures of technological progress.

An important aspect of the presently carried-out research is the distinction of the intersectoral technological progress spillover effect on technological progress fluctuations. The methodology formed in our dissertation allows distinguishing the impact of the technological progress spillover effect on the growth of the technological progress from the impact of the effects of the variables which are internal to the analyzed sectors operating in the manufacturing industry.

This dissertation also incorporates the agent-based modelling framework into the analysis of technological progress growth. The agent-based modelling methodology is fairly new in the field of economics, but it is also a powerful tool as each and every participant in the market is represented as a different agent with their own distinct parameters.

Theoretical analysis and systemization of academic literature was applied to distinguish the most appropriate methods for the evaluation of economic development so that to emphasize important factors influencing technological development and establish most suitable methods for the estimation of the measure of technological progress. This theoretical analysis is used to form unique adjustments in the methodological part of the research.

The evaluation model of technological progress assessment which is constructed in the hereby presented dissertation can be used to build personalized models for the analysis of technological progress and for obtaining assessment of various manufacturing industries operating in different markets and countries. An evaluation model is developed with the objective to analyze how efficiently the effect of intersectoral technological progress is being utilized by companies operating in manufacturing sectors and which factors influence the growth of the technological progress the most, thus suggesting what factors should be targeted when trying to stimulate further economic growth through the technological progress development.

Further research can be carried out to improve technological progress and economic growth assessment methodologies as described in our research paper. These future improvements could lead to the formation of new, more advanced, economic growth evaluation theories, thus improving the understanding of the technological effect and its impact on economic growth along with its measurement techniques.

Structure of the dissertation

The volume of the main body of this dissertation is 150 pages. It contains 16 tables, 24 figures and 83 equations. The number of references used in this dissertation is 125. The dissertation itself consists of the introduction, 3 main parts and conclusions. The introduction presents the relevance and the scientific problem of the conducted research. It also familiarizes the reader with the object of the research, the main aim of the dissertation and the objectives which were achieved while conducting the research, while also depicting the scientific novelty and the possible practical application of the dissertation results.

The first part of the body of the dissertation defines the theoretical foundations for the conducted research. In this part, the significance of the theoretical progress in economic growth theories is described, the variables potentially influencing the technological progress growth are introduced, and the most popular methods for the measurement of technological progress are defined. The second part of the dissertation describes the methodology used in the conducted research. The evaluation model itself consists of four parts: technological progress evaluation, intersectoral technological progress spillover effect assessment, technological progress relationship function construction, and the conduction of sensitivity analysis. The third part presents the empirical findings of the research by analyzing the dynamic changes of the technological progress for the sectors operating in the Lithuanian manufacturing industry.

Finally, the dissertation is completed with conclusions which summarize the findings of the conducted research and supply comments concerning the established objectives.

Approval of the research results: 4 articles were published on the topic of the dissertation, and the research results were presented in 4 international scientific conferences.

Scientific articles:

1. Markauskas, M., Saboniene, A. (2019). *Proceedings of IAC 2019 in Budapest*, 104-111, ISBN 978-80-88203-10-0. Evaluation of Technological Progress Measures: Case of Lithuanian Manufacturing Industry.
2. Markauskas, M., Saboniene, A. (2020). *Inzinerine Ekonomika-Engineering Economics*, 2020, 31(2), 169–177, Online ISSN: 2029-5839. Evaluation of Capital Cost: Long Run Evidence from Manufacturing Sector.
3. Markauskas, M., Saboniene, A. (2020). *Proceedings of ISERD International Conference, Barcelona, Spain*, 44-52, ISBN 978-93-89732-92-4. Intersectoral Spillover Effect of Technical Progress: Case Study of Lithuanian Manufacturing Industry.
4. Markauskas, M., Baliute, A. (2020). *Mediterranean journal of social sciences*, vol. 11, iss. 6, November 2020. Online ISSN: 2039-211, Modelling technological progress evaluation: case of Lithuanian manufacturing industry.

International scientific conferences:

1. Markauskas, M. (2019). International Academic Conference of Management, Economics and Marketing. *Evaluation of Technological Progress Measures: Case of Lithuanian Manufacturing Industry*. Budapest, Hungary.
2. Markauskas, M. (2019). International Scientific Conference, Perspectives of Business and Entrepreneurship Development in Digital Transformation of Corporate Business. *Cost of Capital in Lithuanian Manufacturing Industry*. Brno, Czech Republic.
3. Markauskas, M. (2020). International Society for Engineering Research and Development International Conference on *Economics, Management and Social Study*. Barcelona, Spain.
4. Markauskas, M. (2021). 11th International Conference on Applied Economics: Contemporary Issues in Economy. Online Conference, Poland.

1. TECHNOLOGICAL PROGRESS IN ECONOMIC GROWTH THEORIES AND FACTORS INFLUENCING TECHNOLOGICAL DEVELOPMENT

1.1. Significance of technological progress in growth theories

The history of the evolution of the economic growth theory is long; it traces back to the 18th century and the works of Adam Smith. In the early days of the science of economics development, technological progress was perceived in the form of the increased specialization and discovery of new production methods which led to diminishing returns (Cavusoglu, Tebaldi, 2006). The economic growth theories which emphasized the importance of technological progress in the evolution of economic development came into prominence in the middle of the 20th century. This chapter is dedicated to analyzing the effect of technological progress for the sake of better comprehension of factors leading to long-term economic growth.

1.1.1. Technological progress examination by using Solow's neoclassical growth theory

There are a few basic properties which need to be satisfied for an economic growth theory to be considered neoclassical (The Neoclassical Model of Solow and Swan) (Barro, Sala-i-Martin, 2004):

- Constant returns to scale should be exhibited in a neoclassical growth function, as presented in the given equation:

$$F(\lambda K, \lambda L, T) = \lambda * F(K, L, T) \tag{1}$$

The properly presented in Equation 1 is also known as homogeneity of degree one. The important part of the property is that the definition of scale includes only the capital (K) and labor (L) parameters while excluding technological progress (T). This indicates that an increase of capital and labor by a given multiplier with a fixed amount of technological progress will lead to an increased output amount by the same multiplier.

- In the case of the neoclassical growth theory, positive and diminishing returns to private inputs are witnessed, as presented in the given formula:

$$\frac{\partial F}{\partial K} > 0, \quad \frac{\partial^2 F}{\partial K^2} < 0 \;\; ; \;\; \frac{\partial F}{\partial L} > 0, \quad \frac{\partial^2 F}{\partial L^2} \tag{2}$$

Equation 2 indicates that, according to the neoclassical growth theory, when holding the technological progress measure constant, each additional unit of either capital or labor results in the positive increase in output, although with diminishing effects.

- The next defining condition of the neoclassical growth theory is the marginality effect of labor and capital inputs, as presented in the equation given below:

$$\lim_{K\to 0}\left(\frac{\partial F}{\partial K}\right) = \lim_{L\to 0}\left(\frac{\partial F}{\partial L}\right) = \infty\,;\ \lim_{K\to \infty}\left(\frac{\partial F}{\partial K}\right) = \lim_{L\to \infty}\left(\frac{\partial F}{\partial L}\right) = 0 \qquad \textbf{(3)}$$

This equation represents the idea that, as capital and labor approaches 0, the marginal product of capital and the marginal product of labor draws closer to infinity. The opposite is also true: as capital and labor increases and approaches large values, the marginal product of capital and the marginal product of labor goes towards zero.

- The final property which is attributed to the definition of the neoclassical production function is the assumption of essentiality, as presented in the formula given below:

$$F(0, L) = F(K, 0) = 0 \qquad \textbf{(4)}$$

Equation 4 indicates that all inputs presented in the production function are essential in producing output. The given property also implies that strictly positive amounts of inputs are needed so that to produce positive amounts of output and, when both production inputs are positive, as long as either input quantity approaches infinity, the total produced output also goes to infinity.

When assuming that the given presumptions hold, the analyzed production function can be considered a part of the neoclassical growth model. One of the most essential equations which presents the fundamental foundations on the Solow's neoclassical growth theory is shown in the given function (Barro, Sala-i-Martin, 2004):

$$\dot{k} = s * f(k) - (n + \delta) * k \qquad \textbf{(5)}$$

When analyzing economic growth by using the Solow's neoclassical growth theory, an assumption is made that, during the analyzed period, the labor force input parameter is held constant. The production function shape should also not change over time, which, on condition that the Cobb-Douglas production function is used, means that the technological progress parameter should remain at the same level (Weil, 2013). As the labor force parameter is held constant in the analysis, the capital growth is measured per unit of labor force in order to simplify the equation and to remove constant parameters which do not influence the change in the employed capital value.

The above presented Equation 5 indicates which factors affect changes of the amount of physical capital when it is employed in the output production process throughout time. The growth of capital stock over time depends upon the production function, presented as *f(k)*, and the savings rate, defined as s. The product of these two parameters is called gross investment. Decline of capital per unit of labor rate during time, according to the neoclassical growth theory, is determined by the growth rate of labor force, indicated by n, and the rate of capital depreciation, marked with δ. The whole term $(n + \delta) * k$ is called effective depreciation. Relationship between gross investment and effective depreciation ratios is presented in Figure 1.

The gross investment curve shares the same shape as the production function, with the only difference being the positive fraction multiplier s. As the capital value grows larger, the gross investment curve gets flatter, which is in accordance with the previously described marginality effect property. Effective depreciation in Figure 1 is represented by a straight line. Excluding the point of intersections for X and Y axes, there is only one point where the gross investment curve can cross the effective depreciation line.

The intersection point between gross investment and effective depreciation is called the steady state, which, according to the neoclassical growth theory, settles down in the long run. Fluctuations of different parameters in the short run influence the steady state value of capital per unit of labor in the long run, where the employed capital value is considered to be a constant. The increasing value of the savings rate raises the available capital in the financial markets, which leads to the appreciation of the employed capital per unit of labor amount. On the other hand, with the increasing population, which leads to the growth of labor force, faster depreciation of the employed capital leads to the decline of capital per unit of labor and shifts the steady state value in the short run.

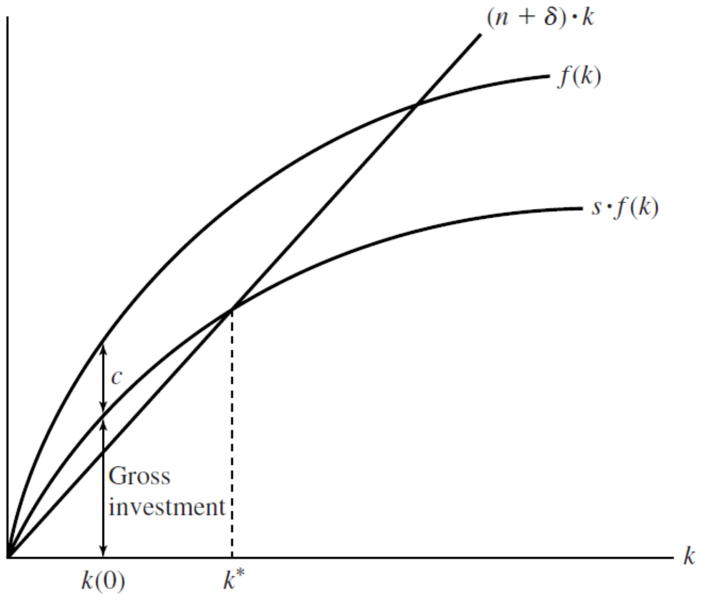


Figure 1. Fundamental equation of Solow-Swan neoclassical growth model. Barro, Sala-i-Martin, 2004

The savings rate, the population growth rate and the capital depreciation rate have a limited growth potential, and these parameters cannot be determinate factors in explaining long-term economic growth. In the absence of the constant population number increase, economy cannot grow forever at a positive rate. Due to diminishing returns to capital, the national income and production output does not grow as fast as the capital stock, which leads to the increase of the depreciation rate outpacing the savings rate (Aghion, Garcia-Penalosa, Howitt, 2004). For this reason, a supplementary proposition is necessary, which implies that additional knowledge is gained in the production process, which leads to the long-run growth of income per capita even while production exhibits decreasing returns to capital accumulation. In order to explain the occurrence of the constant growth of the capital per unit of labor, an additional term was incorporated into the model called *technological progress*. The measure of the growth of technological progress leads to the upward shift of the production function. After the incorporation of technological progress in the neoclassical growth theory, the condition for change in the capital stock over time is presented in the formula given below:

$$\dot{k} = s * F[k, T(t)] - (n + \delta) * k \qquad \textbf{(6)}$$

In Equation 6, the production function is depicted as F[k, T(t)], which indicates that the produced output is defined not only by the employed capital per unit of labor value, but is also influenced by the T(t) parameter which is the technology term, and, according to the model, it grows at a constant rate throughout time. Usually, in the case of the Solow's neoclassical growth theory, the Cobb-Douglas production function is used to define the aggregate production output of the analyzed market.

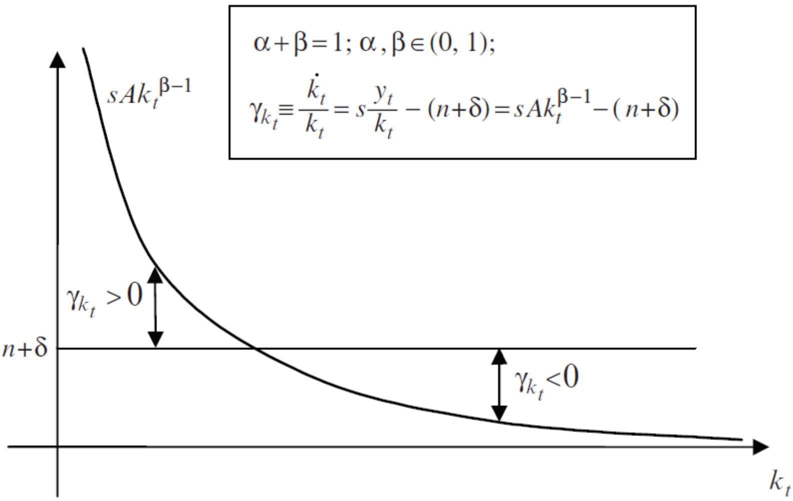


Figure 2. Cobb-Douglas production function impact on Solow's neoclassical growth theory. Aghion, Garcia-Penalosa, Howitt, 2004

The basic expression of the Cobb-Douglas production function is presented in the given formula (Aghion, Garcia-Penalosa, Howitt, 2004):

$$Y_t = AK_t^{\alpha}L_t^{\beta}\ ;\ \alpha,\beta\ \geq 0 \qquad \textbf{(7)}$$

The above presented Equation 7 suggests that the total output produced in a closed market depends on the technological progress, the employed capital and labor force. Parameters of α and β, respectively, represent the output elasticity of capital and the output elasticity of labor.

The output elasticity of capital is especially important in the analysis of economic growth as it indicates how much economic output will grow if the amount of the employed capital is increased by 1 percent. Figure 2 represents how economic growth is depicted with regard to the Cobb-Douglas production function. As the output elasticity of the capital value varies between 0 and 1, capital has a diminishing marginal growth effect on any changes in the produced output. When, in a short-term time period, the growth rate of the employed capital per unit of labor is larger compared to the population growth and depreciation rates, the economic growth rate is larger than its long-term stable state, but, due to the depreciating marginal capital value, the growth rate will drop to its stable state. The only way to increase the long-term economic growth rate is by increasing the technological progress value as the technological progress growth shifts the production function upwards. The term of technological progress from the Cobb-Douglas production function is claimed to be of the labor-saving variety because, as A_t increases, the same amount of output can be produced with a lower level of labor input (Novales, Fernandez, Ruiz, 2009). For this reason, the L_t^{β} parameter is also known as effective labor. If not for decreasing returns to scale aspect of the Solow's neoclassical growth theory, the technological progress would result in even larger economic growth due to the increased production efficiency.

As the technological growth model increases at a constant rate, the steady state capital level, reflected by k^* in Figure 1, at a consistent pace, shifts to the right on the x axis. When the steady state of capital is reached, then, the output of the production function can be depicted by the formula (Barro, Sala-i-Martin, 2004) given below:

$$y^{ss} = A(k^{ss})^{\alpha} = A^{1/(1-\alpha)} * (\frac{s}{\delta})^{\alpha/(1-\alpha)} \quad \textbf{(8)}$$

Equation 8 indicates that there exists positive relationship between the savings rate and the produced output per unit of labor employed in the production process. The above given equation also includes parameter α which depicts the output elasticity of capital. Neoclassical economic growth theories also hold the presumption that, when economy is analyzed as a closed entity, all the income which is saved and not consumed, through the system of financial markets, is reinvested into the further growth, and the savings ratio becomes equal to the investment ratio (Weil, 2013), (Novales, Fernandez, Ruiz, 2009). The impact of the investment ratio in the neoclassical growth theory is particularly important as it strives to explain why economies in different countries converge or diverge. There are various ways in which the investment rate explains the difference of the growth rates in separate markets:

- *If two markets have the same investment rate but different income levels, the market with the lower income level will grow faster*. Identical investment rates between markets indicate that steady state income levels between markets are the same. The previously described marginality effect property indicates that, as the capital value increases, the marginal product of the capital value decreases, thus slowing down the economic growth. This leads to convergence between two markets.

- *If two markets have different investment rates but identical levels of income, the market with a larger investment rate will grow faster*. As the larger investment rate leads to a higher steady state production output level, the market with a larger investment rate will be further away from its steady state. For this reason, the marginal product of the capital rate will be higher as the output level needs to grow more in order to reach the steady state.

- *A market which manages to increase its investment level will experience an increase in the income level growth*. The increased investment level also increases the steady state of the production output level. A higher steady state leads to the increased marginal product of the capital rate and thus increases the economic growth.

Figure 3 depicts the increase of the investment effect on the production output derivative value according to the Solow's neoclassical growth theory. At a given level of technological progress, the economic growth settles down at a stable level, marked as g. At the time of an increase in investment t^*, the output per unit of labor starts increasing at a more rapid rate than technology: $\frac{\dot{y}}{y} > g$. Due to the diminishing marginal production of the capital effect, the total produced output growth steadily decreases until the output-technology ratio reaches its new steady state. At this point, the growth has returned to the long-term level of g.

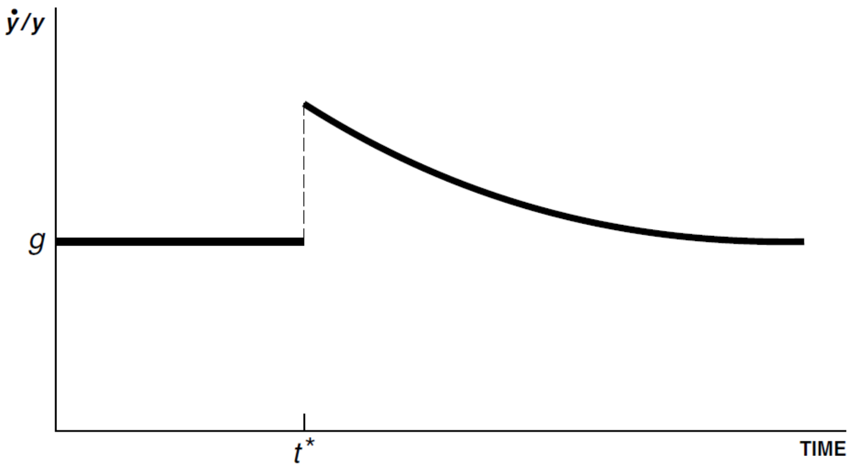


Figure 3. Effect of investment on growth of economic output in the neoclassical growth theory. Jones, Vollrath, 2013

After analyzing the neoclassical growth theory in detail, some shortcomings of the Solow's model could be distinguished that could lead to inaccurate analysis of economic growth. The main drawbacks of the Solow's model are:

- In the Solow's neoclassical growth model, the only source of difference to the produced output per unit of labor comes from the employed capital amount dynamics (Weil, 2013). Any other factors, which can potentially affect the shape of the production function are disregarded in the neoclassical growth theory (Aghion, Garcia-Penalosa, Howitt, 2004).

- Technological progress in the neoclassical growth theories is handled as an exogenous variable. Instead of modelling where technological progress comes from, measure is simply recognized to be growing at a constant rate (Jones, Vollrath, 2013). This kind of measure of the technological progress variable and its interpretation is unsatisfactory as a tool to explore the determinants of the long-term growth (Barro, Sala-i-Martin, 2004). The growth of economies should depend on the technological development which is obtained as an outcome from intentional decisions of economic agents (D'Agata, Freni, 2003).

- The Solow's model identifies that differences in investment rates lead to either convergence or divergence of economic growth between markets, but the sources of difference in the investment rate values are not analyzed (Weil, 2013). The reasons for inequalities of differences in investment rates are not analyzed by the theory.

- The reasons of growth in the neoclassical growth models are fully explained by the factors on the supply side. Unaccounted differences in the dynamics of demand variables may lead to uneven growth between different markets, although the neoclassical growth theories might suggest consistent economic progress evaluating growth from the supply side (Landreth, Colander, 2001).

Later on, other economic growth theories came into popularity. They analyzed economic development through the perspective of technological progress and innovation but also addressed the shortcomings witnessed in the neoclassical growth models. One of the most popular ones is the endogenous growth theory.

1.1.2. Technological progress analysis based on endogenous growth theory

The endogenous growth theory in the broad sense can be defined in either of the two ways (Roberts, Setterfield, 2007):

- A theory where the rate of growth is determined by the equilibrium solution of the growth model itself rather than being imposed upon the model from outside.

- A theory in which technological progress is explicitly modelled rather than treated as an exogenously given coefficient value.

At its basic level models of endogenous growth theory are an extension of neoclassical growth theory. Primary version of endogenous growth theory is the AK model (Aghion, Howitt, 2009). AK model combines physical capital accumulation and technological progress growth, witnessed in neoclassical growth theory, with intellectual capital accumulation produced when technological advances are made to stimulate economic growth. Due to intellectual capital property introduction in AK model diminishing marginal product effect, emphasized in neoclassical growth theory, becomes obsolete in endogenous growth theory. As accumulated capital is invested into technological progress, technological development leads to creation of intellectual capital which can be invested into further technological progress and economic growth. AK model even shares the same capital accumulation equation as Solow's neoclassical growth model, presented in formula 6. Thus at the fundamental level AK model is Solow's model without diminishing returns. Production function of AK model is presented in the given equation (Aghion, Howitt, 2009):

$$Y = AK \quad \textbf{(9)}$$

The above presented Formula 9 indicates that the production function of the AK model follows the Cobb-Douglas production function pattern, the same as used in the neoclassical growth theory, just with some tweaks. Parameter α of the Cobb-Douglas production function, as presented in Equation 7, in the case of the AK model, is equal to 1, while parameter β is equal to 0 thus eliminating labor force from the production function. Equating output elasticity of the capital value to 1 indicates that the invested capital does not depreciate during the long-term of economic growth thus sustaining the effect of technological progress on the economic growth in the long run.

The theories of endogenous growth also incorporate consumption into the models of analysis of economic growth. Consumers, under assumptions of the theory of endogenous growth, try to maximize their utility given their risk aversion preferences. The utility maximization function is presented in the equation given below (Novales, Fernandez, Ruiz, 2009):

$$\max U_0 = \int_0^{\infty} e^{-\theta t} \frac{c_t^{1-\sigma} - 1}{1-\sigma}, \ \sigma > 0 \quad \textbf{(10)}$$

In the above given Formula 10, parameter θ represents pure time preference (Baldwin, Braconier, Foslid, 2005) which indicates at which point in time consumers prioritize to consume the goods. Parameter σ displays which part of the income consumers choose to spend on consumable goods rather than save to maximize their utility. The growth rate of consumption throughout time can be defined as given below (Baldwin, Braconier, Foslid, 2005):

$$\gamma_{c_t} = \frac{dc_t/dt}{c_t} = -\frac{1}{\sigma}\frac{\dot{\lambda}_t}{\lambda_t} = -\frac{1}{\sigma}(\theta + \delta + n - A), \forall t \quad \textbf{(11)}$$

Beside the pure time preference and the consumption share of income parameters presented in Equation 11, other variables are already familiar from analysis of the neoclassical theory of growth. Variable δ is the rate of capital depreciation, *n* represents the growth rate of labor force, and *A* indicates technological progress. Function 11 indicates that the growth rate of consumption stabilizes in the long run and becomes constant over time as in the right-most part of the equation, after differentiation is performed, values of included parameters do not depend on change in time. This equation also suggests that if $A > \ \theta + \delta + n$ due to the increase in technological progress, consumption in the market will grow. Otherwise, consumption in the economy will shrink. Stabilizing the condition between the parameters of the demand and supply side can be depicted as follows (Baldwin, Braconier, Foslid, 2005):

$$\gamma_c \sigma + \theta = A - (\delta + n) \quad \textbf{(12)}$$

The dependence of the growth rate of consumption on structural parameters, as depicted in Equation 12, can be interpreted as the cost of one unit less of consumption at a fixed time is equal to the benefit of saving that unit in the form of physical capital.

Despite the AK model improvement over the Solow's neoclassical growth model, there still are some essential elements in the process of economic growth not addressed by the AK model. The Schumpeterian model tries to deliver a more detailed explanation of the long-run economic growth due to knowledge creation, which is a more appropriate explanation of the cross-country convergence due to technological progress and knowledge strengthening innovations, a more adequate framework to discuss policy issues related to the creation and diffusion of knowledge (Aghion, Garcia-Penalosa, Howitt, 2004).

The Schumpeterian endogenous model includes research and development (R&D) as a parameter into the analysis of economic growth. R&D is assumed to draw on labor only as labor is supposed to be homogenous. It can be equally employed in the production of goods and R&D labs (Englmann, 1994). The amount of labor employed in the creation of R&D innovation can be described with the formula given below:

$$L^R = s^R * P * \frac{1}{w} \quad \textbf{(13)}$$

According to Equation 13, $s^R * P$ of profits is spent on hiring labor force which works in the labs trying to produce R&D innovations. As labor in the given model can be switched between working on producing goods and R&D innovations, wage *w* in the above presented equation is presumed to be uniform for all workers. The relationship between R&D success and expenditures on the employed labor is depicted in the deterministic way. Thus, the constant improvement in labor productivity of the future technology due to R&D work can be described by the following learning curve (Englmann, 1994):

$$\dot{d}_i^R = d_i^R * \left(d_i^{R^{max}} - d_i^R\right) * \beta_i * \frac{L^R}{L^S}, \ i = 1, 2 \ldots \quad \textbf{(14)}$$

Equation 14 indicates that labor productivity throughout time depends on $\frac{L^R}{L^S}$ which depicts the ratio between the workers employed to work on R&D and the total labor force. Another important parameter is β_i which indicates labor productivity while working on R&D. $d_i^{R^{max}}$ denotes the maximum achievable level of labor productivity. For a fixed value of $\frac{L^R}{L^S}$, the time interval needed to increase the labor productivity to a higher level is defined as given below (Englmann, 1994):

$$\Delta_{\pi \to \pi'} = \frac{L^S}{\beta_i L^R} * \ln\left(\frac{\pi'(1-\pi)}{\pi(1-\pi')}\right) \quad \textbf{(15)}$$

As indicated by Equation 15, the interval needed to increase labor productivity to another level does not depend on the current achievable maximum level of labor productivity. This suggests that the time needed to upgrade labor productivity to the next level does not increase with the higher values of technological progress. Also, the technology with improved labor productivity is introduced to the market only when the labor productivity of new technology is higher compared to the labor productivity of the currently employed technology.

Every industry is dominated by a quality leader until a new quality leader emerges with a higher level of labor productivity. The marginal cost of production of the new industry leader thus becomes equal to 1. The amount of monopolistic profit, which is the highest goal from innovators investing in R&D, can be depicted by the formula given below (Chu, Cozzi, Furukawa, Liao, 2017):

$$\Pi_t(\omega, j_\omega) = [\lambda_t(\omega) - 1] * y_t(\omega, j_\omega) = \left[\frac{\lambda_t(\omega)-1}{\lambda_t(\omega)}\right] * (1-\theta)Y_t \qquad \textbf{(16)}$$

In the above given Equation 16, $y_t(\omega, j_\omega)$ indicates the production function of intermediate goods, while $\lambda_t(\omega)$ indicates the equilibrium price. As parameter ω indicates the continuum of different industries, the expected monopolistic profit $\Pi_t(\omega, j_\omega)$ is shared across industries thus suggesting that the increase of technological progress generated from R&D expenditure can be spilled over between industries. Braunerhjelm, Acs, Audretsch and Carlsson (2010) suggest that, though entrepreneurship and innovation, spillover of knowledge is formed into economic growth. Bharadwaj, Clark and Kulviwat (2005) in their research emphasize the importance of knowledge spillovers from one industry to another to stimulate economic growth beyond the bounds of the theory of endogenous growth.

The output of the sector of consumption goods is presented in the formula given below (Batabyal, Nijkamp, 2012):

$$Y\left(\frac{t}{q}\right) = \frac{1}{1-\beta} q L^E \left(\frac{t}{q}\right) \qquad \textbf{(17)}$$

As the above given Equation 17 shows, the total output does not depend on the labor force working on R&D investments as L^E indicates the labor force of the consumption goods sector. The effect of R&D investment on the production output is presented through parameter q which indicates the quality of intermediate goods used in the production process. For that reason, both the labor force employed in the production process and the labor force working on R&D contribute to increasing the produced output: L^E directly through producing consumption goods, and L^R through working on increasing the labor productivity and improving the quality of intermediate goods used in the production process.

Schumpeterian endogenous models support the idea of the constant returns on knowledge but also take into account the delirious effect on growth of productivity which arises from product proliferation (Ha, Howitt, 2007). The growth rate of technological progress according to the model is depicted in the function given below:

$$g_A = \lambda\left(\frac{X}{Q}\right)^\sigma \qquad \textbf{(18)}$$

According to the Schumpeterian theory, new people entering industries with their own different products dilute R&D expenditure over a large number of separate products thus resulting in a flatter movement of the value of technological growth. This effect is depicted in Equation 18 with the help of Q parameter which shows product variety. Parameter σ indicates R&D elasticity. The above given equation also supports the idea that raising the fraction in allocating the society's resources to R&D will result in the long-run growth of technological progress.

1.2. Factors influencing changes of values of technological progress

Analysis of academic literature indicates that there exists a multitude of different factors which could affect dynamic changes of the values of technological progress. Table 1 summarizes these findings and lists the variables which, theoretically, can affect fluctuations in technological progress while presenting the sources which led to the given conclusions.

Table 1. Factors theoretically influencing changes in technological progress values

Factors	Main sources
Ability to earn profit / Cost of capital	Grant, 2003; Damodaran, 2012; Rao, Stevens, 2007; Fabozzi, Drake, 2009; Kumar, 2016
Capital investment / Foreign direct investment	Wang, Wong, 2016; Gugler, Brunner, 2007; Chaudhuri, Mukhopadhyay, 2014; Meon, Sekkat, 2012; Seck, 2012
Capital structure	Li, Niskanen, Niskanen, 2018; Miglo, 2011; Rao, Stevens, 2007; Cekrezi, 2013; Leary, Roberts, 2010
Financial liquidity measures	Nanda, Panda, 2017; Yu-Thompson, Lu-Andrews, 2016; Michalski, 2010; Anderson, Carverhill, 2012; Wang, 2012
Increased competitiveness in foreign markets (growth in export)	Raza, Karim, 2017; Fortunato, Razo, 2014; Dreger, Herzer, 2013; Vernon, 2004; Hsu, Li, 2009
Energy consumption efficiency	Ozokcu, Ozdemir, 2017; Cantore, Cali, Velde, 2016; Shahbaz *et al.*, 2013; Ahmed, 2017; Zhang *et al.*, 2013; Feng, Wang, 2017

The rest of the chapter is dedicated to analysis and in-depth explanation of how the presented factors might affect changes in the values of technological progress and, at the same time, the development of economic growth. Factors themselves can be differentiated into two groups. The first group of measures are those which influence the values of technological progress directly. These factors are the ability to generate profit, foreign direct investment, competitiveness in foreign markets, and energy consumption efficiency.

Meanwhile, the other group consists of factors which influence the values of technological progress indirectly, by affecting the amount of employed capital and changing the output elasticity of capital. These factors include the cost of capital, capital investment, capital structure, and financial liquidity.

1.2.1. Ability to generate profits and Cost of capital

Analysis of the theory of endogenous growth carried out in the previous chapter emphasized the importance of profit in maintaining economic growth. Equation 16 indicates that the total produced output depends on the quality factor of intermediate goods used in the production process. Labor productivity, according to this theory, increases with the growing amount of labor force working on R&D. The growing profits could be spent to employ the increasing amount of labor force which would work on R&D thus stimulating the development of technological progress.

A company is truly profitable only when it covers its usual production and operating expenses while providing appropriate return on the owners' invested capital (Grant, 2003). There are different ways of describing value creation by companies which can lead to economic growth. One way in which the process of value creation can be defined is the ability to generate and reinvest cash flows in new projects whose returns on consistent basis exceed the cost of capital (Subramanyam, 2014). Some analysts assess the economic value of a company in terms of free cash flows which can be paid out as dividends after the required debt payments have been met, and reinvestment in operating assets has been performed (Wahlen, Baginski, Bradshaw, 2010). The ability of value creation should also be reflected in the stock prices of companies as it is closely associated with the shareholders' wealth creation (Becerra, 2009).

One thing is certain – the 'regular' profitability measures do not suffice when trying to assess the value creation of companies as profit by itself does not disclose the cost of the employed capital which was used in the production process. One of the more popular measures for the evaluation of companies' value creation is the Economic Value Added (EVA) criterion. EVA measures the dollar surplus value created by a firm on its existing investment (Damodaran, 2012). The main advantage of EVA is that this method evaluates the earned profit in the context of both the direct cost of debt and the indirect cost of equity capital. The method for EVA estimation is presented in the formula given below (Grant, 2003):

$$EVA = NOPAT - Capital * WACC \tag{19}$$

NOPAT represents the net operating profits after tax, while WACC is the weighted average cost of capital. According to Damodaran (2012), the inclusion of the net income measure instead of NOPAT is also a valid option. The WACC measure can be evaluated as shown below:

$$WACC = w_E * r_E + w_D * r_D * (1 - T) \tag{20}$$

In Equation, 20 w_E and w_D, respectively, represent the weight of equity and the weight of debt in the total capital structure. On the other hand, both *r* variables in the equation indicate the rates of return on equity and debt. Tax rate variable T is also included as, due to the tax shield effect, the debt equity is exempted from the income tax. The measure of WACC is vastly used by regulators and business managers for rate regulations, investment decisions, restructuring activities and bankruptcy valuations (Rao, Stevens, 2007). This indicates that the measure of WACC is universally recognized as a valid way to assess the required rate on return for companies which needs to be surpassed for an investment project to be profitable and to create value. Assessment of an investment can be performed by using the formula given below which represents the NPV model (Rao, Stevens, 2007):

$$NPV = Capital * \frac{(ROC-COC)}{(1+COC)} = \frac{EVA}{(1+COC)} \qquad \textbf{(21)}$$

In Equation 21, NPV represents the net present value measure of the potential investment project. EVA in the given situation represents the difference between the forecasted return on the invested capital and the cost of capital multiplied by the monetary value of the invested capital. The cost of capital in the given scenario can be represented by the above mentioned WACC measure. WACC is also used in the denominator as a discount factor. Thus, the created wealth can be evaluated by discounting the EVA measure by the discount rate of WACC (Grant, 2003). The relationship between the given measures can be seen in Figure 4.

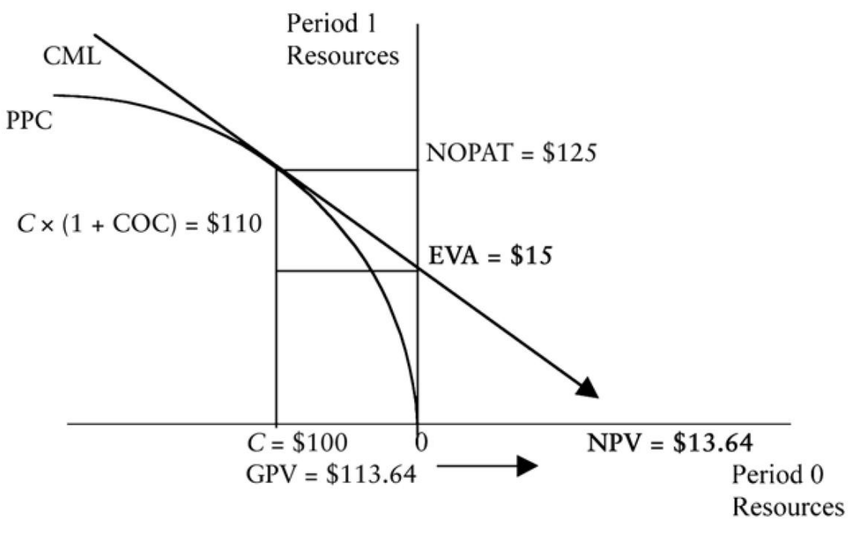


Figure 4. NPV model depicting economic value creation. Grant, 2003

In Figure, 4 PPC indicates the production possibility curve, and CML is the line depicting the capital charge. The point where the production possibility curve and the capital charge line intersect, NOPAT represents the earned cash flows of the investment in the form of the net operating profit after taxes. As the capital charge line has a positive intercept value, this leads to a positive EVA value. In that case, investment is interpreted as value (wealth) creating. When the CML line is steeper, the intercept of the line can become negative, and the investment will be labeled as losing value. The CML line can become steeper due to a couple of factors: either the anticipated cash flow from the investment is lowered because of diminishing expectations, or the cost of capital value increases as the WACC estimate value becomes higher.

Meanwhile, the assessment of the WACC value depiction of return on debt value is fairly easy. It is the weighted average value of the interest rates priced on the borrowed capital. The evaluation of return on equity capital is trickier in the given context. This can be performed with the help of the capital asset pricing model (CAPM), as presented in the formula given below (Albanez, 2015):

$$r_E = r_{rf} + \beta_i(r_m - r_{rf}) \quad \textbf{(22)}$$

There are various methods for the evaluation of equity capital pricing, but analysis of academic literature indicated that CAPM is the preferred option for the given task. According to Britzelmaier *et al*. (2013), around 75% of surveyed professors in the field of finances advised using CAPM as the best way to assess the required rate of return on equity capital with regard to capital budgeting evaluation. A research carried out by Michelfelder (2015) concluded that 87% of all firms and 91% of publicly traded companies use CAPM for the required return on equity capital evaluation.

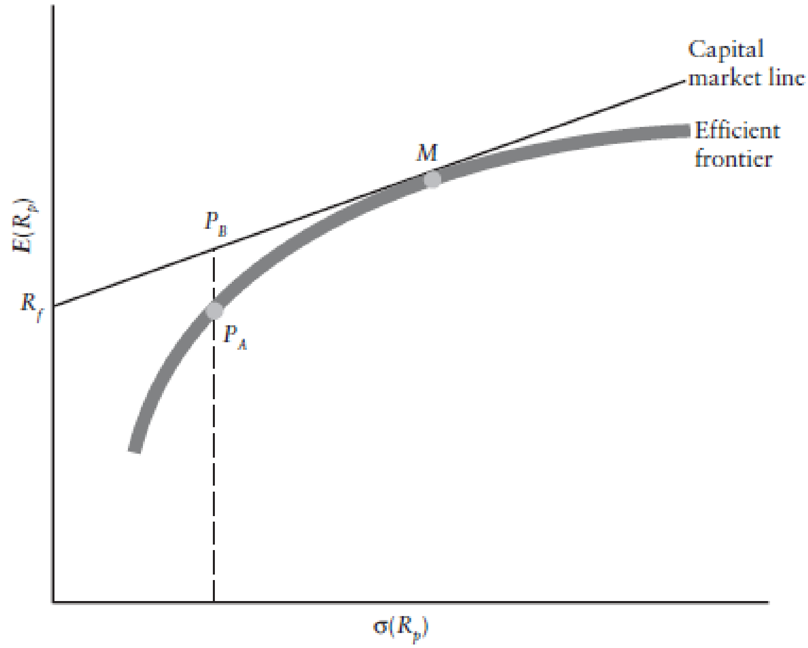


Figure 5. Capital market line. Fabozzi, Drake, 2009

In the above presented Equation 22, parameter r_{rf} represents the risk-free rate of return, r_m is the market rate of return, while β_i is the volatility of the rate of return within the analyzed market. For the risk-free rate earnings of high-quality, government bonds are usually used because the return from investment on low risk bonds has the smallest probability of default. Risk premium is the return earned above the risk-free rate by taking on the systematic risk persisting in the market. The value of β_i is the covariance of asset divided by the market portfolio which measures the risk added by investing in a particular market (Damodaran, 2012). The capital market line, which is the basis of CAPM analysis, is presented in Figure 5. The risk of the portfolio in the above given figure is presented in the x axis as the standard deviation of the portfolio return, while the y axis represents the rate of return for the portfolio.

When comparing two points in Figure 5, P_A and P_B, it is visible that, at point P_B, the portfolio earns a higher rate of return with the same attributed level of risk. For this reason, portfolio P_B is preferable. To maximize the risk-return rate of the investment, a set of risk-free and risk possessing financial assets should be chosen such that the portfolio in the presented graph lands at the tangent point between the capital market line and the efficiency frontier curve. The slope of the capital market line depicts how much of additional return is needed to compensate for a unit change in risk. In such a case, the value of β is a key element for the risk measurement of investment.

Although the risk premium value of β can be easily assessed in an economy with large and liquid financial markets, in developing economies with less active financial markets, there is not enough information to properly assess the market investment risk. When analyzing markets where the majority of companies are not listed in the local stock exchanges, Kumar (2016) suggests estimating the risk and the rate of return of a maturely developed market and then adding additional risk premium of the economy with lesser developed financial markets.

1.2.2. Capital investment and Foreign direct investment

One of the essential characteristics in the neoclassical growth theory is the dynamics of capital accumulation. Throughout time, capital depreciates, and it needs to be replenished in order to sustain the produced output and earned income. Diminishing of the marginal product of capital is also witnessed, which means that every subsequent euro invested in capital leads to a lower amount of the produced output than the previous level. For these reasons, maintaining the employed capital amounts and reinvesting into a more advanced technology is essential for economic development and growth.

Foreign direct investment (FDI) is an important part of economic development, although neoclassical models usually do not include FDI as a growth initiator due to the assumption of closed economy conditions. FDI is typically considered a vehicle for transferring tangible assets, such as machinery and equipment, and intangible assets, such as managerial techniques and better production designs, from one economy to another (Wang, Wong, 2016). FDI in the best case scenario can lead to productivity spillovers from the more technologically advanced economies to the less advanced ones. There are two different ways in which FDI can lead to productivity spillover: through intra-industry linkages, and through inter-industry linkages.

Intra-industry technological spillover through FDI can be carried out in three main ways: by demonstration, training of employees, and competition. Firstly, nonaffiliated companies can increase their productivity by trying to imitate organizational innovations, product designs and processes of companies linked with foreign enterprises. Secondly, technological progress through productivity enhancement can be obtained from labor turnover. Those employees who are trained in multinational companies can absorb their know-how and transfer the newly acquired skills when changing jobs. Thirdly, FDI inflow into the local market can lead to increased competition, and local companies need to increase their own investment into R&D in order not to lose their market share to the newcomers.

Inter-industry FDI spillovers can happen due to the vertical linkages between sectors. When one sector is more technologically advanced than another, the more technologically advanced product supplies intermediate goods to the less technologically advanced sector, and higher quality intermediate goods may lead to an increase in productivity of the consumer goods producing sector. If companies from two different industries work together, the company from a more technologically advanced industry may impose higher requirements for the produced goods or supplied services onto another company. This can be an incentive to increase quality through productivity improvement. Thus, inter-industry spillover through FDI can be achieved when companies of the more advanced sectors transfer their technology to their suppliers or customers in other industries.

For domestic companies, in order to absorb positive effects on productivity due to FDI, suitable assets and technological framework need to be developed. Only when local companies have invested a sufficient amount of the capital into their absorptive capacitance of knowledge can they benefit from FDI spillover (Gugler, Brunner, 2007). For the companies which have invested enough resources into R&D, evidence suggests that a significant amount of productivity growth can come from FDI, which leads to increased competitiveness even for the local companies. According to Alvarez and Marin (2013), the existence of relationship between competitive performance and entrepreneurial capabilities of absorption is the factor which leads developing economies to the advancement of their systems of innovation. The ability to adapt technology development in different markets and the effort to innovate is key in creating upward shifts of competitiveness. Investment into R&D and absorptive capability not only increases competitiveness, but also boosts economic growth and development, thus leading to the rising level of welfare and wealth (Sener, Saridogan, 2011). Bayarcelik and Tasel (2012) also suggest that R&D expenditures have a significant effect on economic growth, and those countries which want to sustain a high level of economic growth need to increase their R&D activities just because the countries with the leading levels of R&D expenditure are the leaders in innovation and economic development.

The FDI effect on the local economies can be explained with the help of the general equilibrium framework. General equilibrium models try to explain how the behavior of demand, supply and prices fluctuates while interacting with different markets. According to the general equilibrium models, due to FDI, those sectors which receive capital from foreign sources are more likely to expand, while the sectors which act as substitutes for investment receiving products and services should contract (Chaudhuri, Mukhopadhyay, 2014). FDI, according to the framework, should affect all the key variables of the analyzed economy including income, unemployment, social welfare and human capital formation. The basis of the 2x2 Heckscher-Ohlin-Samuelson model is presented in the equations given below (Chaudhuri, Mukhopadhyay, 2014):

$$\theta_{L1}\widehat{W} + \theta_{K1}\hat{r} = \widehat{P_1} \quad \textbf{(23)}$$

$$\theta_{L2}\widehat{W} + \theta_{K2}\hat{r} = \widehat{P_2} \quad \textbf{(24)}$$

In the above presented Equations 23 and 24, parameter $\widehat{W}$ represents the differential value of the wage rate, while $\hat{r}$ indicates the differential value of the return on capital. Capital and labor inputs in the model are represented, respectively, by K and L parameters. According to the model, there exist two sectors – the first one produces goods that are more labor-intensive, while the second one is more capital-intensive. The difference between the growth in the labor price and the capital price can be estimated by the function presented below (Chaudhuri, Mukhopadhyay, 2014):

$$\left(\widehat{W} - \hat{r}\right) = \left(\frac{1}{|\theta|}\right)\left(\widehat{P_1} - \widehat{P_2}\right) \quad \textbf{(25)}$$

Equation 25 includes parameter θ which shows the change between labor and capital intensities for the two given sectors. If $\widehat{P_1} > \widehat{P_2}$, the assumption holds, and the first sector is labor-intensive, and raises in wage to the capital return ratio will be amplified. Thus, the given model indicates that if FDI is directed into the labor-intensive sector, local companies operating in the labor-intensive sector will reap the benefits of the increased labor-intensive production factor efficiency in the form of the increased price of the produced output. On the other hand, the companies operating in the capital-intensive sector will take a loss. The elasticity of capital and labor factors substitution is presented in the equation given below:

$$\sigma_i = \frac{\widehat{a_{Ki}} - \widehat{a_{Li}}}{\widehat{W} - \hat{r}} \quad \textbf{(26)}$$

The presented theory, all in all, suggests that changes in endowment of a factor at constant commodity prices leads to the expansion of the commodity which uses the factor intensively and to the contraction of the other commodity.

It has already been established that R&D expenses help to assimilate the technological spillover initiated by FDI. There are other factors which ease the absorption and spread of the technological progress spillover between sectors (Seck, 2012):

- *Human capital*. The theory of endogenous growth argues that the countries whose governments spend adequate amounts of investment on subsidizing education observe the increasing long-run economic growth rate (Kopf, 2007). Ten years ago, most innovative companies used to spend at least one third of their total investments into knowledge-intensive intangible capital, and, in the light of the current business environment, the share could be even larger. During the last 70 years, universities have tended to shift from funding their R&D expenditures from the federal government budgets to increasing the share of investment from the self-funding and private industry level sources. A research by Chen and Fang (2018) analyzed factors of economic growth in Chinese prefecture cities between 2003 and 2012. The researchers concluded that, during the analyzed period, 1% investment into the human capital led to the economic growth between 0.03% and 0.09%, and, in some parts of China, even exceeded the elasticity estimates of the physical capital.

- *Role of institutions*. Political risk may impose substantial effect on the investors' choice whether to divert the capital flow into a particular market. Political instability may reduce the ability of firms to raise adequate amounts of capital, which may lead to underinvestment into increasing production efficiency. Poor political environment may also hinder capital accumulation through a high cost of equity capital which is required to compensate for the consisting risk (Belkhir, Boubakri, Grira, 2017). According to Meon and Sekkat (2012), FDI inflows on average are negatively affected by political risk, although aversion to risk decreases as the global volume of capital flow grows large(r). This suggests that, when, during an economic boom, capital becomes abundant, investors tend to take higher levels of risk. This leads to the next point. The security of property rights, ensured by political institutions and laws, may also increase the ability to absorb technological progress transferred through FDI (Seck, 2012). As investment in R&D, which could increase absorption capabilities, is not cheap, the protection of intellectual property may encourage investors to go through with it.

- *Economic cycles*. Financial and economic crises may have long lasting adverse effects on the economic development even after the end of the recession of a business cycle (Crafts, 2017). Economic crisis may lead to interrupted flows of the invested capital, which might result in the decline of technological progress due to cutbacks in R&D or in the cases if innovations creating firms cannot obtain financing. The efficiency of human capital may also dip when less expenditures are directed towards increasing labor productivity while the increased amount of unemployment in economy may lead to people losing skills.

This suggests that even those countries which do not invest in R&D expenditure can increase their technological progress spillover absorption by improving their system of education, opening markets for foreign capital flows, or by passing laws which increase the safety of intellectual property (Seck, 2012).

1.2.3. Capital structure

In the perfect world, the capital structure should not affect the value creation process of a company, but various theories suggest that different debt and equity capital proportions affect the evaluated worth of a company, and, at some times, may lead to either hardships in attracting capital for further investments, or make the price of capital larger thus preventing the implementation of new projects (Li, Niskanen, Niskanen, 2018).

The trade-off theory suggests that a company determines its own capital structure by balancing its share of debt capital between the benefits of the tax-shield and potential bankruptcy costs related to fund borrowing. The agency theory of capital structure suggests that conflicts due to the separation of ownership and management can be incurred, which has the potential to be costly. Thus, the choice of financing according to this theory is influenced by the agency costs which stem from conflicts of interest between the principal agents. The pecking-order theory suggests that a firm's first choice is to use internal financing in the form of retained earnings, whereas debt usually is the second option of financing future investments, and equity remains the last choice among the options of a financing source.

According to the static trade-off theory, the performance of a company influences its target debt ratio level, which affects the company's choice of issued securities and changes in the ratios of the capital structure. The choice in setting the level of the capital structure according to this theory is affected by the following factors (Cekrezi, 2013):

- Increase in costs of financial distress reduces the optimal debt level.
- Increase in non-debt tax shields reduces the optimal debt level.
- Increase in the personal tax rate on equity increases the optimal debt level.
- At the point of the optimal capital structure, an increase in the marginal bondholder tax rate reduces the optimal level of debt.
- The effect of risk is ambiguous even if uncertainty is assumed to be normally distributed. The relationship between debt and volatility is negative.

The trade-off theory can be described by the equation given below (Miglo, 2011):

$$V_d + V_e = \frac{\bar{R}-D}{\bar{R}} D + \frac{D}{\bar{R}} \frac{D(1-k)}{2} + \frac{\bar{R}-D}{\bar{R}} \left(\frac{\bar{R}+D}{2} - D \right) (1-T) \qquad \textbf{(27)}$$

The above given Equation 27 represents the value of a company by dividing it into the value created from the equity capital and the value created from the debt capital. In the equation, $\bar{R}$ represents the random cash flow, while *T* indicates the constant tax rate on the corporate income. If the generated cash flow is not sufficient to cover debt payments *D*, loss of *kR* is incurred, which consists of direct and indirect costs of bankruptcy. Thus, the value of debt is indicated by the first part if Equation 27, $\frac{\bar{R}-D}{\bar{R}} D + \frac{D}{\bar{R}} \frac{D(1-k)}{2}$. Here, $\frac{\bar{R}-D}{\bar{R}}$ indicates the probability that cash flows will be sufficient enough to cover the debt expenses, and $\frac{D}{\bar{R}}$ is the probability to suffer bankruptcy. On the other hand, the final part of the equation, presented as $\frac{\bar{R}-D}{\bar{R}} \left(\frac{\bar{R}+D}{2} - D \right) (1-T)$, indicates the market value of the equity capital. If the cash flows are large enough, equity holders earn a profit of *(R-D)(1-T)*. Given all the assumptions, the choice of leverage in order to maximize the company's profit can be presented as (Miglo, 2011):

$$D = \frac{T\bar{R}}{T+1-k} \quad \textbf{(28)}$$

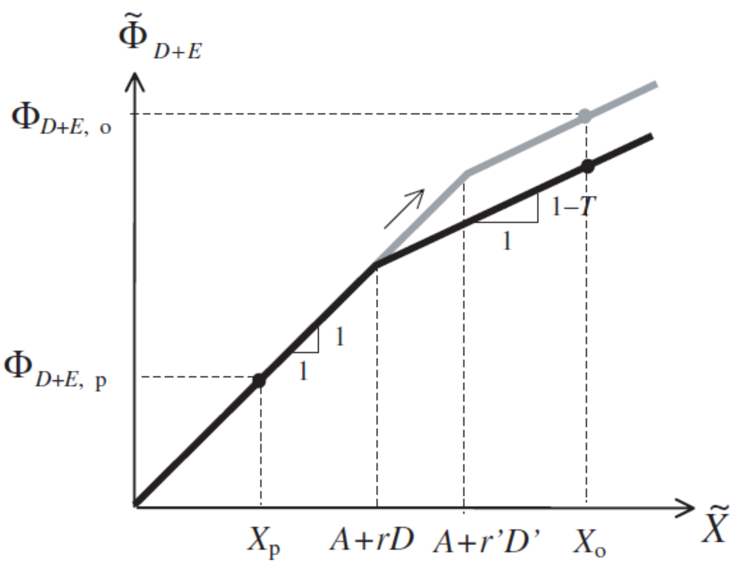


Figure 6. Depiction of the creation of incremental tax shields from borrowing. Rao, Stevens, 2007

Figure 6 depicts how an increase in borrowing leads to the creation of the tax shield effect. The X axis of the figure represents the value of the total invested capital into the company, while the Y axis indicates the cash flow of the leveraged firm. When the value of debt is increased from D to the new level of D', the interest rate on the debt also rises to r'. This generates an incremental tax shield at the state of 'o', and the after-tax cash flow of the analyzed company increases. Although the risk of the total tax shield for the whole company rises, so does the firm value.

Figure 6 indicates that the growing debt increases the value of a company due to the effect of the tax shield and the increased cash flows from borrowed funds which are reinvested, but this kind of value creation in the form of capital restructuring cannot be performed indefinitely. Equity capital in a sustainably growing company cannot be equal to zero or be negative. The term describing a company reaching its borrowing limit is called debt capacity. The required rate on debt can be estimated by creditors only up to a certain level of debt in the company's capital structure. Beyond this point, lenders cannot rationally price debt as the risk becomes too high, and additional credit evaporates. Thus, the optimal level of debt and equity in the capital structure is reached when the marginal value of benefits associated with the debt offsets the increase in the present value of costs associated with issuing more debt (Cekrezi, 2013). The trade-off theory also suggests that firms with higher levels of profitability tend to have a larger debt capacity. The reason for this is the lower probability of bankruptcy and the higher leverage ratio as undistributed profits can be reinvested as equity capital.

Figure 7 indicates the above described effect. The risk of tax shields in this figure is described by parameter β_{DTS}. At the lower levels of debt, the risk of tax shields is stable as the increased share of debt in the capital structure of the company is counterbalanced by the growth of the generated cash flows.

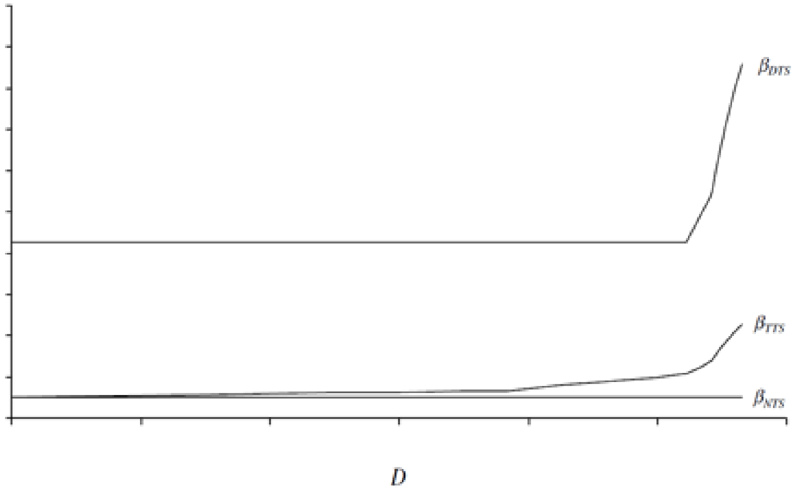


Figure 7. Relationship between risk of tax shields and amount of debt. Rao, Stevens, 2007

At some point, the company approaches its debt capacity level, and the risk of tax shields becomes too large to be offset by the increasing value of the company. This sharp growth of the tax shield risk eliminates the supply of credit for the particular company as creditors refuse to accept such a large level of risk and therefore refuse to lend capital.

The pecking order theory analyzes how companies choose to finance their new investments. There exist three distinct sources of funding which are available for companies: retained earnings, debt, and equity. Retained earnings have no adverse selection problem, which makes this source of finance the least risky and the most preferable. Debt has a minor adverse selection problem, while equity is subjected to the largest adverse selection problems. Both debt and equity have a substantial selection risk premium, but, in the case of equity, that premium is larger (Frank, Goyal, 2003). Thus, if possible, a company will choose to finance all of their projects by using retained earnings, while debt financing will be used in the case that the amount of retained earnings is inadequate. Companies are not the pursuing optimal capital structure, and the debt ratio is the cumulative result of hierarchical financing decisions (Zhang, Kanazaki, 2007). Sub-optimal choices of the capital structure arise from the attractiveness of debt related benefits, displayed in the form of the above mentioned tax shield effect, the threat of financial distress, and the assumption that debt-related agency costs are of the second order.

The pecking order theory can be depicted with a set of equations given below (Leary, Roberts, 2010):

$$Equity_{it} = \begin{cases} 1, & Investment_{it} \geq \widetilde{D_{it}} \\ 0, & \widetilde{C_{it}} \leq Investment_{it} < \widetilde{D_{it}} \end{cases} \quad \textbf{(29)}$$

Equation 29 suggests that equity capital is used to finance new investment projects only when the amount of funds required to implement a new investment project exceeds the available internal financial recourses and that the outstanding debt has reached the debt capacity level. Only then do companies turn to equity capital. Parameter $\widetilde{D_{it}}$, depicted in Equation 30, is represented by the following formula:

$$\widetilde{D_{it}} = \left(internalFunds_{it} - \alpha_{it}^{C} - \varepsilon_{it}\right) + (\alpha_{it}^{D} + \eta_{it} - Debt_{it-1}) \quad \textbf{(30)}$$

A number of research papers support the idea that the pecking order theory is observable in the real-life economy. According to Bolton and Freixas (2000), firms face informational dilution when they issue equity whose cost they try to reduce by issuing bonds or taking out a bank loan. Chen and Chen (2011) produced analysis of Taiwan market which also supported the idea that companies tend to prefer the internal capital to finance new projects. When the internal capital is insufficient, then, the debt is issued while leaving equity as the last resort option.

1.2.4. Financial liquidity measures

There are two main theories which suggest that liquidity measures affect profitability, and, through profitability, the value of the company (Nanda, Panda, 2017). The first theory suggests that holding high values of liquid assets leads to an increase of the levels in maintenance costs in the form of opportunity cost. This can lead to underinvestment, and, at the same time, loss of value. The given theory holds only in the short-term. The second theory indicates that low liquidity measures can result in low profitability. In the previous chapter, we analyzed that the pecking order theory indicates that retained earnings are first in the priority list for financing new investment projects. Without liquid assets, managers can choose to pass on the investment due to a higher cost of debt or the fact that debt capacity for the particular company has been reached. Thus, non-fulfilled investments, due to lack of liquid assets, can impede growth in the long run.

Liquidity measure values sometimes depend on the corporate structure. A negative relationship between agency problems and cash reserves was identified in the United States as weakly controlled managers choose to quickly spend money on acquisition and capital expenditure (Yu-Thompson, Lu-Andrews, 2016). This can be explained by the fact that shareholders with more effective control of their managers will allow the managers to store more internal funds thus preventing underinvestment due to potentially costly external finance whenever an investment opportunity arises. A suggestion has also been made that holdings of liquid assets increase when companies face more risk, while holdings fall when the corporate governance weakens. In such a case, corporate governance has a significant importance on how companies manage their money and choose investments, while liquidity measures can be used as a proxy for the measurement of the corporate governance strength.

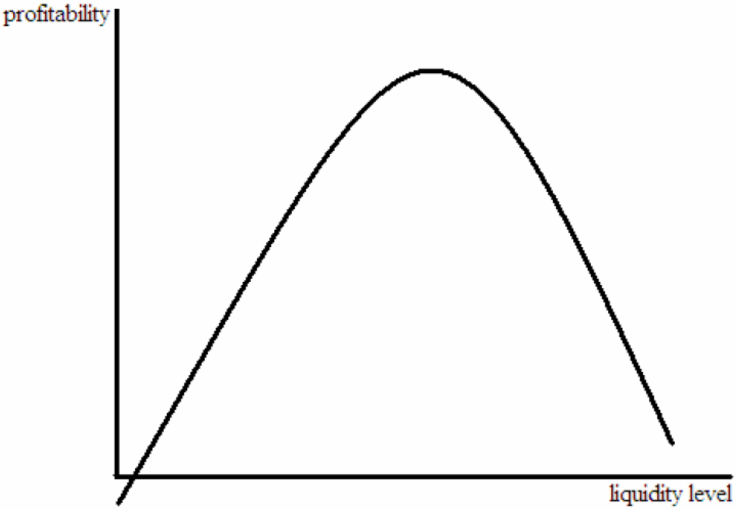


Figure 8. Effect of liquidity level management on profitability. Michalski, 2010

According to Michalski (2010), adequate liquidity management in the form of the sufficient cash level and working capital maintenance must be ensured to hold the company's operating risk in check. Liquidity management influences the company value as the cash investment levels entail the rise of alternative costs. Fluctuations of the working capital require balancing of the future cash flows thus affecting the company valuation fluctuations and changes. The increasing value of a company enables to attract cheaper capital and provides opportunities for investment into the further growth.

All of the above mentioned theories and suggestions concerning the liquidity management effect on the company profitability and value can be summarized by Figure 8. If the liquidity level is too low, the risk of underinvestment is present as even if a desirable investment opportunity turns up, either limited finance attraction capabilities or a higher cost of capital due to borrowing can prevent the implementation of the project. On the other hand, the surplus of liquid assets may result in ineffective utilization of resources, which can lead to the loss of potential profits.

Individual corporate liquidity management decisions affect the level of free cash flows to firm (FCFF) influencing the value of the company. The interconnection of free cash flows with the changes in the value of the company is presented by the function given below (Michalski, 2010):

$$\Delta V_p = \sum_{t=1}^{n} \frac{\Delta FCFF_t}{(1+k)^t} \quad \textbf{(31)}$$

According to Equation 31, there are three main ways how the liquid asset management policy may affect changes in the value of a company. The first way is through the FCFF factor value. Too cautious investment policy due to lack of liquid assets may result in downsizing of sales and the reduction of the generated cash flows. This may lead to loss in profits as presented in Figure 8. The second way is through parameter *k* indicating the cost of the capital employed in new investments. Liquid asset deficiency may lead to the rising risk of the company thus increasing the cost of financing investment projects and a potential loss in the value of the company. Lastly, the company value may be affected by parameter *t* depicting the lifespan of the company. Bad liquidity management decisions may lead to a reduced forecasted lifespan of the corporation during which free cash flows are earned. A decrease in the lifespan also has a negative effect on the value of the company.

Choices of liquidity management may affect both financial and operating risks of a company (Michalski, 2010). Operating risks are controlled by ensuring sufficient liquid assets to cover customarily payments made by the company. Precautionary motives also affect managerial choices to maintain sufficient levels of liquid assets as negative cash balances may occur due to delays in the collection of accounts receivable or demand shocks resulting in the decline of sales. Financial risk factors to retain cash reserves can be of speculative variety. Companies can hold higher levels of cash so that to preserve the possibility of purchasing additional asset levels due to exceptionally attractive prices.

Wang (2002) supports the idea by stating that, from the liquidity management point of view, investors should focus their concern on two main things. Firstly, they should avoid situations which could lead to default by emphasizing the ability of the company to cover its obligations with cash flows from mobilizing inventory and receivable investments. Secondly, they should keep operating cash flows sensitive to changes in sales and earning throughout periods of economic adversity. In order to supervise the quality of liquid asset management, a measure of the cash conversion cycle (CCC) is advised. The measure of CCC is denoted by an advantage compared to other liquidity measures as it is not static. Most of the measures analyze the situation of liquid assets at a fixed point in time, while CCC focuses on the length of time between the company making payments for stock or intermediate goods and receiving cash flows for the production which has been sold. Research conducted by Wang (2002) indicates that there exists a strong linear relationship between aggressive liquidity management and enhancement of operating performance. Thus, a decline in the CCC value by reducing the time between cash outflows to suppliers and money inflows from customers can increase the value created by the company from its operational activities.

Anderson and Carverhill (2012) suggest that there exists a relationship between profitability and liquidity policies. According to the model, companies set a target on the level of their cash reserves which decreases whereas, in parallel, profitability increases. Earnings are put aside into the reserve until the target level has been reached. Then, the surplus amount of cash tends to be paid out to the shareholders in the form of dividends. The target level is usually reached only at high profitability, while the average profile of cash holdings is a humped function in terms of the company's profitability. The function of corporate value assessment according to a research by Anderson and Carverhill (2012) is depicted in the equation given below:

$$J_t^q(\rho, C) = \max_{dD_t}\{dD_t + e^{-rdt} E_t^{(\rho,C)}[J_{t+dt}^q(\rho_{t+dt}, C_{t+dt})]\} \quad \textbf{(32)}$$

According to Equation 32, the value of a company's equity can be described as a function of the current profitability value ρ and its cash reserve C. Parameter dD_t indicates the derivative value of dividend payment, whereas e^{-rdt} is the discount term. The above presented function also includes the expectation term $E_t^{(\rho,C)}$ which indicates that the value of equity depends on the profitability level anticipated in the foreseeable future and the long-term liquid asset management plan. Dividend payment should be carried out in such a way that the diminished reserve of liquid assets would not deteriorate the company's ability to generate future cash flows. If the liquid reserve in the future periods becomes too low, the company will need to attract additional financial assets through borrowing or in the form of issuing additional stocks. The latter option may lead to equity dilution thus potentially reducing the value of the company.

1.2.5. Competitiveness in foreign markets

Exports can affect economic development mainly in three different ways (Raza, Karim, 2017). Firstly, an increase in the volume of exported production can improve the balance of payments. Secondly, an increase of competitiveness in international markets may be a source of job creation. Thirdly, it helps to enjoy the exporting country the economies of scale, which helps to accelerate technological advancement in production.

There exist a number of different theories which analyze the association between export and economic development. Some studies support the idea of the export-led growth hypothesis which suggests that export is the cause of economic growth. Other studies support the growth-led export hypothesis which indicates that economic development is the cause of an increase in export activities. The also exist some studies which analyze economic growth and export as two entities complementing each other. In all of the given cases, there is no attempt to deny that some interconnection between economic development and exports exists. For example, a research conducted by Sathyamoorthy and Tang (2018) which analyzes 119 countries over the period of 1990 to 2010 supports the export-led growth hypothesis, although the research also concludes that adequate institutional quality is needed to reinforce the effect of export activities on economic development.

One of the main arguments regarding export importance on economic growth is the fact that sustainable economic growth cannot be maintained in domestic markets because of the limited size. As demand in export markets usually is vastly larger, operating in (an) international market does not involve such strict growth restrictions on the demand side thus implying a potential catalyst for the output growth as an expansion of aggregate demand (Dreger, Herzer, 2013). Through the increase of competitiveness in foreign markets, exports can increase productivity by concentrating investment into more efficient sectors of the economy, thus utilizing the comparative advantages of production. Increased exporting activities may also lead to the promotion of cross-border knowledge spillovers, thus creating incentives for technological improvements, labor training and more efficient management due to the increased international competitiveness.

There exists a variety of various measures which try to assess potential technological transfer through export activities. One of them is called the export sophistication index. It is an outcome-based measure of a country's export package sophistication (Fortunato, Razo, 2014). This measure tries to capture the implied productivity of exported goods, as presented in the equation given below:

$$PRODY_k = \sum_j \frac{\frac{x_{kj}}{X_j}}{\sum_j \frac{x_{kj}}{X_j}} Y_j \qquad \textbf{(33)}$$

In Equation 33, parameter X_{kj} represents the export amount of product *k* by country *j*, X_j is the total value of exports of country *j*, and Y_j parameter indicates the gross national income per capita. If a product contains a larger share in the export basket of poorer countries while also maintaining a low share in the structure of the richer countries' export basket, then, the product will have a lower *PRODY* value. On the contrary, if a product is mostly exported by richer countries and if poorer countries do not export the given product, then, the product possesses a larger value of the *PRODY* measure. The export sophistication value of a particular country is then estimated as given below (Fortunato, Razo, 2014):

$$EXPY_{jt} = \sum_k \frac{X_{kjt}}{X_{jt}} PRODY_k \qquad \textbf{(34)}$$

In the below presented Equation 34, the term $\frac{X_{kjt}}{X_{jt}}$ represents the share of exported product *k* in the total value of *j* countries' exported goods. A higher level of the observable export sophistication is considered to display positive correlation with the technological intensity of the given country (Fortunato, Razo, 2014). The measure tries to avoid direct determination of the intrinsic features of the relevant product, such as the technology embedded in it, R&D investments, specialized skills required to produce the item and other applicable aspects. Instead, the export sophistication measure infers whether a product requires greater levels of development from the observed patterns of trade (Jarreau, Poncet, 2012). There exist various critiques for the results of the *EXPY* measure, with the main one being a large sensitivity of the country size to the value of export sophistication. Research conducted by Jarreau and Poncet (2012) which analyzed the relationship between the export sophistication measure and the economic growth in China over the period of 1997–2009 concluded that export sophistication matters for economic growth. This research also suggested that different sources of export upgrading, such as the adequate export regime and the firm type, need to be in place for the export sophistication to positively affect technological improvement and lead to economic growth.

Up to this point, analysis of literature indicates that the increased competitiveness in international markets may induce the economic growth of the exporting country in two main ways: by utilizing the comparative advantage of produced goods and by creating the economies of scale effect. Comparative advantage can be clarified by the production function of goods, as presented in the equation given below (Vernon, 2004):

$$z_i = nf_i\left(\frac{x_i}{\psi_{1i}(n)}, \frac{t_i}{\psi_{2i}(n)}\right), \quad i = 1, 2 \qquad \textbf{(35)}$$

The production function, as presented in Equation 35, makes an assumption that a product is created by using two inputs: parameter x_i represents raw materials, and t_i indicates the time needed to produce the goods. In different economic models, inputs can change. For example, production functions in the neoclassical growth models employ labor and capital as inputs for manufacturing goods. The main assumption is that both input variables should have constant returns to scale. Production technologies in the given scenario also do not vary between inner-market companies, but the production quantities grow with the increasing returns to the household size. The marginal rate of the technical substitution between inputs used in the manufacturing of the goods depends on the relative economies of scale (Vilcu, Vilcu, 2013):

$$MRTS_i = -\frac{dx_i}{dt_i} = \frac{\partial f_i / \partial t_i}{\partial f_i / \partial x_i} \frac{\psi_{1i}}{\psi_{2i}}, \quad i = 1, 2 \qquad \textbf{(36)}$$

The marginal rate of technical substitution indicates to what extent the first production input needs to be replaced by what amount of the second production input in order to maintain the same output of the analyzed item of goods. If the country has comparative advantage of a particular input used in the production process of an item of goods, then, the companies operating in the country can use more of that input during the production process. In such a way, the less effectively utilized production input can be substituted out of the production process. The elasticity of substitution in the case of the neoclassical growth model where capital and labor inputs are used in the production function is presented in the equation given below (Vilcu, Vilcu, 2013):

$$\sigma = \frac{(\partial f / \partial L)(\partial f / \partial K)}{f(\partial^2 f / \partial K \partial L)} \qquad \textbf{(37)}$$

The Cobb-Douglas production function, preferably used in the neoclassical growth theories, meets the requirements for the twice differentiable two-input homogenous production function with the constant elasticity of the substitution property. Thus, it can be concluded that the marginal rate of the technical substitution effect can be assessed in the neoclassical growth theory models.

The average production cost per unit of labor is represented as follows (Hsu, Li, 2009):

$$\frac{L_{n_k}}{f_{n_k}} = \frac{C(v_{n_k})}{f_{n_k}} + c(v_{n_k}), \ \forall n_k \qquad \textbf{(38)}$$

In Equation 38, parameters $C(v_{n_k})$ and $c(v_{n_k})$, respectively, represent the capital costs and the variable production costs. The capital costs are fixed costs which are related to the purchasing and installation of the equipment used in the production process, plant construction, land rental fees and other capital-operating expenses.

The production variable costs consist of the costs related to input factors other than raw materials (such as labor, utility and insurance). Equation 38 indicates that, with the increasing production amount f_{n_k}, the average production cost declines as the fixed capital costs are attributed to a larger amount of manufactured goods. This indicates the effect of economies of scale – that is, the increasing amount of produced goods leads to the declining average cost per unit of manufactured goods. This effect is represented in Figure 9.

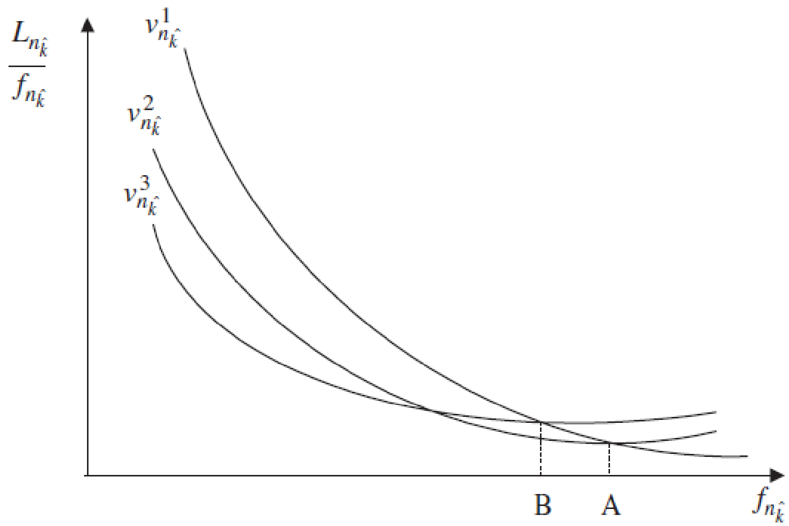


Figure 9. Relationship between average production cost and amount of produced goods. Hsu, Li, 2009

This figure represents the relationship between the average cost per unit of production and the amount of manufactured goods. The relationship is depicted for three manufacturing plants with different sizes of capacity. When the amount of production is low, the average cost is the largest for the plant with the highest capacity as it possesses the largest fixed capital costs. With the increase of the production amounts, the average costs per unit of manufactured goods decline down to a certain point. After the production level surpasses amount A, the manufacturing plant with the largest capacity (the highest level of fixed capital costs) secures the lowest average cost value. Since the average production cost per unit of manufactured goods depends on demand, a plant with a large-sized capacity maximizes its profits in international markets. Thus, the increased competitiveness in international markets may lead to economies of scale and the growth of the company value under assumption that a large enough amount of capital has been invested into the production process.

1.2.6. Energy consumption efficiency

There exist various research papers which support the idea of the existence of relationship between the economic growth and the efficiency of energy consumption. One of the more relevant theories on the topic is the environmental Kuznets curve (EKC). The hypothesis of EKC suggests that the relationship between the economic growth and CO_2 emissions is non-linear, but is rather of the inverted-U shape

(Shahbaz *et al.*, 2013). At the initial state of economic development, CO_2 emissions increase linearly, but, according to the theory, the level of emissions starts declining once the economy has matured. The relationship is presented in Figure 10.

The EKC hypothesis presented in Figure 10 argues that, in the short run, the increasing economic activity can have a negative effect on the environment, but, in the long run, the economic development can be beneficial to the environment. Thus, the economic growth is the remedy for environmental deterioration rather than a threat to the environment. After the breaking point has been reached, a negative linear relationship between the economic growth and environmental degradation can be witnessed.

Beside the long-term economic growth, empirical evidence supports the effect of the trade openness, financial development and proper institutional governance in controlling the environment from degradation (Shahbaz *et al.*, 2013). Adequate policies in the financial sector enable companies to utilize more advanced technologies which lead to lower CO_2 emissions and enhanced domestic production. Ahmed (2017) performed a research analyzing the effect of economic growth, financial development, capital and trade openness on energy consumption. In the research, the BRICS countries were analyzed over the period of 1991–2013. The obtained conclusions supported the EKC hypothesis suggesting that economic growth, financial developments and trade openness reduce the pressure on energy demand after the threshold level of income has been reached. It was also added that government interference is needed to reinforce the effect of the EKC theory by switching economic proprieties from the export-led growth policies to the services-led economic development.

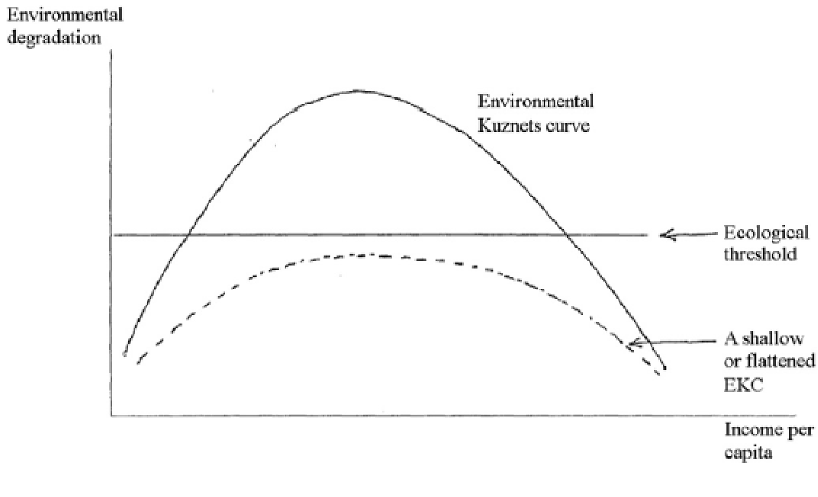


Figure 10. Environmental Kuznets curve. Ozokcu, Ozdemir, 2017

The idea of the relationship between technological progress and energy efficiency has also been proposed. The theoretical framework built by Di Vita (2006) suggests that an inverse relationship between the rate of use of exhaustible resources and the changes in knowledge accumulation exists, and it is represented by the parameter of productivity in the analyzed sector of economy. An increase in knowledge obtained from the growing technological progress allows reducing the pressure on the environment in various ways: the improvement of production input efficiency used in the manufacturing process; an increase of the possibility of using other resources in the manufacturing process instead of exhaustible ones; reduction of the quantity of resources extracted from earth.

An extension of the Cobb-Douglas production function is offered wherever the measure of technological progress can be derived as given below (Cantore, Cali, Velde, 2016):

$$TFP = \frac{y}{k^{\alpha} l^{\beta} e^{\theta} m^{\delta}} \quad \textbf{(39)}$$

Equation 39 represents the production function which is also known as KLEM. Parameters *k* and *l* are the same capital and labor measures as presented in the Cobb-Douglas production function and used in the neoclassical growth model. Two additional parameters are energy, indicated by parameter *e*, and materials, presented by *m*. Research by Cantore *et al.* (2016) analyzed the effect of energy efficiency on the technological progress in the context of the KLEM production function. The research evaluating manufacturing firms from 29 different developing countries concluded that higher energy efficiency can be associated with larger technological development in the vast majority of developing countries. This research also adopted the measure of energy efficiency (referred to as energy intensity) which is quite popular in academic literature. Energy intensity is estimated according to the equation presented below (Cantore *et al.*, 2016):

$$EI = \frac{EC}{TS} \quad \textbf{(40)}$$

In Equation 40, energy intensity is estimated as the ratio between the measure of consumed energy (EC) and the total sales (TS). Energy intensity was used as a proxy for energy efficiency as this measure is often used to determine energy efficiency over time. Energy intensity is one of the best rough surrogates for energy efficiency, although the measure may mask structural and behavioral changes which do not actually represent the true improvements of efficiency. The measure of energy intensity is usually estimated as the ratio between the energy amount and the value of output obtained from the production process, although Cantore *et al.* (2016) affirm that the monetary value rather than the physical amount of energy can be used in the estimation of energy intensity.

Zhang *et al.* (2013) suggested a few more measures to assess the interaction between the economic growth and the energy consumption efficiency:

- *Ratio of non-renewable energy to renewable energy (RNR)*. The RNR indicator reflects the energy mix as the ratio showing for every unit of renewable energy used, how much of nonrenewable energy is employed in the production process. The larger is the value of the ratio, the greater is the dependence of economic activity on nonrenewable energy. This indicates that companies operating in the given industry have not reached the breaking point in EKC and have not invested enough into technological progress to maintain long-term sustainable economic growth. A high value of RNR also indicates more emissions when other conditions are kept constant.

- *Energy use per unit GDP (EUPG, J/US$)*. EUPG measures the total energy consumption divided by GDP. A high level of this measure suggests lower energy efficiency of the economic activity. This indicator is mainly affected by the energy mix and the technological progress. A high level of renewable energy and (a) more advanced technology can help to enhance the energy efficiency of an economic activity. The generalized form of EUPG is also helpful in the analysis of economic development as the structure of energy sources is not taken into account thus easing the estimation process.

- *Environmental cost per unit of GDP (ECPG, sej/US$)*. The presently discussed measure estimates the amount of energy loss due to emissions against the value of GDP. A large value of the indicator suggests a high level of the environmental cost of the economic activity. The ECPG ratio is influenced by the industrial structure, the technological progress, and the governmental environment protection measures. Thus, large levels of the presently discussed measure may indicate the lack of investment in technological progress.

- *Impact of emissions per unit energy consumption (IEPEC, sej/J)*. The measure of IEPEC is the ratio between the energy of emissions impact and the energy share of the total energy consumption. The ratio reflects the intensity of environmental loading, with large values indicating a higher intensity of the environmental loading of energy consumption. IEPEC is also affected by the level of technological progress, the energy structure, and the governmental environment protection measures. A higher level of technological progress will lead to a reduced IEPEC value due to a larger share of renewable energy resources used in the production process.

- *Environmental benefit per unit environmental protection investment (EBPEI, sej/US$)*. This measure is the ratio of the energy of the impact of reduced emissions to the related investment into environmental protection. EBPEI reflects the efficiency of investment into environmental protection, with larger values indicating an increase in the efficiency of the investment.

Feng and Wang (2017) suggest using the meta-frontier concept to assess the energy efficiency in a market. The main aspect of meta-frontier is the measure of decision making units (DMUs) which can be divided into independent subgroups where technologies inside the same DMU group should be identical while being heterogenous across groups. The idea behind meta-frontier analysis is presented in Figure 11.

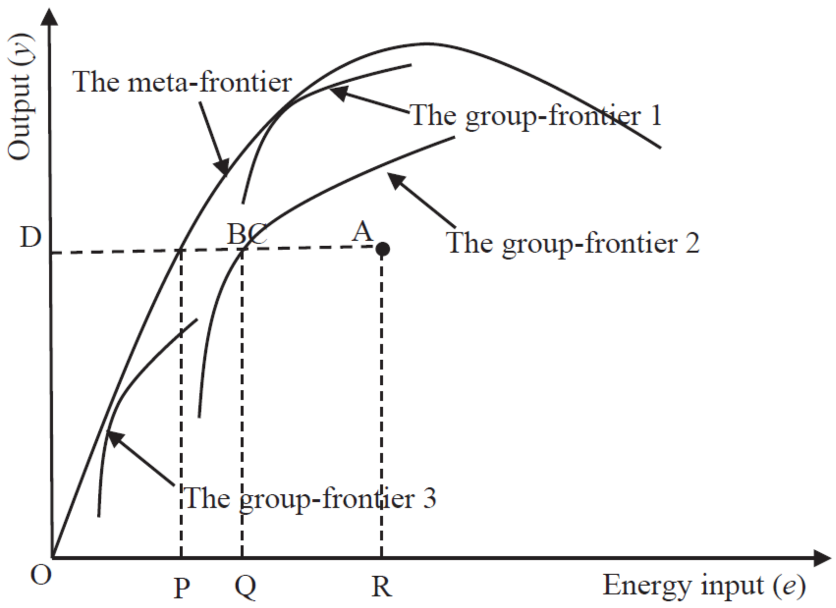


Figure 11. Concept of meta-frontier data envelopment analysis. Feng, Wang, 2017

Different group-frontiers in the presented figure indicate efficient levels of energy consumption for every DMU, while meta-frontier envelops all the group frontiers. Let us consider a DMU depicted by letter A, while making an assumption that it belongs to group-frontier No. 2. The actual energy input of DMU A can be projected on the X axis as OR. This energy amount used in the production process is inefficient as, according to group-frontier 2, the same DMU could produce the identical level of output with the energy input of OQ. The group-frontier itself is not fully efficient compared to the other groups of DMUs. If the second group could improve its technology up to the level of the most efficient groups in the market, the group frontier would shift to the left, and the DMUs in group-frontier 2 could produce the same amount of output with the OP amount of energy input. The ratio between OP and OQ is called the technology gap between the group-frontier and the meta-frontier.

The total-factor energy efficiency of a given DMU can be defined as $TFEE = \vartheta_m(l_i, k_i, e_i, y_i, c_i|CRS)$ while denoting that the energy efficiency level depends on labor inputs, capital inputs, energy inputs, economic outputs and the level of CO_2 emissions for the i^{th} DMU under the assumption of constant returns to scale. The total-factor energy efficiency can be decomposed into three components, as presented in the equation below (Feng, Wang, 2017):

$$\begin{cases} TFEE = TGR * SE * ME;\ TGR = \dfrac{\vartheta_m(l_i, k_i, e_i, y_i, c_i|CRS)}{\vartheta_g(l_i, k_i, e_i, y_i, c_i|CRS)}; \\ SE = \dfrac{\vartheta_g(l_i, k_i, e_i, y_i, c_i|CRS)}{\vartheta_g(l_i, k_i, e_i, y_i, c_i|VRS)};\ ME = \vartheta_g(l_i, k_i, e_i, y_i, c_i|VRS) \end{cases} \quad \textbf{(41)}$$

In Equation 41, parameter *TGR* measures the technology gap between the group-frontier and the meta-frontier. The closer the *TGR* parameter is to the value of 1, the smaller degree of heterogeneity is witnessed in the model. *SE* and *ME* represent, respectively, the scale efficiency and the management efficiency.

To conclude the analysis of academic literature on the relationship between economic growth and energy consumption efficiency, the results are conflicting. Some researchers suggest that the long-term economic growth cannot be sustained without increasing energy inputs and CO_2 emissions while others indicate that an increase in the technological progress results in a structural shift from non-renewable energy sources to the renewable ones, which reduces the harm inflicted upon the environment. Despite the disagreements, a sufficient number of theories and hypotheses were examined supporting the relationship between economic growth and energy consumption efficiency so that to include the latter parameter into the research model and analyze its effect on technological progress. For the future of economic development, Sorrell (2010) suggests that, for the economy to sustain its growth and at the same time preserve the environment with the limited quantity of non-renewable energy resources we possess, fiscal reforms, progressive efficiency standards and caps on emissions and resource use are necessary. Thus, energy efficiency will influence the development of economic growth even more firmly in the foreseeable future.

1.3. Technological progress measurement methods

Analysis of academic literature indicated that there exist two main ways to classify and measure the technological development of an industry. Productivity growth consists of two components: technological progress and technological efficiency improvement (Wang, Wong, 2016). Technological progress refers to the outward shift of the production frontier which is caused by the improvement in the technology in use. Technological efficiency measures the produced output level towards the production frontier. As efficiency at the firm level is not fully reached due to being caused by underutilization of the capital and labor employed in the production process, a difference emerges between the actual output and the output depicted by the production function. The first part of this chapter analyzes the subtleties of the assessment and analysis of the measure of technological efficiency. As the measure of technological progress from the theoretical standpoint has already been analyzed in the context of the neoclassical growth theory, the second part of the chapter is dedicated to reviewing empirical models in academic literature designed to evaluate technological progress in manufacturing industries.

1.3.1. Measure of technological efficiency

There are two main methods for the estimation of technological efficiency (Charoenrat, Harvie, 2014): stochastic frontier analysis (SFA) and data envelopment analysis (DEA). The SFA method is usually adopted for technological efficiency assessment as it is a parametric approach where the form of the production function is assumed to be known and can be estimated statistically. Another advantage of SFA is that hypotheses can be tested with statistical rigor, and relationships between the inputs and the outputs follow an already known statistical form. This SFA can simultaneously estimate the stochastic production model and the model of technical inefficiency effects.

The stochastic frontier model of cross-sectional data can be represented by the equation given below (Belotti *et al.*, 2013):

$$y_i = \alpha + x_i'\beta + \varepsilon_i, \;\; i = 1, \ldots, N \tag{42}$$

In Equation 42, parameter y_i represents the output, submitted in the logarithmic form, of i^{th} productive unit, x_i indicates the vector of inputs, and β is the vector of the parameters of technology. The error term ε_i in the given model is the sum of normally distributed disturbance v_i, which indicates the measurement and specifications errors, and one-sided disturbance u_i represents the inefficiency term. These two error terms are assumed to be independent from each other and identically distributed across observations. The basic form for technological efficiency evaluation from SFA is presented in the equation given below (Nguyen, 2010):

$$TE_i = \frac{y_i}{f(x_i;\beta)*e^{V_i}} \tag{43}$$

In the below presented Equation 43, the expression $f(x_i;\beta) * e^{V_i}$ represents the stochastic production frontier with β being the parameters of the production function, and with V_i representing the random noise of the model. Thus, from the theoretical standpoint, technological efficiency is represented as a ratio between the observed output and the maximum possible output under the condition of random shocks. Under the conditions given in Equation 43, producer *i* reaches the maximum level of output only when $TE_i = 1$. In case of $TE_i < 1$, the value of technological progress represents a measure of any shortfall of the observer output from the feasible output in the environment characterized by e^{V_i}. Estimates of technological efficiency can by assessed as shown below (Nguyen, 2010):

$$\widehat{TE_i} = E(\widehat{e^{-U_i}}|E_i) \tag{44}$$

According to Equation 44, the technological inefficiency parameter U_i is estimated after the distributional assumptions have been imposed on the error components of the equation from the derived conditional distribution of $U_i|E_i$. In such a way, the technological inefficiency term U_i is separated from the random shock term V_i.

The graphical representation of the interpretation of the technological efficiency measure estimated by using the SFA method is shown in Figure 12. The *GR* curve in the figure represents the production technology (also known as the production possibilities set) which indicates the set of feasible input-output vectors.

The dot presented in Figure 12 indicates that a producer is using x^A amount of resources to manufacture y^A amount of output. The production process of the manufacturer is technically inefficient as it is operating beneath the production possibilities set *f(x)*. In the given instance, the producer may choose between two approaches in order to increase its technical efficiency. One way is the contraction of the production inputs used in the manufacturing process such that $y^A = f(\theta^A x^A)$. The other way is the expansion of the produced output with the given amount of inputs used in the manufacturing process, such that the output reaches $\phi^A y^A$. In both cases, when the set of inputs and outputs reaches a point on the production technology frontier, $TE = 1$, and the producer starts operating at its maximum efficiency level.

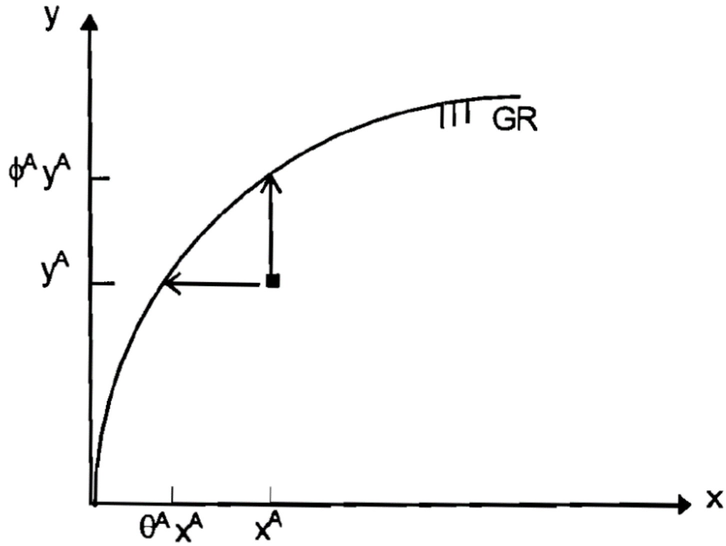


Figure 12. Technological efficiency measure representation using SFA method. Kumbhakar, Lovell, 2003

The concept behind estimating technological efficiency while using the DEA method is rather different. The estimation of the production technology with the help of DEA can be formulated as given below (Yu, 2008):

$$T = \{(x, y): \sum_{j=1}^{J} z_j y_{jm} \geq y_{km}\,,\ m = 1, \dots, M,\ \sum_{j=1}^{J} z_j x_{jn} \leq (1-\beta) x_{kn}\,,\ n = 1, \dots, M,\ z_j \geq 0,\ j = 1, \dots, J\} \quad \textbf{(45)}$$

In Equation 45, the intensity variables z_j are the combinations of inputs and outputs deduced from the set of all the observed inputs and outputs. The DEA method utilizes a sequence of linear programs for the construction of a linear production frontier, from which, efficiency indexes are estimated with relation to the frontier. In the case of technical efficiency, sometimes, the Two-stage DEA (TDEA) model is used which is treated as an input-oriented DEA model. The basic idea behind TDEA estimation is presented in Figure 13.

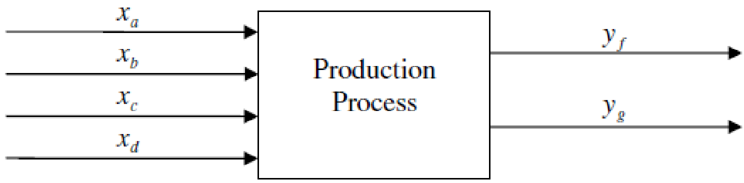


Figure 13. Two-stage DEA model used for estimation of technological efficiency. Yu, 2008

The input x_i minimization assumption is used while assessing technological efficiency where the optimal intensity parameters are estimated to evaluate the potential linear production frontier. Then, the estimation of the directional distance function, given the technology described in Equation 46, is performed while complying with the imposed optimization constraints (Yu, 2008):

$$\max \overrightarrow{D_g}(x, y; g_x, 0) = \beta \tag{46}$$

Thus, technological efficiency measures $(1 - \beta)$ are estimated; they measure how close the observations are to the assessed linear production frontier calculated in terms of the proportional decrease in the inputs. In the DEA model, the value of 0 indicates that the production unit is on the frontier, and the manufacturing process is efficient, while a value larger than 0 indicates inefficiency in the technology in use.

There are various papers which analyze the technological efficiency estimation results gained from both SFA and DEA methods. Odeck and Brathen (2012) compared the technological efficiency results gained in 40 different studies on seaports. They concluded that the results of DEA models had higher mean technical efficiency scores than those gained from parametric SFA models. Odeck in his other research (2007) where he analyzed Norwegian grain production data stated that the technological efficiency results received from SFA and DEA methods yielded only midrange correlation results across efficiency scores. This can be attributed to the fact that the SFA method incorporates the stochastic factor in the estimation process. The differences on both measures can also be attributed to the sensitivity on levels of segmentation for both the cross-sectional and the annual data levels. Still, if the research tries to define the relationship between economic growth and technological development, the better choice for technological efficiency estimation is the SFA parametric approach as the results can be obtained in their functional form, which eases the integration of various statistical methods.

1.3.2. Total factor productivity measure

The importance of the total factor productivity (TFP) measure on the long-term sustainable economic growth was discussed in detail while analyzing the neoclassical growth theory. This section of our analysis elaborates on the assessment methods of TFP and the interpretation of this measure.

There are various descriptions of the TFP measure. Hulten (2001) simplifies the definition of TFP by treating it as the changes of output per unit of labor. According to Comin (2010), TFP is the portion of output not explained by the amount of inputs used in the production. Thus, the measure determines how efficiently and intensely the inputs are utilized in the production process. Machek and Hnilica (2012) suggest that TFP is a method used for measuring productivity and its growth. Despite the differences in definition, all of the above mentioned researchers agree that TFP measures the relationship between the resources used in the production process and the total produced output thus defining how efficiently the production inputs are utilized in the manufacturing process.

In the economic practice, there are two main ways for TFP estimation: by measuring productivity indexes and productivity indicators (Ondrej, Jiri, 2012). The indexes have the multiplicative form, while the indicators have the additive form. The basic form of the Cobb-Douglas production function, used in the neoclassical growth theories while analyzing technological progress effect on economic growth, is defined as given below (Rabbani, 2006):

$$Y = AK^{\alpha}L^{1-\alpha} \quad \textbf{(47)}$$

In Equation 47, the TFP measure is represented by parameter *A*. According to the expression, TFP can be described as a multiplier which depicts how much of economic growth is conditioned by the production factors other than capital and labor. An important parameter of the Cobb-Douglas production function is parameter α which describes the output elasticity of the capital. It can be derived as shown in the equation below (Rabbani, 2006):

$$\frac{(\alpha A(^{L}/_{K})^{1-\alpha})K}{AK^{\alpha}L^{1-\alpha}} = \alpha \quad \textbf{(48)}$$

The parameter of the output elasticity of capital suggests that, for every additional monetary unit invested in capital, α amount of output is additionally produced due to the investment, where $\alpha \leq 1$. In such a case, the share of income spent on capital will be constant term α if a company wants to sustain the long-term growth without decreasing the amount of capital employed in the production process. In Equation 48, the value of α does not depend on the amount of capital in use, which means that the income spent on capital by a company does not depend on the amount of the employed capital.

A nonparametric index number approach which does not impose a specific form on the production function of the model is suggested. It is based on the logarithmic differential of the production function (Hulten, 2001):

$$\frac{\dot{Q}_t}{Q_t} = \frac{\partial Q}{\partial K}\frac{K_t}{Q_t}\frac{\dot{K}_t}{K_t} + \frac{\partial Q}{\partial L}\frac{L_t}{Q_t}\frac{\dot{L}_t}{L_t} + \frac{\dot{A}_t}{A_t} \quad \textbf{(49)}$$

Equation 49 indicates that the growth rate of real output can be factored into the growth rates of capital and labor weighted by both of their output elasticities and the growth rate of the Hicksian efficiency index. The growth rates of capital and labor represent movements alongside the production function, while the Hicksian efficiency index parameter indicates a shift of the function. Equation 50 can be rearranged to yield the Solow residual value (Hulten, 2001):

$$R_t = \frac{\dot{Q}_t}{Q_t} - s_t^K\frac{\dot{K}_t}{K_t} - s_t^L\frac{\dot{L}_t}{L_t} = \frac{\dot{A}_t}{A_t} \quad \textbf{(50)}$$

In Equation 50, the output elasticity of capital and labor are substituted with their corresponding marginal products. This converts the unobserved output elasticities into observable income shares, s^K and s^L. In this case, the Solow residual R_t factor estimates the residual growth rate of the output not explained by the growth inputs, which is the exact definition of the TFP measure. Erken, Donselaar and Thurik (2018) include the parameter of human capital into the evaluation of the TFP measure:

$$\ln(TFP) = \ln(^{Y}/_{L}) - \alpha\ln(^{K}/_{L}) = (1-\alpha-\beta)\ln(A) + \beta\ln(^{H}/_{L}) \quad \textbf{(51)}$$

First of all, Equation 51 indicates that the logarithmic value of TFP can be estimated by regressing the logarithmic form of the produced output per unit of labor on the logarithmic form of capital per unit of labor. This is similar to the Solow residual depicted in Equation 50, except that the output and capital in Formula 51 are expressed per unit of labor. Secondly, the TFP measure can be described by the sum of the term of technological progress and the parameter of human capital per unit of labor. This indicates that the qualitative measure of human capital is included into the TFP measure, and that it affects effective utilization of the resources used in the production process.

The estimation process of the Solow residual is more of a theoretical framework as, in practice, it does not always yield efficient estimations of the TFP measure. The reason for this is the fact that the Solow residual is a residual measure of the linear equation, and sometimes it captures the measurement error, the omitted variable bias, the aggregation bias, or the model misspecification, which can lead to misleading results of the TFP value gained while using this methodology (Hulten, 2001).

There exists another way for the estimation of the total factor productivity, although this method is somewhat more complex. The method is called the Malmquist total factor productivity index. The Malmquist index can be estimated in the following way (Candemir *et al.*, 2011):

$$M_0(y^t, x^t, y^{t+1}, x^{t+1}) = \left[\frac{D_0^t(y^{t+1}, x^{t+1})}{D_0^t(y^t, x^t)} x \frac{D_1^{t+1}(y^{t+1}, x^{t+1})}{D_1^{t+1}(y^t, x^t)}\right]^{\frac{1}{2}} \quad \textbf{(52)}$$

The Malmquist total factor productivity index formula, as depicted in Equation 52, can be decomposed into two separate parts:

$$M_0^{t,t+1} = Efficiency\ Change * \ Technical\ Change \quad \textbf{(53)}$$

The first term in Equation 53 indicates changes in the measures of efficiency, while depicting the catching up to the best practice frontier for each observation between periods t and t+1. The second term of the Malmquist index represents the technical change index which measures the shift of the technology (or innovation) frontier between two adjacent time periods. Thus, the first part of Equation 52 represents the value of the technological efficiency measure which was described in the previous section, while the second part of the equation represents the TFP value. The Malmquist total factor productivity index can be calculated by utilizing the DEA methodology by evaluating four distinct functions and measuring changes between the two periods which produce the TFP measure. The main drawback of the presented approach is the fact that the production frontier needs to be estimated by using econometric or mathematical programming methods before the assessment of the Malmquist total factor productivity index can actually begin.

Analysis of academic literature revealed the existence of numerous different approaches for the evaluation of technological progress development. The neoclassical growth theory is selected as the basis for the construction of the model because the TFP measure was determined to be most appropriate to accomplish the goal which we have set for this particular research. Analysis of academic literature also helped to distinguish the factors potentially influencing the changes in the technological progress values throughout time, while the presence of a relationship between these factors and the values of technological progress will be tested in the empirical part of the research. The analyzed factors influencing the technological progress values of manufacturing industries can also vary between different markets and countries. For this reason, the model constructed in the presented research can be adjusted according to the characteristics of the evaluated manufacturing industries. It also depends on data availability – different proxies can be used to represent various variables according to how the data is gathered and evaluated. Theoretical findings also helped to define the most essential drawbacks of the neoclassical growth theories; these shall be addressed and improved upon in the methodological part of the research.

2. METHODOLOGY OF TECHNOLOGICAL PROGRESS EVALUATION AND ASSESSMENT OF THE EFFECT OF FACTORS ON TECHNOLOGICAL PROGRESS IN MANUFACTURING INDUSTRY

Analysis of academic literature indicated that the main problem with technological progress evaluation in the neoclassical growth theories is the fact that the measure of technological progress is analyzed as an exogenous parameter. This means that technological progress is usually added to the production function as a fixed parameter, and the effect of dynamic changes in technological progress is not taken into account when estimating the potential production output with the given amount of inputs used in the manufacturing process. The goal of the research is to create a model which addresses the dynamic nature of the parameter of technological progress and evaluates how different changes in factors affecting the value of technological progress lead to the growth of the produced economic output. After the methodology of the model has been defined, empirical research will be performed for the case of the Lithuanian manufacturing industry. A generalized form of the model used to assess the effect of factors on the technological progress in manufacturing industries is shown in Figure 14.

Technological progress measure estimation			
Time series regression			
Cash ratio	*Capital leverage ratio*	*Export to total turnover*	*Reinvestment ratio*
Time trend		*Interaction terms between capital and time*	

↓

Intersectoral technological progress spillover effect assessment
Granger causality test

↓

Technological progress relationship function construction		
Vector autoregression model		
Lagged technological progress values	*Lagged reinvestment ratio values*	*Current labor productivity ratio*
Current foreign capital structure ratio	*Current inflation adjusted net profit values*	

↓

Sensitivity analysis of manufacturing level indicators on technological progress values			
Agent-based modelling framework			
Four different simulations performed:			
Increase in inflation adjusted net profit by 5%	*Increase in inflation adjusted net profit by 10%*	*Increase in labor productivity ratio by 5%*	*Increase in labor productivity ratio by 10%*

Figure 14. Evaluation model of factors affecting technological progress in manufacturing industry

Figure 14 presents an evaluation model whose objective is to assess the values of technological progress dynamically by estimating the effect of various macroeconomic level parameters on the changes in the measures of technological progress thus affecting the development of economic growth. The model itself consists of four main parts. The first part is the evaluation of the measures of technological progress with the help of time series regression. TFP was chosen as a parameter for technological progress representation as, according to the neoclassical growth theory and the Cobb-Douglas production function, long-term shifts in the production function indicating the potential output growth which can be produced with a fixed set of inputs, are affected by technological innovations indicated by the TFP measure. The second part of the research explores whether the technological progress spillover between different sectors in the manufacturing industry does actually exist. The presence of the technological progress spillover would suggest a causal relationship between the values of technological progress in different sectors. The third part of the research is dedicated to the construction of vector autoregression (VAR) models. Various VAR models are built for each sector in the manufacturing industry so that to define a unique set of variables which influence changes in the values of the measures of technological progress. The final part of the research is the performance of sensitivity analysis which indicates how changes in the values of various parameters affect the fluctuations of the measures of technological progress. The remaining part of this chapter is dedicated for detailed analysis of the methods used in the presented model.

All the data used in the presented research was gathered from Statistics Lithuania.

2.1. Technological progress measurement by using time series regression

For the assessment of technological progress, the TFP measure was chosen and estimated on the basis of the neoclassical growth theory as developed by Solow. It was preferred over the technological efficiency measure estimated by using the stochastic frontier analysis method because TFP is superior at describing long-term technological progress development and is easier to integrate into the constructed model.

Analysis of academic literature indicated a couple of main methods for TFP assessment, although both of the approaches suffer from their own shortages. The first method consists of evaluating Solow residuals which measure the growth rate of technological innovation. A drawback of this method is the endogeneity problem arising from the nature of the Solow residual parameter. The value of the Solow residual measure might include a hidden parameter in the error term which correlates with the production output but has nothing to do with the measure of technological progress. In such a case, the estimated TFP value will be inaccurate. The second way to measure TFP is the formation of the Malmquist total factor productivity index. The problem with this approach comes from the complexity of the methodology as the exact form of the production frontier needs to be established before the Malmquist index can be assessed. Thus, a new methodology for TFP evaluation is structured for this research; it tries to eliminate the problems of the previously described TFP estimation methods.

The basis for TFP evaluation is the Cobb-Douglas production function which is used in the neoclassical growth theory when trying to describe the long term economic growth. The Cobb-Douglas production function is presented in Equation 54. In the formula given below, the production function has an exponential form, but it can be transformed into a linear form. After the natural logarithm of all parameters has been taken, the Cobb-Douglas production function can be converted into a linear equation:

$$\ln(Y) = \ln(A) + \alpha * \ln(K) + (1 - \alpha) * \ln\,(L) \qquad \textbf{(54)}$$

The time series regression method can be applied to Equation 54 in order to estimate the value of parameter α which represents the output elasticity of capital. The output elasticity of capital is an essential parameter of the Cobb-Douglas production function needed to establish TFP values. For the time series regression to present the accurate results of the parameter of the output elasticity of capital, the possible endogeneity of regression, the stationarity of the time series data, and the collinearity of the parameters used in the model need to be addressed.

Endogeneity in regression analysis can be broadly described as a correlation between the explanatory variables and the error term of the regression (Abdallah, Goergen, O'Sullivan, 2015). The endogeneity problem may arise due to the omission of explanatory variables which would lead to error term correlation with the explanatory variables thus violating the basic assumption behind the ordinary least squares (OLS) regression analysis. Endogeneity may be of the simultaneous type where contemporaneous realizations of both the dependent variable and the explanatory variables affect each other, and the dynamic type, where the past realization of the dependent variable influences the current realizations of one or more explanatory variables.

The bias of endogeneity due to an omitted variable can be explained by the equations given below (Chen *et al.*, 2015):

$$y_t = x_t'\beta + e_t \qquad \textbf{(55)}$$

$$e_t = \lambda(v_t) + u_t \qquad \textbf{(56)}$$

Variable x_t', included in Equation 55, represents the vector of independent variables which are added to time series regression. Variable e_t is the error term of the regression equation which is comprised of two parts: $\lambda(v_t)$ and u_t. Variable u_t is the independent error term, while $\lambda(v_t)$ is the linear function of the parameters which are not included in the time series regression as explanatory variables. An assumption is made that $\lambda(v_t)$ and u_t are not correlated with each other, but correlation exists between some variables in vector x_t' and the omitted parameters from the linear function $\lambda(v_t)$. In such a case, coefficients β of the independent variables which are correlated with the error term are inaccurate. In order to fix the endogeneity problem, the omitted parameters should be included into the time series regression thus lifting the function $\lambda(v_t)$ from the error term to the regression itself thus removing the correlation between the explanatory variables and the errors of the regression model.

The second aspect which needs to be addressed when building a time series regression is the stationarity of parameters included in the model. A time varying process is said to be stationary when its probability distribution remains unchanged as the time progresses (Pesaran, 2015). There two main assumptions of the stochastic process stationarity are as follows: the strict stationarity assumption and the weak stationarity assumption.

Stochastic process $\{y_t, t \in \tau\}$ is said to be strictly stationary of order s when the joint distribution of functions $\{y_{t1}, y_{t2}, \dots, y_{tk}\}$ and $\{y_{t1+h}, y_{t2+h}, \cdots, y_{tk+h}\}$ is identical for all the values of $t_1, t_1, \dots, t_k$ and h, where k are all positive integers and meet the requirement of $k \leq s$. The one important implication of strict stationarity is that y_t will have the same distribution for all t. This ensures constant estimation of the unknown parameters of the process from time averages. In the time series regression, strict stationarity is not a requirement. The weak assumption of stationarity is required for a time series to be called stationary. Stochastic process $\{y_t, t \in \tau\}$ is said to be weakly stationary if it has a constant mean and variance, while the covariance function of time series is defined as (Pesaran, 2015):

$$\gamma(t_1, t_2) = Cov(y_{t1}, y_{t2}) = E(y_{t1}, y_{t2}) - E(y_{t1})E(y_{t2}) \qquad \textbf{(57)}$$

The weak stationarity assumption requires the constant mean and variance. For this reason, time series with either trend or seasonality cannot be classified as stationary. As annual data will be used in the presented research, problems with data seasonality can be disregarded. There are two distinct ways to remove the trend of time series (Enders, 2015): differencing and detrending.

Differencing is not only a way to remove a trend from a time series, but also a way to transform the time series data from non-stationary into stationary. This is represented by the system of equations series given below (Enders, 2015):

$$E(\Delta y_t) = E(a_0 + \varepsilon_t) = a_0 \qquad \textbf{(58)}$$

$$var(\Delta y_t) = E(\Delta y_t - a_0)^2 = E(\varepsilon_t)^2 = \sigma^2 \qquad \textbf{(59)}$$

In case of $s \neq 0$:

$$cov(\Delta y_t, \Delta y_{t-s}) \equiv E[(\Delta y_t - a_0)(\Delta y_{t-s} - a_0)] = E(\varepsilon_t \varepsilon_{t-s}) = 0 \qquad \textbf{(60)}$$

The above presented equations suggest that the expected mean of the time series variable with a trend after differentiation varies around the constant value of a_0 while the variance is equal to σ^2. As both the mean and the variance of the given time series do not depend on time variable t, stationarity assumptions are met. The covariance measure confirms the given conclusions as covariance between Δy_t and any lagged values of the same time series Δy_{t-s} results in 0 thus suggesting no relationship between the current and the lagged values of the time series.

Another option of removing a trend from a time series parameter is detrending as not all time series models can be transformed via the help of differencing without losing important information. Detrending can be accomplished by adding a time trend variable into the time series regression, as shown in the equation series presented below (Enders, 2015):

$$y_t = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + \cdots + a_n t^n + e_t \quad \textbf{(61)}$$

In Equation 61, variable e_t is the error term which becomes a stationary process after detrending. The variables of t, included into the regression, form a deterministic polynomial time trend. Equation 61 presents a generalized form of detrending as the polynomial form of the time trend can become linear when $a_2 = a_3 = \cdots = a_n = 0$.

For the evaluation of stationarity, the Dickey-Fuller test is used (Wooldridge, 2012). The test is performed by running an autoregressive model of the 1st order on the variable used in the time series regression model. The conclusions of the test depend on the lagged coefficient value estimated by the AR(1) model. If the coefficient value is found to be equal to 1, then, the unit root has been perceived in the time series parameter specifying that it is not stationary. In the case that the coefficient value of the lagged parameter is proven to be significantly lower than 1, the AR(1) process is stable, and the analyzed time series parameter is concluded to be stationary. In most cases, the augmented Dickey-Fuller test is used for evaluating stationarity because it includes lagged changes of the analyzed parameter. In most cases, not even a single parameter which is not stationary can be included in a time series regression if accurate coefficient values are expected. There exists a special case with the vector of variables. If all of the variables included in a vector achieve stationarity after differencing, they could have linear combinations where the joint stationarity condition is met even if – by themselves – some of the variables are non-stationary. This condition is called cointegration (Dolado, Gonzalo, Marmol, 2003). Cointegration can be tested firstly by performing a time series regression for the vector of variables. Then, the augmented Dickey-Fuller test should be performed on the residuals of the time series model. If the test indicates that the residuals of the time series model are stationary, then, the variables are jointly cointegrated, and the obtained coefficients are eligible for interpretation.

The next problem which might arise while performing time series regression and which needs to be addressed is multicollinearity. Multicollinearity is a statistical phenomenon in which two or more explanatory variables in a regression model are highly correlated (Daoud, 2017). Multicollinearity in a regression model can be observed when large changes in the estimated coefficients occur after a variable has been added or deleted, or if large changes in coefficients are witnessed when a data point has either been altered or dropped. Thus, multicollinearity is detected when the correlation among some predictors is large. When two or more explanatory variables are highly correlated, omitting one of the variables from the regression model helps to deal with the problem of collinearity in the parameters.

In order to deal with the above described possible problems which might occur in a time series regression, the presently given model is used for estimating the output elasticity of capital:

$$\ln(Y_t) = \beta_1 + \beta_2 * \ln(K_t) + \beta_3 * \ln(EN_t) + \beta_4 * \ln(CASH_t) + \beta_5 * \ln(ETD_t) + \beta_6 * \ln(EXP_t) + \beta_7 * \ln(INV_t) + \beta_8 * T + \varepsilon_t \quad \textbf{(62)}$$

It was distinguished that the Solow residual parameter which is used for the assessment of TFP might be inaccurate due to the endogeneity problem as only output, capital and labor are included into the regression for the estimation of the measure.

For this reason, a time series regression developed to estimate the output elasticity of the capital parameter includes additional explanatory parameters so that to eliminate any possible correlation between the error term and the capital. Thus, beside output per unit of labor, represented by Y_t, and capital per unit of labor, represented by K_t, additional parameters are included into the model as well. These additional parameters have been chosen in accordance with analysis of academic literature performed in the theoretical part of the research. Parameter EN_t portrays energy consumption in the production process represented by the parameter of energy intensity. Parameter $CASH_t$ represents the cash ratio thus indicating the extent of short-term liabilities which is covered by disposable cash and cash equivalents. ETD_t is the leverage ratio estimated by dividing the equity value by the total debt value. EXP_t indicates the ratio of the export turnover to the total turnover. Finally, the INV_t variable represents the reinvestment ratio which is estimated by dividing the investment on material assets by the total value of the material assets. The values of the presented variables and the statistical characteristics of the data are presented in Tables A.1–A20 of the Appendix. The presented variables were chosen to be included into the model depicted by Formula 62, because, out of all the variables analyzed in Section 1.2, they influenced the changes in technological progress values by affecting the amount of the accumulated capital and the output elasticity of the capital values.

In order to satisfy the stationarity assumption, time series variable T is included to perform the detrending. The augmented Dickey-Fuller test is also performed on error term ε_t in order to assess whether cointegration between parameters of time series regression exists.

The final thing which needs to be addressed is the fact that coefficient β_2 is constant throughout the analyzed time period. When evaluating a time series of around 20 years, the output elasticity of capital varies in accordance with different stages of the economic cycle. For this reason, the interaction term between the time and capital parameters needs to be incorporated into the time series regression model. Interaction terms are included into regression models when the effect of an independent variable on a dependent variable is affected by the magnitude of another explanatory variable (Wooldridge, 2012). In this case, the effect of the capital value on the produced output depends on the time period at which the relationship is measured. Therefore, after the inclusion of the interaction parameters in time series regression, the improved model looks as given below:

$$\ln(Y_t) = \beta_1 + \beta_2 * \ln(K_t) + \beta_3 * \ln(EN_t) + \beta_4 * \ln(CASH_t) + \beta_5 * \ln(ETD_t) + \beta_6 * \ln(EXP_t) + \beta_7 * \ln(INV_t) + \beta_8 * T + \sum_{i=1}^{4} \beta_i * \ln(K_{t+i}) * Year_{t+i} + \varepsilon_t, \quad \forall\, i, Year_{t+2,i} < Year_{t,i+1} \qquad \textbf{(63)}$$

According to Equation 63, four interaction terms are added into the model in order to address dynamic changes in the output elasticity of the capital throughout time. The only restriction is that a single interaction term cannot cover a shorter time period than three years. If the interaction term could evaluate time periods shorter than three years, there would exist a larger possibility of β_i coefficient values being affected by discrepancies not related to the dynamic changes in the output elasticity of the capital parameter.

$$A_{i,t} = \frac{Y_{i,t}}{K_{i,t}^{\alpha_{i,t}} * L_{i,t}^{(1-\alpha)_{i,t}}} \quad \textbf{(64)}$$

When the annual output elasticity of the capital values are estimated, the TFP measures for each distinct sector of the analyzed manufacturing industry can be assessed in accordance with Equation 64.

2.2. Evaluation of intersectoral technological progress spillover effect

For the evaluation of the technological spillover effect between sectors, academic literature suggests using the Granger causality test. The advantage which Granger causality test is deemed to possess over the other cause-effect relationship assessment methods is the fact that its probabilistic concept of causality does not rely on the specification of a scientific model. Thus, this method is particularly suited for empirical investigations of the cause-effect relationships (Eichler, 2011). The Granger causality test has extensive possibilities of utilization. For example, Lu, Chen and Wang (2006) performed the Granger causality test to evaluate the relationship between R&D and productivity growth, while assuming that productivity growth might arise from the technological progress spillover effect induced by changes in R&D expenses. Hong, Liu and Wang (2009) also used the Granger causality test method to assess whether the risk of investment in one market can spill over into the markets of other countries. Granger causality evaluation can be depicted by the formulas given below (Tuppura *et al.*, 2016):

$$Y_t = \alpha_0 + \sum_{j=1}^{n} \alpha_j Y_{t-j} + \sum_{k=1}^{n} \beta_k X_{t-k} + e_{1t} \quad \textbf{(65)}$$

$$X_t = \gamma_0 + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \sum_{k=1}^{n} \delta_k X_{t-k} + e_{2t} \quad \textbf{(66)}$$

According to Equations 65 and 66, Granger causality is tested between two different variables X and Y (in the case of the given research, these variables are the TFP values of two different sectors operating in the manufacturing industry). Variable X is said to be Granger causing variable Y if the group values of coefficients β_k are statistically significantly different from zero, while variable Y is said to be Granger causing variable X if coefficient values δ_k are jointly statistically significantly different from zero. The Granger causality test requires the assumption that both e_{1t} and e_{2t} error terms are uncorrelated. It should be emphasized that the Granger causality test does not support bidirectional relationship, nor does it indicate a real causality (for example, that changes in variable X cause changes in the values of variable Y). It just indicates the fact that changes in one parameter are preceded by changes in another parameter.

In order to estimate whether variable X Granger causes changes in variable Y, the model presented in Equation 65 is evaluated two times. The first time, it is evaluated normally (as an unrestricted model), while for the second time, it is evaluated by fixing the values of coefficients β_k to zero (as a restricted model). Then, the error values of both models are compared, as presented in the formula given below (Bressler, Seth, 2011):

$$F_{X \to Y} = \ln \frac{var(e_{1t})}{var(e'_{1t})} \quad \textbf{(67)}$$

In Equation 67, variable e_{1t} represents the error term of the restricted model, while e'_{1t} indicates the error term of the unrestricted model. If the variability of the error term from the unrestricted model is significantly lower than the variability of the error term from the restricted model, then, the inclusion of variable X lagged values significantly improve the model, and coefficients β_k are jointly significantly larger than zero thus indicating Granger causality. The statistical significance of the unrestricted model over the restricted model can be measured with the help of the F-statistic parameter which can be calculated as given below (Bressler, Seth, 2011):

$$F = \frac{RSS_r - RRS_{ur}/_m}{RSS_{ur}/_{T-2m-1}} \quad \textbf{(68)}$$

In Equation 68, parameters RSS_r and RRS_{ur}, respectively, represent the residual sum of the squares of restricted and unrestricted models, while T is the total number of observations, and *m* represents the degrees of freedom of the model. A significant F-statistic measure presents evidence that the unrestricted model provides a better prediction of variable Y than the restricted model, thus variable X is said to Granger cause variable Y.

The Granger causality test results are also affected by the stationarity of the time series variables between which the causality is being evaluated. According to He and Maekawa (2001), conventional F tests erroneously detect spurious Granger causality with a high probability when the analyzed processes are either non-stationary, trend stationary, or when random walks with drifts are observed. In such cases, non-stationarity should be removed by using either differencing or detrending, as described in the previous chapter. An exception is when the time series variables are jointly cointegrated. Shukur and Mantalos (2000) compared the results of various tests used to interpret F-statistic results estimated by using Equation 68. They concluded that, when cointegration between the analyzed time series parameters exists, there are no noticeable differences between different tests, and the regular Wald test is sufficient to precisely evaluate Granger causality between the variables. When no cointegration between the parameters exists, all the tests perform badly, especially in the case of a small sample size. Thus, if parameters by themselves are not stationary but they still meet the joint cointegration requirements (i.e., the error terms of time series regression are stationary), then, Granger causality can be assessed with the help of the results of the Wald test.

The assessment of Granger causality requires the determination of lag length *t*. A research paper by Verspagen and Loo (1998) estimated that the technological progress spillover initiated by the increased expenses in R&D starts declining rapidly after a time period of three years has passed. The above mentioned research also identified that earlier years have a larger weight in the spillover effect compared to the time periods with larger lag values. As the goal of the Granger causality test in this research is to identify the potential technological progress spillover effect and not to measure the intensity of the effect (in order to achieve this objective, a different methodology is used at the later stages of the model), the lag length of three years was deemed to be sufficient.

2.3. Technological progress relationship function formation by using vector autoregression model

Analysis of the neoclassical growth theory indicated that the technological progress parameter is usually analyzed as an exogenous variable. This means that the TFP parameter is included into the production function as a fixed value. This has two implications for the results of a model analyzing the economic development in the manufacturing industry. Firstly, the dynamic changes of TFP created by either the investment into R&D or induced by the technological progress spillover effect are not addressed. Secondly, the parameters influencing the changes of TFP values are not integrated into the model. Thus, the extent of the effect that different variables have on the TFP parameter is not measured. The goal for this part of the model is to create a function which defines the relationship between changes in the technological progress and the parameters that influence fluctuations in technological development.

The two initial parts of the defined model helped to evaluate the TFP annual values for each of the sectors operating in the analyzed manufacturing industry and to assess the technological progress spillover effect in the form of Granger causality. The third part of the model seeks to determine which factors and to what extent affect changes in the TFP measures and estimate the exact extent of the technological spillover effect between various sectors in the manufacturing industry. In order to achieve the above given objective, the vector autoregression (VAR) model is utilized. The VAR model is appropriate for the task as it helps to analyze the joint dynamic of the variables exploring the linear interactions between them (Damasio, Mendonca, 2019).

The VAR model is a model based on the statistical properties of the data (Zhou, Luo, 2018). It is constructed by considering each endogenous variable as a function of the hysteresis value of all the endogenous variables in the system thus generalizing the univariate autoregressive model to a vector autoregressive model composed of multivariate time series variables. The popularity of the model arises from the fact that VAR is easy to use and interpret. The basic mathematical expression of the VAR(p) model is depicted as given below (Zhou, Luo, 2018):

$$y_t = \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + Hx_t + \varepsilon_t,\ t = 1,2,\ldots,T \quad \textbf{(69)}$$

In Equation 69, variable y_t represents the vector of endogenous variables, x_t presents the vector of exogenous variables, and ε_t is the error term of the model. The value of p indicates the lag length of the model. The VAR model, due to its structure, embodies unique superiority compared to other similar methods. Firstly, in order to explain the relationships between different parameters, a large number of explanatory variables can be included into the model, thus managing to evaluate complex relationships as long as enough degrees of freedom are available to support the increased quantity of the modelled parameters. Secondly, if exogenous variables are excluded from the model, VAR has an advantage in the construction of forecasting models as the predicted results of small and easy to interpret VAR models are usually better than large, structured simultaneous systems.

There exist different variations in the methods used for the VAR model estimation, each with its own purpose. For example, the Bayesian vector autoregression (BVAR) method is used for forecasting. The fundamental object in the BVAR method is the posterior predictive distribution $p(y_{t+1:t+H}|Y_t)$ of the future datapoints conditional on the currently observed data (Karlsson, 2013). This method should be used when the predictive distribution captures all the required information about the predictive future events; thus, the predictive distribution is relevant for the given situation and should be represented in the forecasting model. In order to estimate the BVAR model, three main factors are taken into account: the distribution of future observations conditional to unknown values of parameters (θ), the observed data $p(y_{t+1:t+H}|Y_t, \theta)$ of the parameters which are being forecasted, and the distribution of the observed data $L(Y_t|\theta)$. Then, the likelihood of a predicted future event with regard to the distribution of the parameters used in the BVAR model can be represented as given below (Karlsson, 2013):

$$L(Y_T|\theta) = \prod_{t=1}^{T} f(y_t|Y_{t-1}, \theta) \quad \textbf{(70)}$$

As the historic values of predicted variable Y_T are extended so that to include the initial observations of the parameters that the likelihood is conditioned on, the distribution of future observations is modelled to maintain the same form:

$$f\left(y_{T+1,T+H}\middle|Y_T, \theta\right) = \prod_{t=T+1}^{T+H} f(y_t|Y_{t-1}, \theta) \quad \textbf{(71)}$$

The prediction function of variable Y_T, in the case of the BVAR model, takes the form presented in Equation 71 where the forecasted values depend both on the past values of the analyzed variable and the predictive distribution form perceived in the historical data.

Another extension of the VAR model is the structural vector autoregression model (SVAR). The SVAR model seeks to extract structural parameters from the error term thus excluding influences of unrelated factors from the model. The basic form of the SVAR model can be written as (Brischetto, Voss, 1999):

$$B(L)x_t = u_t,\ Eu_tu_t' = D,\ Eu_tu_{t+s}' = 0,\ \forall s \neq 0 \quad \textbf{(72)}$$

In Equation 72, parameter *B(L)* indicates the p^{th} order matrix polynomial of lag operator L which can be presented as $B(L) = B_0 - B_1L - B_2L^2 - \cdots - B_pL^p$. This parameter shows the contemporaneous relationships between parameters in the SVAR model. The SVAR model in its reduced form can be derived as:

$$A(L)x_t = \varepsilon_t,\ E\varepsilon_t\varepsilon_t' = \Sigma,\ E\varepsilon_t\varepsilon_{t+s}' = 0,\ \forall s \neq 0 \quad \textbf{(73)}$$

Parameter *A(L)* from the reduced form of the SVAR model equation can be depicted as $A(L) = B_0^{-1}B(L) = I - A_1L - A_2L^2 - \cdots - A_pL^p$, and the error term then becomes $\varepsilon_t = B_0^{-1}u_t$. Thus, the SVAR model helps to extract parameter B_0^{-1} from the error term and include its effect into the model.

In the presented framework, the regular VAR model will be used as neither the BVAR nor the SVAR model conforms with the goals of the research and the structure of the data gathered for the empirical analysis of the manufacturing industry.

There are various estimators used to assess the coefficients of the VAR model. The most conventional one is the ordinary least-squares (OLS) method. OLS for each equation separately evaluates the most efficient estimators where every estimator of the VAR(p) model can be presented as given below (Kilian, Lutkepohl, 2017):

$$\hat{A} = \left[\hat{v}, \hat{A}_1, \dots, \hat{A}_p\right] = \left(\sum_{t=1}^{T} y_t Z'_{t-1}\right)\left(\sum_{t=1}^{T} Z_{t-1} Z'_{t-1}\right)^{-1} = YZ'(ZZ')^{-1} \quad \textbf{(74)}$$

Under general assumptions, OLS estimators presented in Equation 74 are denoted by asymptotic normal distribution. A sufficient condition for the consistency and normality for OLS estimators is that the error term ε_t is a continuous independent and identically distributed (i.i.d.) random variable. If the time series parameters used in the VAR model are not stationary, the spurious regression problem might arise. Spurious regression occurs when two parameters, dependent and independent variables, are both non-stationary due to a trend which is manifested. Then, the OLS method suggests a significant relationship between two parameters, even if there is none, simply because both variables are growing over time (Wooldridge, 2012). Thus, for the OLS estimated coefficients to be accurate, specific conditions in the time series variables need to be witnessed (Kilian, Lutkepohl, 2017):

$$E(y_t) = \mu \ and \ Cov(y_t, y_{t+h}) = \gamma_h, \ \forall t, h \quad \textbf{(75)}$$

Equation 75 indicates that, for spurious regression not to happen, the estimated values of the dependent variable y_t while using the VAR model should vary around the constant mean term μ, and the covariance between a dependent variable at any two time intervals has to be the constant value γ_h. As both values μ and γ_h do not depend on the time parameter *t*, the model satisfies second-order stationarity conditions. Thus, for the OLS estimators to be able to return accurate results, time series parameters need to be either stationary, transformed by using differencing or detrending methods, or jointly cointegrated. If all the parameters after the first order differentiation are stationary (verified by using the augmented Dickey-Fuller test), and the error term ε_t of VAR model is also stationary, cointegration conditions are met, and non-transformed variables can be included into the VAR model still yielding eligible OLS estimators (Enns, Masaki, Kelly, 2014).

The VAR model, used in the research to assess the function of the technological progress relationship is presented in the equation given below:

$$A_{i,t} = \alpha_i + \sum_{k=1}^{3} \beta_{i,t-k} A_{i,t-k} + \sum_{k=1}^{3} \gamma_{j,t-k} A_{j,t-k} + \sum_{k=1}^{3} \delta_{i,t-k} INV_{i,t-k} + \theta_{i,t} LP_{i,t} + \rho_{i,t} CR_{i,t} + \varphi_{i,t} NP_{i,t} + \varepsilon_{i,t} \quad \textbf{(76)}$$

The choice of the proper lag length for VAR models is important as the balance between the lag periods and the degrees of freedom for the model needs to be maintained. A general guideline suggested by Xu and Lin (2016) is to estimate the statistical values of the Schwarz Criterion (SC) and the Akaike Information Criterion (AIC) and choose the lag length with the smallest values of the estimated criteria. Both measures can be estimated as given below:

$$AIC = -\frac{2l}{n} + \frac{2k}{n} \quad \textbf{(77)}$$

$$SC = -\frac{2l}{n} + \frac{k \log(n)}{n} \quad \textbf{(78)}$$

In the above presented Equations 77 and 78, *k* represents the number of variables included in the VAR model, *n* is the sample size of the data used for estimation, and *l* is the maximized likelihood function of the estimated model.

For the current research, the VAR(3) model was chosen to be carried out. The reasoning for the choice is the same as with the Granger causality test. Firstly, the analyzed time period for the gathered data is too short to choose any other VAR(p) model where $p > 3$, and this option possesses a sufficient level in degrees of freedom to evaluate the model. Secondly, the research by Verspagen and Loo (1998) suggested that, at the lag length of three years, the technological spillover effect in manufacturing industries reaches its peak level, while declining rapidly afterwards when the lag increases after that.

Equation 76 indicates that two types of parameters are included into the VAR model: endogenous and exogenous. Endogenous variables consist of the lagged technological progress values of the analyzed sector A_i, the lagged TFP values of the other sectors A_j indicating the potential technological progress spillover effect, and the lagged values of the parameter INV_i representing the reinvestment ratio for the analyzed sector. Exogenous variables include LP_i representing the labor productivity ratio, the CR_i parameter indicates the foreign capital structure ratio (the average annual foreign capital value divided by the value of the total employed annual capital), and NP_i measuring the annual inflation adjusted net profit value. The values of the presented variables and the statistical characteristics of the data are presented in Tables A.1–A.20 of the Appendix. These specific variables were chosen because they directly influence the changes in the values of technological progress, and thus they are deemed to be most appropriate for the performed analysis. The VAR model, as presented in Equation 76, is performed on every possible pair of sectors in the analyzed manufacturing industry thus evaluating all the cases of the intersectoral technological progress spillover effect suggested by the built VAR models. Then, a generalized technological progress relationship function for each sector is built where all the cases of the occurrences of the technological progress spillover are included, which yields the evaluation of the connection between different sectors in the manufacturing industry through the technological progress spillover effect.

After the VAR model has been carried out, impulse response analysis can be performed. The goal of the impulse response function is to show how endogenous variables in the model react to shocks of different fundamental disturbances.

The impulse response function traces the effect of one standard deviation or one unit shock on the current and future values of endogenous variables in the system over various time horizons (Beag, Singla, 2014). Ehrmann, Ellison and Valla (2003) suggest using regime-dependent impulse response function analysis which is represented as given below:

$$\frac{\partial E_t X_{t+h}}{\partial u_{k,t}} |_{s_t=\cdots=s_{t+h}=i} = \theta_{ki,h}, \quad for\ h \geq 0 \quad \textbf{(79)}$$

Equation 79 indicates that the regime-dependent impulse response function presents the expected changes in endogenous variables at time $t + h$ to the one standard deviation shock of k^{th} fundamental disturbance at time t, conditional on regime i. Parameter $\theta_{ki,h}$ represents the response vectors which predict changes in the values of endogenous variables due to variations in the input parameter fluctuations.

2.4. Sensitivity analysis of technological progress fluctuations in the manufacturing industry when using agent-based modelling

For the implementation of the analysis of the sensitivity of the manufacturing industry and the effect of the intersectoral technological progress spillover, the evaluation agent-based modelling (ABM) method was chosen. ABM is a modelling methodology where different objects, operating in a complex system, are separated as autonomous decision-making entities called agents (Darley, Outkin, 2007). The agent-based model at the simplest level is a system of agents and relationships between them. Each agent can perform different actions in accordance with the limitations of the system, while interacting with each other.

A number of the models in the economic theory are built on the basis of the equilibrium paradigm where, in the long run, various economic events reach the level of the steady state. Then, the changes in the external factors adjust the steady state level and the endogenous variables of the model shift to a new equilibrium position where they stay until the next external impulse takes place. Analysis of academic literature suggests that the same idea holds in the neoclassical growth theory. The long term growth rate of capital investment reaches a steady state, and a further increase in economic growth can be achieved only by the incrementation of technological progress which is an exogenous variable of the neoclassical growth model. The dynamic nature of ABM has an advantage in the given case as it not only helps to analyze the effect of technological progress on the growth when the economy is in the equilibrium stage, but also it responds to changes in the economic environment on its own terms thus adjusting its behavior to the steady state movement (Arthur, 2005). The ABM method is especially suitable for the models where the equilibrium situation is indeterminant, and the economy is in the constant state of fluctuation. Thus, a more realistic view of economic systems can be represented (Macal, North, 2006).

A special branch of ABM used for the modelling of economic processes is called agent-based computational economics (ACE). The ACE field specializes in computational studies of economics modelled as evolving systems of autonomous interactive agents (Tesfatsion, 2002). The construction of an ACE model consists of defining the basic characteristics of the economy and specifying the initial attributes of the agents operating in the economy. The initial attributes can include type characteristics, behavioral norms, internally stored information about the different states of agents and the internal modes of behavior. The economic environment then evolves over time as all the events that subsequently occur happen due to interactions between agents which result in the changes of their personal attributes.

The agents in ACE models need to possess a few important common characteristics (Monostori *et al.*, 2006):

- Each agent in an ACE model acts to reach a particular goal or accomplish a specific purpose.
- Each agent is autonomous and controls only their own internal attributes while behaving in the environment.
- Each agent must exhibit some form of intelligence by acting in accordance to the fixed rules and by performing reasoning, planning or applying learning capabilities.
- Agents are ideally adaptive, which means that they are capable of changing their behavior in accordance with the shifting environment.

There also exist various behavioral templates for agents, according to which they can interact and operate in the market environment (Chen, 2012). Zero-intelligence agents are the ones which are characterized as randomly behaving. These agents, when making decisions in the given conditions of economy, make a random choice out of the possible given actions. These agents are used in the market conditions where the members of the economy do not have the required information to make rational choices. Swarm intelligence agents are those whose choices can be affected by actions of the majority of the market participants. Each agent has an internal probability parameter for the persuasion to act the same way as the other agents in a simulated environment. Social intelligence behavior can be simulated in the ACE model when individual agents do not possess adequate information to act in a rational way, but the pooling of information between market participants can lead to rational decisions which lead to efficient markets. Near zero-intelligence agents are created by parametrizing the choices of zero-intelligence agents, thus restraining the random behavior of market participants. All of the choices for agent behavior and parameters affecting agent actions in the market environment can lead to the dynamic simulation of economic development which could be hardly repeated when using the regular econometric methods.

A number of ABM studies have been conducted dealing with the effects of knowledge accumulation and technological spillover in economy (Dawid, 2006). Models created on the basis of the ABM framework may include agents (companies or workers) containing the parameter of knowledge accumulation. This could add an empirically relevant structure to the model which would be difficult to repeat by using different methodologies. In such cases, companies could be modelled to increase their knowledge absorption parameter values with the growing R&D expenses and innovation creating activities. The technological progress spillover effect could also occur through the process of employee turnover, and workers could add to the growth of the technological process with the increasing levels of expertise obtained from the experience of working in a given field.

The main critique that the ACE methodology receives is that this approach of economic research does not constitute a theory (Arthur, 2005). The given critique is not always justified as the actions of agents in ACE simulations can follow a well-defined set of functions determined by using other econometric methods (Richiardi, 2012). These functions can either be deterministic or stochastic and depict a fully recursive system while unambiguously defining the macrodynamics of the analyzed economic system. The evolution of each agent's state in the ACE model can be defined by the equation given below (Richiardi, 2012):

$$x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \alpha_i) \quad \textbf{(80)}$$

According to Equation 80, the future period value for the state of the analyzed agent x_i depends on the functional form of the analyzed agent $x_{i,t}$ and all other individuals operating in the given market $x_{-i,t}$ while also being affected by the coefficient values of the analyzed agent α_i. The way in which an agent reacts to the functional form of the phase line $f_i(\dots)$ depends on the selected behavioral rules for the given agent. With the given functional form of each agent's state, the steady state outcome (or the equilibrium) of the analyzed economy can be represented as follows (Richiardi, 2012):

$$Y^e = \lim_{t \to n} Y_t \equiv g(x_{1,0}, \dots, x_{n,0}; \alpha_1, \dots, \alpha_n) \quad \textbf{(81)}$$

Equation 81 indicates that (an) economy approaches the steady state throughout time and reaches it at period *n*. If the economy can reach the equilibrium value, *n* is a fixed time period in the future, whereas if the economy is at a constant fluctuation state, $n = \infty$. Sometimes, convergence to a steady state can be independent from time, and the equilibrium value in such a case is represented as Y^e. In any case, the outcome of the analyzed economy depends on the functional form of the agent states up to time period *n* and on the parameter values of the agents operating in the economy.

The equation representing the execution of the sensitivity analysis for a selected manufacturing industry can be depicted as given below:

$$\ln(Y_t) = \beta_1 + \beta_2 * A_t(\mathrm{x}) + \beta_3 * \ln(K_t) + \beta_4 * \ln(EN_t) + \beta_5 * \ln(CASH_t) + \beta_6 * \ln(ETD_t) + \beta_7 * \ln(EXP_t) + \beta_8 * \ln(INV_t) + \varepsilon_t \quad \textbf{(82)}$$

Equation 82 is similar to Equation 62 which was used in the linear regression analysis when trying to determine the output elasticity of capital vales for different sectors operating in the observed manufacturing industry. The main difference between these two equations is parameter $A_t(\mathrm{x})$. This parameter represents the estimated TFP values of different sectors in the manufacturing industry evaluated by using the vector autoregression model and described by Equation 76. This helps to solve the main problem with the standard models based on the neoclassical growth theory, which is the exogeneity of the technological progress parameter in the analysis of economic development. In the above presented system of equations, the TFP parameter is analyzed both as a dependent variable and an independent variable – the methodology evaluates the effects of different parameters on the changes in technological progress and the impact of technological progress on the ability to produce output in a more efficient manner.

In the case of Equation 82, the possible problems of the endogeneity, non-stationarity and collinearity of variables should be addressed. The possible endogeneity problem is addressed by including additional independent variables into the equation, namely, the energy consumption, the cash liquidity ratio, the equity to debt leverage ratio, the income from export to total turnover ratio, and the reinvestment ratio. All of these variables were included into the time series regression analysis. The collinearity between the variables is removed by including into Equation 82 only those parameters which do not possess strong correlation to the technological progress capital per unit of labor variables. In such a case, the coefficients of these variables will not be distorted due to the linear relationship with the other independent variables. A possible non-stationarity problem in the given regression analysis is addressed by testing for the collinearity between the parameters. This is achieved by performing the augmented Dickey-Fuller test on the error term of the evaluated regression equation.

In order to perform the sensitivity analysis of the effect of technological progress on economic development, a parameter needs to be chosen which will fluctuate when the value of the TFP variable changes. According to the neoclassical growth theory, the growth in technological progress can either increase the produced output with the amount of the fixed capital, or it can decrease the required amount of capital needed to produce a fixed amount of output. As the concept of technological progress in the neoclassical growth theory is analyzed through its effect on the function of production, the effect of TFP on the changes in demand is not analyzed. Thus, a constraint is set for the model in Equation 82 that the changes taking place in technological progress increase the efficiency in the production process thus allowing to manufacture the same amount of output with a lower amount of capital required in the production process. Then, the equation for sensitivity analysis can be rewritten as:

$$\ln(K_t) = \frac{1}{\beta_3} * (\ln(Y_t) - \beta_1 - \beta_2 * A_t(\mathrm{x}) - \sum_{i=1}^{n} \beta_i * x_{i,t}) \qquad \textbf{(83)}$$

In the above given Equation 83, the variable $x_{i,t}$ represents all of the addition independent variables included into the regression equation which do not exhibit a strong correlation with the variables of technological progress or capital per unit of labor.

3. EMPIRICAL IMPLEMENTATION OF MODEL FOR EVALUATION OF THE EFFECT OF FACTORS ON TECHNOLOGICAL PROGRESS: CASE OF THE LITHUANIAN MANUFACTURING INDUSTRY

The research model is built for the case of the Lithuanian manufacturing industry for the time interval of years 2000–2018. 18 sectors of the Lithuanian manufacturing industry are analyzed, as listed in Table 2. Time series regression is constructed for each sector while trying to assess their output elasticity of capital and the TFP measures throughout time. Then, the evaluated TFP values are analyzed while trying to determine whether the technological progress spillover effect between the sectors exists and which factors affect the dynamic changes of the values of technological progress throughout time.

Table 2. Sectors of the Lithuanian manufacturing industry and their identification codes

Code	Name	Code	Name
C10	Food products	C23	Non-metal mineral products
C11	Beverage	C24	Metal processing
C13	Textile	C25	Metal products, excluding machinery
C14	Apparel	C26	Computers, electronics and optical devices
C15	Leather and leather products	C27	Electricity equipment
C16	Timber products, excluding furniture	C28	Other machines and equipment
C17	Paper and paper products	C30	Other transportation equipment
C18	Printing and reproduction	C31	Furniture
C22	Rubber and plastic products	C33	Machinery repairs and equipment

The empirical part of the research consists of four parts. The first part is the technological progress evaluation for each of the sectors in the Lithuanian manufacturing industry, the second part is the assessment of the technological progress spillover effect between sectors, the third part is devoted to the construction of models identifying which factors and to what extent influence changes in technological progress, whereas the fourth part focuses on the implementation of technological progress sensitivity analysis.

3.1. Technological progress estimation of sectors operating in the Lithuanian manufacturing industry

The construction of time series regression models for each sector in the Lithuanian manufacturing industry yields the output elasticity of capital values which is presented in Table 3 and calculated by using Equation 63. The time and capital interaction parameters included into the time series regression model suggest

Table 3. Output elasticity of capital values for sectors in the Lithuanian manufacturing industry

Sector	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
C10	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.63	0.63	0.63	0.63	0.58	0.58	0.58	0.58	0.56	0.56	0.56	0.62
C11	0.43	0.43	0.43	0.43	0.43	0.46	0.46	0.46	0.46	0.46	0.43	0.43	0.43	0.43	0.43	0.43	0.40	0.40	0.40	0.44
C13	0.49	0.49	0.49	0.49	0.49	0.47	0.47	0.47	0.47	0.43	0.43	0.43	0.40	0.40	0.40	0.38	0.38	0.38	0.38	0.44
C14	0.64	0.64	0.64	0.64	0.67	0.67	0.67	0.67	0.64	0.64	0.64	0.73	0.73	0.73	0.64	0.64	0.64	0.64	0.64	0.66
C15	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.46	0.46	0.46	0.46	0.46	0.41	0.41	0.41	0.41	0.41	0.48
C16	0.73	0.73	0.73	0.70	0.70	0.70	0.70	0.70	0.68	0.68	0.68	0.69	0.69	0.69	0.73	0.73	0.73	0.73	0.73	0.71
C17	0.57	0.57	0.57	0.60	0.60	0.60	0.61	0.61	0.61	0.60	0.60	0.60	0.60	0.60	0.60	0.57	0.57	0.57	0.57	0.59
C18	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.64	0.64	0.64	0.69	0.69	0.69	0.69	0.67	0.67	0.67	0.72
C22	0.79	0.79	0.79	0.71	0.71	0.71	0.71	0.71	0.58	0.58	0.58	0.58	0.61	0.61	0.61	0.58	0.58	0.58	0.58	0.65
C23	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.43	0.43	0.43	0.45	0.45	0.45	0.45	0.38	0.38	0.38	0.49
C24	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.32	0.32	0.32	0.32	0.35	0.35	0.35	0.29	0.29	0.29	0.29	0.29	0.32
C25	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.57
C26	0.64	0.64	0.64	0.64	0.64	0.57	0.57	0.57	0.76	0.76	0.76	0.77	0.77	0.77	0.77	0.77	0.85	0.85	0.85	0.72
C27	0.65	0.65	0.65	0.65	0.65	0.65	0.56	0.56	0.56	0.41	0.41	0.41	0.41	0.34	0.34	0.34	0.26	0.26	0.26	0.47
C28	0.32	0.32	0.32	0.40	0.40	0.40	0.42	0.42	0.42	0.36	0.36	0.36	0.36	0.36	0.36	0.32	0.32	0.32	0.32	0.36
C30	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.50	0.50	0.50	0.36	0.36	0.36	0.42	0.42	0.42	0.42	0.57
C31	0.48	0.48	0.48	0.45	0.45	0.45	0.45	0.45	0.37	0.37	0.37	0.37	0.37	0.33	0.33	0.33	0.29	0.29	0.29	0.39
C33	0.69	0.69	0.69	0.87	0.87	0.87	0.87	0.87	0.87	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.75

Source: author’ s calculations

that the variable of the output elasticity of capital for each analyzed sector more or less fluctuated throughout the analyzed time interval, and not a single score of the output elasticity of capital value remained static throughout the analyzed period of 19 years. The sectors can be distinguished into three separate groups: the sectors with an increasing output elasticity level of the capital values throughout the analyzed time periods, the sectors with a declining output elasticity level of the capital values, and the sectors with stable output elasticity of the capital values.

For the majority of the sectors, the values of output elasticity of the capital decreased during the analyzed time interval. The measure of the output elasticity of capital in the case of the electricity equipment sector decreased from 0.65 to 0.26, for the other transportation equipment sector, the decline was from 0.73 to 0.42, for the furniture sector, the value shrank from 0.48 to 0.29, and for the non-metal mineral products manufacturing sector, it went down from 0.57 to 0.38. The receding values for the measures of the output elasticity of capital indicate that the companies operating in the analyzed sectors cannot sustain long-term growth merely by increasing investment into capital as every additional euro of investment creates diminishing returns. For this reason, the growth of the given sectors can only be preserved by utilizing the operating capital in a more efficient manner and thus increasing the technological progress of the production process.

For the other sectors, the values of the output elasticity of capital during the analyzed period either remained at relatively the same level, or even increased. In the cases of the apparel sector, the timber products sector, the paper and paper products sector, the other machines and equipment sector and the machinery repairs and equipment sector, the values of the output elasticity of capital were the same in 2000 as well as in 2018. The values of the measure of the output elasticity of capital for the computers, electronics and optical devices sector even increased by 24 percent during the analyzed time frame. The dynamic stability in the measure of the output elasticity of capital indicates that the growth of the sector is attained jointly by the increased amount of the capital employed in the production process and the technological progress achieved by the increased efficiency of operating activities. The more dominant factor depends on the value of the output elasticity of capital.

The common trend for most of the sectors is the decline in the measure of the output elasticity of capital during the global economic crisis witnessed during the years 2008–2009. A few years before the crisis affected the manufacturing industry, companies had been achieving growth by increasing the physical amount of capital used in the production process. The higher levels of the output elasticity of capital suggest that companies could get larger returns on the produced output just by increasing the amounts of investment. After the economic crisis, the demand shrank, thus giving incentive for the companies to seek further growth not by increasing the quantity of the capital used in their operating processes but rather by increasing the efficiency of the utilized resources.

Table 4 presents estimated TFP values for each of the sectors in the Lithuanian manufacturing industry; the estimation was performed by using Equation 64. The results presented in the table below indicate that the values of technological progress for each of the sectors increased throughout the entire time frame. This means that

Table 4. Total factor productivity values of sectors in the Lithuanian manufacturing industry

Sector	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Average
C10	1.07	1.22	1.20	1.31	1.40	1.44	1.62	2.06	1.76	2.13	2.02	2.26	2.46	2.52	2.46	2.80	3.08	3.19	3.17	2.06
C11	3.18	3.27	3.67	3.37	3.98	3.92	4.42	5.80	5.07	4.64	4.41	4.40	4.93	4.84	6.26	6.40	6.22	6.18	5.63	4.77
C13	1.40	1.43	1.61	1.80	2.10	2.26	2.27	2.44	2.51	2.52	3.04	3.90	4.24	4.56	4.87	4.98	5.69	5.96	6.19	3.36
C14	1.95	2.12	2.21	2.18	2.34	2.48	2.56	2.70	2.66	2.40	2.89	3.22	3.16	3.43	3.81	3.77	3.83	3.95	3.87	2.92
C15	0.84	0.99	1.39	1.49	0.52	1.46	1.66	1.64	2.49	2.13	2.18	2.15	2.51	2.69	3.17	3.47	3.62	3.83	3.78	2.21
C16	1.15	1.12	1.23	1.28	1.31	1.46	1.42	1.41	1.29	1.12	1.36	1.47	1.51	1.75	1.76	1.75	1.88	1.98	2.14	1.50
C17	1.17	1.44	1.20	1.66	1.59	1.68	1.85	1.89	2.03	2.12	2.14	2.42	2.60	2.90	2.99	3.20	3.16	3.41	3.88	2.28
C18	0.76	0.85	0.86	1.06	0.95	1.44	1.57	1.39	1.27	1.16	1.41	1.88	1.87	1.89	2.09	2.31	2.52	2.60	2.69	1.61
C22	1.14	1.21	1.38	1.71	1.27	1.62	2.22	1.90	2.16	1.95	2.36	2.46	2.81	2.77	3.14	3.21	3.59	3.61	3.96	2.34
C23	0.87	1.19	1.30	1.54	1.78	1.91	2.76	3.35	2.60	2.04	2.21	2.84	3.12	3.36	3.72	3.58	4.94	5.11	5.49	2.83
C24	2.37	2.77	1.89	2.07	2.16	2.06	3.04	3.71	4.66	1.89	3.42	5.56	5.20	7.18	6.45	7.15	7.81	9.12	8.60	4.59
C25	1.15	1.25	1.28	1.46	1.70	1.99	2.22	2.65	2.85	2.31	2.83	3.31	3.41	3.46	4.19	4.50	4.57	4.57	4.42	2.85
C26	2.00	2.21	1.76	1.61	1.70	1.40	1.46	1.55	2.72	2.28	2.98	3.04	3.05	3.29	3.14	3.65	3.52	4.51	3.97	2.62
C27	1.19	1.34	1.60	1.85	2.24	2.53	2.86	3.15	3.39	2.75	4.50	5.73	5.21	6.66	6.62	7.35	9.56	9.69	9.40	4.61
C28	1.16	1.65	2.47	2.37	2.60	3.31	4.40	5.04	4.91	4.26	5.41	5.98	6.88	7.40	7.34	8.21	8.45	9.88	10.41	5.38
C30	1.32	1.50	1.33	1.23	1.86	2.03	2.29	2.67	3.12	4.52	6.55	3.53	2.49	3.88	6.00	7.15	7.12	8.96	9.87	4.07
C31	1.96	2.02	2.34	2.76	2.82	2.60	2.79	3.66	2.86	3.82	4.59	5.12	5.20	5.61	6.47	6.93	7.75	8.49	8.68	4.55
C33	1.17	1.39	1.01	1.07	1.72	1.95	2.44	2.47	2.53	2.37	2.83	3.36	3.80	3.49	3.46	3.96	4.53	5.15	6.08	2.88

Source: author’ s calculations

the growth of the total output produced by companies operating in the Lithuanian manufacturing industry outpaced the growth of the capital employed in the production process. The range of the TFP values varies broadly in accordance with the nature of different sectors: the lowest average TFP values for the time period of 2000–2018 was witnessed in the case of the timber products sector with the value of 1.50, while the largest value was identified in the other machines and equipment sector, specifically, 5.38.

The TFP results also suggest that separate sectors of the Lithuanian manufacturing industry managed to deal with the economic crisis of 2008–2009 differently. In the case of some sectors, the values of technological progress during the times of recession declined. For example, the TFP value of the non-metal mineral products sector between the years 2007 and 2009 declined by 39 percent. For the given sector, it took 6 years to recover until it even reached the pre-crisis level of the measure of technological progress. The reason for that was the increasing investments into capital during the period of rapid economic growth. Between 2004 and 2009, the amount of capital per unit of labor employed by the non-metal mineral products sector increased more than twice. After the crisis decreased the demand for the output of the given sector, the capital used in the production process could not be utilized as efficiently.

The opposite situation is witnessed in the case of the computers, electronics and optical devices sector. The value of the TFP measure for the given sector grew even throughout the years of economic recession: from the TFP value of 1.55 in 2007, it jumped to 2.72 in 2008 and 2.28 in 2009. Despite the absence of decline of the measure of technological progress during the years of the economic crisis, it did not help the development of the sector in the long run. Compared to the other sectors in the Lithuanian manufacturing industry, the TFP value of the computers, electronics and optical devices sector was below average.

Figure 15 compares the values of the capital per unit of labor and the output per unit of labor measure for the sectors with the largest and the smallest average technological progress values throughout the analyzed time frame.

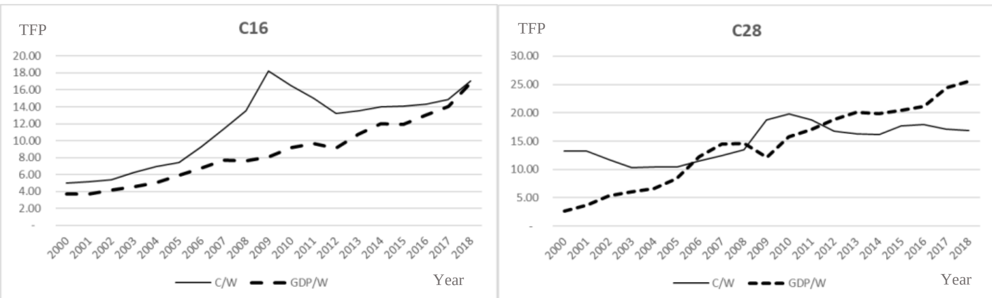


Figure 15. Output per unit of labor and capital per unit of labor measure values of Lithuanian timber products sector and other machines and equipment sector, 2000–2018.
Source: author's calculations

In the case of the timber products sector, the growth of the measure of capital per unit of labor outpaced the growth of the produced output per unit of labor between 2005 and 2009. During this time interval, the amount of the capital employed in the production process grew by 146 percent, while the additional value created by the given sector increased by 37 percent. This suggests that the investment projects carried out during the presented time frame did not result in the adequate growth of the production output. Right after the global economic crisis, between 2009 and 2012, the value of capital per unit of labor declined by 27 percent.

Table 5. Independent variable coefficients estimated from time series regression models

Sector	log (EN_t)	log ($CASH_t$)	Log (ETD_t)	Log (EXP_t)	Log (INV_t)	Trend	$CASH_t$	ETD_t	EXP_t
C10	-	-	-	-	-	0.073 (0.000)	-	-	-
C11	0.340 (0.001)	-	-	-	-	0.049 (0.000)	-	-	-
C13	-	-	-	-	-	0.077 (0.000)	0.008 (0.034)	0.295 (0.000)	-
C14	0.074 (0.010)	-	-	-	0.126 (0.000)	0.043 (0.000)	-	-	-
C15	-	-	-	-	-	0.080 (0.000)	-	0.420 (0.000)	-0.265 (0.014)
C16	-	0.126 (0.000)	-	-	0.144 (0.001)	0.029 (0.000)	-	-	-
C17	-	-	-	-	-	0.059 (0.000)	-	0.158 (0.042)	-
C18	-	0.378 (0.000)	-	0.4306 (0.000)	-	-	-	-	-
C22	-	-	-0.261 (0.033)	-	-	0.084 (0.001)	-	-	-
C23	-	-	0.925 (0.025)	-	-	0.115 (0.000)	-	-	-
C24	-	-	-0.070 (0.038)	-	0.285 (0.000)	0.073 (0.000)	-	-	-
C25	-	-	-0.417 (0.000)	-	-	0.098 (0.000)	-	-	-
C26	-	0.269 (0.018)	-	-	-	-	-	-	-
C27	-	-	-	-	-	0.156 (0.000)	-	-	-
C28	-	-	-0.072 (0.000)	-	-	0.127 (0.000)	-	-	-
C30	-	0.2040 (0.006)	-	-0.1796 (0.019)	-0.192 (0.043)	0.122 (0.000)	-	-	-
C31	0.2351 (0.005)	-	0.525 (0.013)	-	-	0.098 (0.000)	-	-	-
C33	-	-	0.0668 (0.001)	-	-	0.0916 (0.000)	-	-	-

Source: author's calculations

Despite the lowering measure value of capital per unit of labor, the produced output per unit of labor during the corresponding time frame increased by 12 percent, which indicates overinvestment throughout the economic growth cycle. This inefficient utilization of capital in the production process led to the lowest average technological progress value out of all the analyzed sectors in the Lithuanian manufacturing industry.

The opposite situation can be perceived in the case of the other machines and equipment sector. Between the years 2002 and 2009, the employed capital per unit of labor increased by 61 percent, while the measure of the produced output per unit of for the same period increased by 126 percent. After 2010, the measure value of the capital per unit of labor started decreasing, and, during the interval of 2010–2018, it declined by 15 percent, while, throughout the same time frame, the output per unit of labor increased by 63 percent. The presented results indicate that, during the analyzed time period, the growth of the other machines and equipment sector was achieved by the more efficient utilization of the capital employed in the production process rather than by the increasing capital base.

Table 5 presents the values of other independent variables included into the time series regression models calculated from Equation 63 which were determined to exert a significant effect on the produced output changes for every sector operating in the Lithuanian manufacturing industry. The parameters which manifest a strong linear relationship with capital (featuring the Person correlation coefficient value of 0.7 or larger) were excluded from the regression so that to avoid multicollinearity.

Out of all independent variables in the constructed time series regression models, the ETD_t parameter, indicating the capital leverage ratio, had a significant effect on the largest number of sectors in the Lithuanian manufacturing industry. For 10 sectors out of the analyzed sample of 18 sectors, the leverage ratio had a significant linear relationship with the amount of the produced output. In 7 out of 10 models, the ETD_t parameter was transformed to its logarithmic form. The cash ratio, represented by the parameter $CASH_t$, was identified to possess a significant effect in cases of 5 time series regressions. Meanwhile, the INV_t parameter, reflecting the reinvestment ratio, was significant in the cases of 4 models, while EXP_t, representing the export turnover to total turnover ratio, and EN_t, indicating the energy consumption in the production process, were significant of cases of 3 analyzed sectors. Another distinct characteristic of the produced output in the sectors of the Lithuanian manufacturing industry is the significance of the parameter of the time trend. The time trend parameter was identified to be significant for 16 out of the 18 analyzed sectors. The production amount for most of the sectors operating in the Lithuanian manufacturing industry throughout the analyzed time frame were trending upwards thus suggesting the constant growth of the industry.

Finally, for the assessment of the constructed time series regressions used to estimate the output elasticity of capital and the TFP measures, various tests were conducted to validate the results gained from the models. The augmented Dickey-Fuller test was used to assess the stationarity of the time series regression residual values.

Table 6. Test results of constructed time series regression models

Sector	Augmented Dickey-Fuller test	Studentized Breusch-Pagan test	Durbin-Watson test	Shapiro-Wilk normality test
C10	-3.2025 ***	0.3656	0.4322	0.4383
C11	-3.2613 ***	0.5846	0.7443	0.9621
C13	-4.5457 ***	0.7696	0.8552	0.583
C14	-3.7738 ***	0.1942	0.9886	0.4241
C15	-3.5215 ***	0.5474	0.8718	0.7054
C16	-4.2871 ***	0.5402	0.3037	0.6107
C17	-2.0832 **	0.075	0.9512	0.2128
C18	-2.7335 ***	0.0778	0.3352	0.6213
C22	-6.1979 ***	0.3225	0.8327	0.2379
C23	-3.474 ***	0.4546	0.2494	0.6695
C24	-2.7793 ***	0.1596	0.6311	0.4946
C25	-3.3994 ***	0.4097	0.6456	0.0778
C26	-2.4921 **	0.2466	0.64	0.4293
C27	-8.0842 ***	0.0673	0.1505	0.5319
C28	-3.8541 ***	0.5455	0.224	0.3041
C30	-2.7056 ***	0.0927	0.1418	0.6603
C31	-3.0621 ***	0.8882	0.228	0.2215
C33	-3.1491 ***	0.0949	0.2147	0.7825

Source: author's calculations

The Studentized Breusch-Pagan test was applied to test heteroscedasticity in the time series regressions. The Durbin-Watson test was employed to evaluate autocorrelation in the residuals of the constructed regressions. The Shapiro-Wilk normality test helped to determine whether the residuals of the time series regressions are normally distributed. The results of the performed tests indicate that the residuals of the time series regression models are stationary, normally distributed and not autocorrelated, while the constructed models are homoscedastic. Thus, the results gained from the constructed time series regression models can be used for further analysis.

3.2. Assessment of the intersectoral technological progress spillover effect in case of the Lithuanian manufacturing industry

Table 7 presents the results of the Granger causality test between the values of the measures of technological progress for the sectors operating in the Lithuanian manufacturing industry. They were estimated by using Equations65 and 66. The goal of the performed test is to assess whether the technological spillover effect is visible in the Lithuanian manufacturing industry. The values in Table 7 indicate whether a sector depicted in the table column *Granger causes* sector is presented in the table

Table 7. Results of Granger causality test

Sector	C10	C11	C13	C14	C15	C16	C17	C18	C22	C23	C24	C25	C26	C27	C28	C30	C31	C33
C10	-	0.857	0.771	0.339	0.661	0.697	0.389	0.085	**0.034**	0.503	0.879	**0.044**	0.809	0.732	0.444	0.492	0.607	0.078
C11	0.374	-	0.190	0.274	0.408	0.218	0.153	0.185	0.135	**0.001**	0.400	0.327	0.666	0.300	0.241	0.995	0.277	0.318
C13	0.539	0.598	-	0.949	0.330	0.058	0.370	0.525	0.897	0.148	**0.032**	0.675	0.151	0.107	0.104	0.347	0.497	0.430
C14	0.186	0.190	0.482	-	0.787	0.251	0.110	0.329	0.889	0.091	0.443	0.699	0.189	0.663	0.903	0.897	0.357	0.955
C15	0.104	0.073	0.122	0.097	-	0.340	**0.004**	0.121	**0.041**	0.305	0.237	**0.022**	0.839	0.326	0.066	0.926	0.490	0.097
C16	0.262	0.089	0.138	0.131	0.148	-	0.359	0.476	0.462	0.795	0.214	0.184	**0.043**	0.115	0.226	0.122	0.058	0.466
C17	0.337	0.273	**0.023**	0.721	0.531	0.226	-	0.876	0.655	0.254	0.473	0.800	0.193	0.070	0.267	0.138	0.203	0.335
C18	0.489	0.498	**0.031**	**0.016**	0.075	0.493	**0.008**	-	0.076	0.390	0.363	0.249	0.278	**0.047**	**0.039**	0.200	0.089	0.575
C22	0.421	0.864	0.245	0.372	0.471	0.496	**0.024**	0.100	-	0.830	0.998	0.649	0.539	0.353	0.414	0.755	0.258	0.437
C23	0.534	0.839	0.095	0.187	0.535	0.092	0.061	**0.015**	0.340	-	0.194	0.299	0.240	0.099	0.077	0.406	0.146	0.331
C24	0.098	0.210	**0.014**	**0.027**	0.635	0.465	0.106	0.059	0.073	0.114	-	0.210	0.283	**0.030**	**0.045**	0.397	**0.042**	0.171
C25	0.129	0.323	0.677	0.562	0.186	0.886	0.158	0.841	0.336	0.340	0.945	-	0.254	0.684	0.908	0.615	0.071	0.931
C26	**0.018**	**0.036**	0.133	0.118	**0.020**	0.350	0.186	0.217	0.074	**0.045**	0.545	**0.017**	-	0.270	0.089	0.262	0.055	0.080
C27	0.384	0.665	0.292	0.878	0.594	0.762	0.463	0.150	0.909	0.075	0.124	0.893	0.347	-	0.492	0.238	**0.028**	0.503
C28	0.282	0.221	0.230	0.744	0.772	0.614	0.321	**0.028**	0.615	**0.047**	0.727	0.372	0.092	0.226	-	0.502	0.158	0.239
C30	0.128	**0.032**	**0.045**	**0.004**	**0.048**	0.052	0.148	**0.047**	0.132	**0.013**	**0.022**	**0.001**	0.221	0.108	**0.010**	-	**0.012**	0.277
C31	0.298	0.404	0.578	0.777	0.139	0.587	0.445	0.818	0.230	0.053	0.263	0.451	0.243	0.396	0.551	0.452	-	0.187
C33	0.080	0.595	0.459	0.623	0.104	0.656	**0.024**	0.117	0.480	0.780	0.453	0.175	0.662	0.220	0.708	**0.049**	0.072	-

Source: author’ s calculations

row. If the p-value shown in the table is less or equal to 0.05, the Granger causality is significant.

Out of all the 18 analyzed sectors in the Lithuanian manufacturing industry, the Granger values of 4 sectors cause the technological progress values of four other sectors. These sectors are the textile sector, the paper and paper products sector, the non-metal mineral products sector, and the metal products, excluding machinery, sector. The measures of the technological progress of these 4 sectors Granger affect the largest number of other sectors operating in the Lithuanian manufacturing industry. Other 4 analyzed sectors in terms of their Granger values cause the technological progress values of three different sectors. These include the apparel sector, the printing and reproduction sector, the other machines and equipment sector, and the furniture sector. The Granger values of 5 sectors operating in the Lithuanian manufacturing industry cause the technological progress values of two other sectors. These sectors are the beverage sector, the leather and leather products sector, the rubber and plastic products sector, the metal processing sector, and the electricity equipment sector. The Granger values of 3 analyzed sectors cause the technological progress values of one other sector operating in the Lithuanian manufacturing industry. These are the food products sector, the computers, electronics and optical devices sector, and the other transportation equipment producing sector. Finally, the timber products sector and the machinery repairs and equipment producing sector did not Granger cause the technological progress values of any particular sector. This means that only 2 out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry did not Granger cause any changes in the technological progress values of any other sector,
and technological progress values of only 3 sectors were not Granger caused by any other sector. The obtained results suggest the presence of the technological progress spillover effect, although the real causality between the measures of technological progress of various sectors should be evaluated by using different methods.

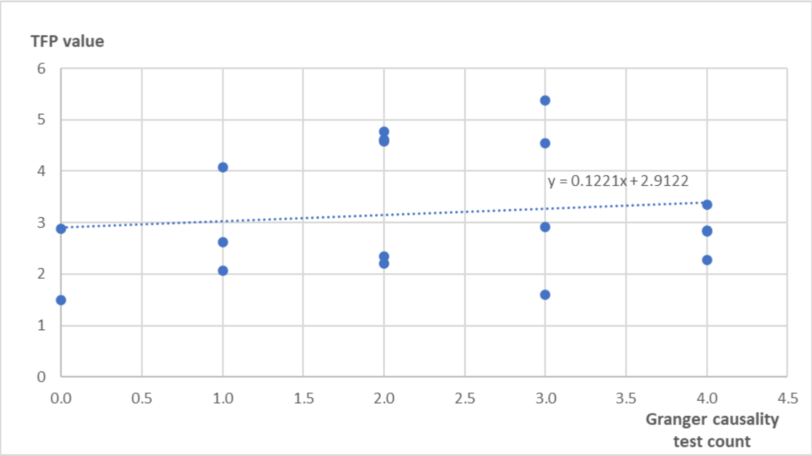


Figure 16. Scatter plot depicting relationship between TFP values and the number of Granger caused sectors. Source: author’s calculations

Furthermore, the relationship between the technological progress measure values and the Granger causality test results is analyzed. A hypothesis is tested whether the sectors with higher technological progress values Granger cause changes in the TFP measures of a larger number of sectors operating in the Lithuanian manufacturing industry. Figure 16 presents a scatter plot graph showing the relationship between the technological progress values of the sectors operating in the Lithuanian manufacturing industry and a number of significant Granger causality tests where the analyzed sector Granger causes the technological progress value of another sector. The scatter plot graph indicates that there exists a slight positive relationship between the two presented parameters.

According to the scatter plot graph, a further increase in the technological progress value by 1 unit leads to a rise in the number of significant Granger causality test results by 0.1221. This means that, for a sector to Granger cause changes in the technological progress values of one additional sector, the TFP measure should increase by 8 units. This kind of relationship is impossible as the highest average value of a TFP measure for all the 18 analyzed sectors reaches only 5.38. Thus, the relationship between the TFP value results and the Granger causality test count seems to be insignificant.

Dependent Variable: GRANGER
Method: Least Squares
Date: 10/18/20 Time: 14:37
Sample: 1 18
Included observations: 18
GRANGER = C(1) + C(2) * TFP

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	1.792646	0.937106	1.912960	0.0738
C(2)	0.152061	0.276339	0.550270	0.5897

R-squared	0.018573	Mean dependent var	2.277778
Adjusted R-squared	-0.042766	S.D. dependent var	1.319784
S.E. of regression	1.347710	Akaike info criterion	3.539129
Sum squared resid	29.06113	Schwarz criterion	3.638059
Log likelihood	-29.85216	Hannan-Quinn criter.	3.552770
F-statistic	0.302797	Durbin-Watson stat	2.275849
Prob(F-statistic)	0.589735		

Figure 17. Linear regression results between technological progress values and Granger causality test results. Source: author’s calculations

Figure 17 presents the outcome of a simplistic linear relationship model constructed between the average technological progress measure values of the sectors operating in the Lithuanian manufacturing industry and the performed Granger causality test results. The p-value of the *C(2)* coefficient in the regression model is larger than 0.05, which indicates that the linear relationship between the analyzed parameters does not exist. Thus, the sectors with higher TFP measures do not Granger cause changes in the technological progress values for a larger number of other sectors operating in the Lithuanian manufacturing industry. This can be partially explained by the specifics of the operational activities in different sectors.

As different sectors produce vastly different products, the production process in separate sectors requires different proportions of the employed capital, labor and technology. For this reason, the TFP values between sectors in their nominal form cannot be compared, and only the rate of growth can be observed throughout time.

3.3. Identification of factors influencing technological progress fluctuations in the Lithuanian manufacturing industry when using VAR models.

Table 8 presents the results of the constructed VAR models for each sector operating in the Lithuanian manufacturing industry while trying to distinguish the intersectoral technological spillover effect on the changes pertaining to the technological progress in the Lithuanian manufacturing industry. The results were sourced from calculations represented by Equation 76.

The estimated VAR models indicate that, in the case of 5 sectors operating in the Lithuanian manufacturing industry, their technological progress values through the spillover effect were affected by the TFP changes of two other sectors. These are the paper and paper product, the printing and reproduction, the non-metal mineral product, the other machines and equipment, and the machinery repairs and equipment sectors. In the vast majority of cases, the technological progress values of the sectors operating in the Lithuanian manufacturing industry were affected by the TFP changes of a single other sector. In the cases of 10 out of the 18 analyzed sectors, this relationship was identified to be present. This includes the sectors of food products, beverage, textile, leather and leather products, metal processing, metal products excluding machinery, computers, electronics and optical devices, electricity equipment, other transportation equipment and furniture. In only 3 out of 18 cases, no intersectoral technological progress spillover effect was present, and the changes in the TFP values were not affected by the variables of other sectors. The VAR models indicate that no technological spillover effect is present in the cases of the apparel, timber products, rubber and plastic products sectors. These results indicate that the inter-sectoral technological spillover effect is present in the case of the Lithuanian manufacturing industry as, for the majority of the sectors operating in the Lithuanian manufacturing industry, changes in technological progress are affected by the fluctuations of the TFP values of other sectors.

When analyzing the other endogenous and exogenous independent variables included in the VAR models, the most prominent influence upon the changes in the technological progress values was induced by the measure of net profit. The measure of net profit was established to exert a significant impact on technological progress fluctuations in the cases of 15 out of the 18 analyzed sectors. Only in the cases of the paper and paper product, computers, electronics and optical devices, and other transportation equipment sectors, no significant linear relationship existed between

Table 8. Results of constructed VAR models

Dependent	Independent variables					Dependent	Independent variables				
AC10, t	AC28, t-2	CR10, t	NP10, t	LP10, t		AC23, t	AC23, t-2	AC14, t-2	AC27, t-1	NP23, t	
	0.0794 (0.02)	2.451 (0.00)	0.0004 (0.01)	19.42 (0.00)			0.297 (0.03)	0.2546 (0.03)	0.2905 (0.00)	0.0014 (0.00)	
AC11, t	AC23, t-1	NP11, t	LP11, t			AC24, t	AC16, t-3	CR24, t	NP24, t	LP24, t	
	0.4385 (0.01)	0.0013 (0.01)	26.45 (0.03)				1.5075 (0.00)	3.4435 (0.00)	0.0366 (0.00)	42.3761 (0.01)	
AC13, t	AC13, t-1	AC15, t-2	INV13, t-2	NP13, t	LP13, t	AC25, t	AC33, t-3	NP25, t	LP25, t		
	0.4961 (0.00)	0.2161 (0.01)	0.0394 (0.00)	0.0032 (0.00)	77.675 (0.00)		0.5251 (0.00)	0.0019 (0.00)	64.78 (0.00)		
AC14, t	CR14, t	NP14, t	LP14, t			AC26, t	AC26, t-2	AC30, t-3	CR26, t	LP26, t	
	2.723 (0.00)	0.0026 (0.00)	275.1 (0.00)				0.4445 (0.00)	0.1238 (0.02)	-0.9669 (0.00)	49.7702 (0.00)	
AC15, t	AC15, t-2	AC13, t-1	CR15, t	NP15, t		AC27, t	AC27, t-3	AC30, t-2	NP27, t		
	0.5614 (0.01)	0.3089 (0.01)	4.4561 (0.00)	0.0109 (0.00)			0.9756 (0.00)	0.3543 (0.00)	0.0033 (0.00)		
AC16, t	AC16, t-1	INV16, t-2	NP16, t	LP16, t		AC28, t	AC28, t-2	AC18, t-1	AC30, t-1	AC30, t-3	NP28, t
	0.3103 (0.05)	0.008 (0.02)	0.0006 (0.00)	24.84 (0.00)			0.3731 (0.00)	0.7995 (0.01)	0.2096 (0.00)	0.1059 (0.01)	0.0067 (0.00)
AC17, t	AC17, t-3	AC23, t-1	AC26, t-1	INV17, t-3	LP17, t	AC30, t	AC30, t-1	AC27, t-3	INV30, t-2		
	0.4844 (0.00)	0.1519 (0.00)	0.1264 (0.04)	-0.018 (0.00)	15.1487 (0.00)		0.4871 (0.01)	0.7977 (0.00)	0.087 (0.01)		
AC18, t	AC18, t-1	AC11, t-2	AC15, t-3	NP18, t		AC31, t	AC31, t-2	AC23, t-3	CR31, t	NP31, t	
	0.3154 (0.03)	0.1294 (0.01)	0.2278 (0.01)	0.0028 (0.00)			0.6625 (0.00)	0.6107 (0.00)	-5.0794 (0.00)	0.0026 (0.00)	
AC22, t	AC22, t-3	NP22, t	LP22, t			AC33, t	AC33, t-1	AC27, t-2	AC30, t-1	INV33, t-2	NP33, t
	0.6164 (0.00)	0.0012 (0.01)	21.59 (0.01)				0.4335 (0.01)	0.1779 (0.02)	0.139 (0.00)	-0.012 (0.03)	0.0011 (0.01)

Source: author’ s calculations

the technological progress values and the inflation adjusted net profit measures.

The independent variable of labor productivity was determined to possess a significant effect on the technological progress value changes in the cases of 10 out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry. These include the food product, beverage, textile, apparel, timber products, paper and paper products, rubber and plastic products, metal products, metal products excluding machinery, computers, electronics and optical devices sectors.

Table 9. Annual technological progress growth share influenced by intersectoral technological spillover effect

Sector	Growth	Sector	Growth
C10	17%	C23	66%
C11	24%	C24	52%
C13	12%	C25	41%
C14	0%	C26	14%
C15	44%	C27	26%
C16	0%	C28	41%
C17	31%	C30	66%
C18	61%	C31	30%
C22	0%	C33	39%

Source: author's calculations

The foreign capital structure ratio had a significant effect in the cases of 6 out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry. These are the food products, apparel, leather and leather products, metal processing, computers, electronics and optical devices, and furniture sectors. The reinvestment ratio was found to have a significant effect on the technological progress value fluctuations in the cases of 5 out of the 18 analyzed sectors: the textile, timber products, paper and paper products, other transportation equipment, and machinery repairs and equipment sectors.

Table 9 presents information about the extent of the growth of technological progress for each of the analyzed sectors operating in the Lithuanian manufacturing industry in terms of the alterations induced by the intersectoral technological progress spillover effect. 3 instances were determined where the technological progress spillover effect does not influence the technological growth of the analyzed sectors. These sectors are the apparel, timber products, and rubber and plastic products sectors. The VAR models of these sectors did not identify any external variables which seem to have significantly influenced the changes in the measures of technological progress.

6 cases were identified where the technological progress growth of the sectors operating in the Lithuanian manufacturing industry were influenced by the intersectoral technological spillover effect, with the values increasing by up to 30 percent. These include the food products, beverage, textile, computers, electronics and optical devices, electricity equipment, and furniture sectors.

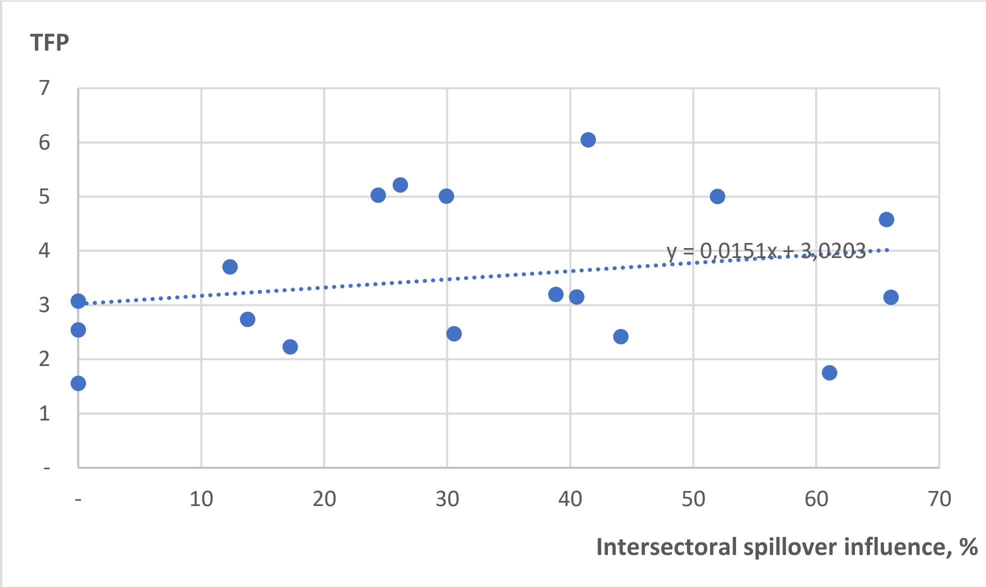


Figure 18. Scatter plot depicting relationship between TFP values and intersectoral spillover effect on technological progress growth. Source: author's calculations

In the cases of 5 sectors, their technological progress growth was influenced by the intersectoral spillover effect between 30 and 50 percent. These sectors are the leather and leather products, paper and paper products, metal products excluding machinery, other machines and equipment, furniture, and machinery repairs and equipment. Finally, in 4 cases, the technological progress spillover effect influenced more than 50 percent of the total growth of the sectoral technological progress. These sectors include the printing and reproduction, non-metal mineral products, metal processing, and other transportation equipment sectors. Thus, in some cases, the impact of the intersectoral technological spillover effect was determined to possess substantial influence on the technological progress growth at the sectoral level. A question which arises from these conclusions is whether the sectors denoted by larger intersectoral technological progress spillover influence possess higher values of technological progress. The graph presented in Figure 18 is intended to answer the question.

The scatter plot presented in Figure 18 depicts the relationship between the values of the TFP measure and the intersectoral spillover effect percentage influence on the growth of the sectoral technological progress. The trendline presented in the scatter plot graph suggests a slight positive linear relationship between the influence of the intersectoral spillover effect and the TFP measure: an increase of the intersectoral spillover effect on the growth of the sectoral technological progress by 1 percent is suggested to increase the measure of technological progress by 0.0151. In such a case, an increase of the intersectoral spillover effect on technological progress by 30 percent would lead to the growth of the TFP measure by the value of 0.45. For such a large increase in the intersectoral technological spillover effect, the resulting growth of the TFP measure is minuscule. The estimated Pearson correlation coefficient supports the conclusions that no significant linear relationship between the analyzed measures exists: the value of the correlation coefficient is 0.25. This indicates very small positive linear relationship. These conclusions support the theoretical framework: in order to absorb and maximize the effect of technological spillover, companies need to make adequate investments. Without adequate investments, the spillover effect will not lead to sustainable growth of technological progress.

Table 10. Standard deviation values of measures of technological progress measures

Sector	Std. Deviation	Sector	Std. Deviation
C30	0.653	C31	0.134
C27	0.603	C33	0.125
C24	0.496	C28	0.110
C11	0.360	C18	0.097
C15	0.197	C14	0.088
C26	0.183	C10	0.087
C22	0.170	C13	0.067
C23	0.167	C17	0.051
C25	0.162	C16	0.047

Source: author's calculations

In order to assess whether the constructed VAR models are valid, Table 10 presents the standard deviation values of the VAR model residuals. Out of all the 18 analyzed sectors, the standard deviation values for 4 models are larger than 0.3. These sectors involve the other transportation equipment, electricity equipment, metal processing, and beverage sectors. For 14 other sectors, the residual standard deviation measures are significantly lower, and they possess values lower than 0.2, and, in some cases, even under the value of 0.1. In order to evaluate the VAR models for the sectors with the largest standard deviations in the residuals, more detailed analysis is required. Figure 19 presents graphs of the VAR model residuals for sectors with the highest standard deviation values.

In the case of the other transportation equipment sector whose VAR model has the largest residual standard deviation value, no indication of serial correlation or heteroscedasticity was observed. The constructed model slightly underestimates the recovery of the growth of technological progress during the years 2010–2011, but, despite these two years, the modelled values are significantly close to the actually produced output values. A similar situation is present in the case of the electricity equipment sector where no signs of serial correlation or heteroscedasticity are present. For the year 2009, the model slightly overstates the value of technological progress, while, in some later years, the values of technological progress are slightly underestimated, yet the fit seems to be significant.

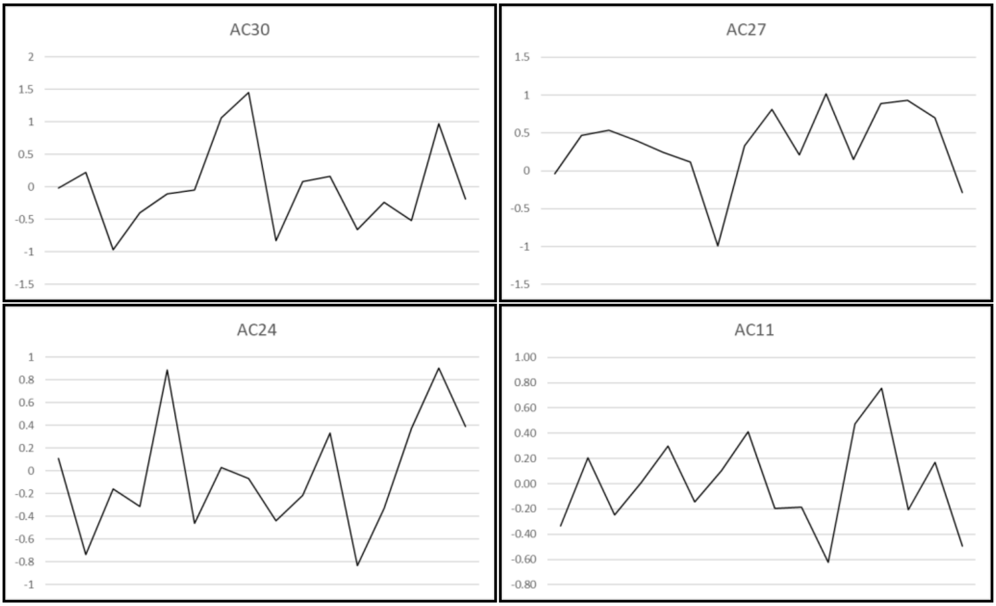


Figure 19. Residuals for VAR models with largest residual standard deviation values.
Source: author's calculations

In the case of the metal processing sector, some slight variations are visible, which could suggest potential heteroscedasticity of the residuals in the model. For the years 2007 and 2017, slight overestimation of the technological progress values is visible in the model, but further tests are needed to assess whether these deviations are significant. For the beverage sector in the early years of the analyzed time interval, the modelled values follow the results of the actual technological progress closely, while, in 2014–2015, there is a slight overestimation of the values of technological progress. Further tests for both of the presented sectors are needed to conclude whether the constructed VAR models are precise and can be used in the further research. More detailed tests were conducted in order to assess whether the VAR models are valid and can be used in the next step of analysis. Again, the Augmented Dickey-Fuller test is used to evaluate whether the residuals of the VAR models are static, and the Studentized Breusch-Pagan test helps to assess whether the residuals of the constructed models are homoscedastic, the Durbin-Watson test is employed to conclude whether the serial correlation in the residuals can be determined, and the Shapiro-Wilk normality test indicates whether the residuals are distributed normally.

The results of all the 18 built models indicate that no heteroscedasticity and no autocorrelation is perceived to be present in the VAR models, and that the residuals of the constructed models are normally distributed and static. Thus, the results of the models are proper and can be used in the next stage of our research model.

Table 11. Test results of constructed VAR models

Sector	Augmented Dickey-Fuller test	Studentized Breusch-Pagan test	Durbin-Watson test	Shapiro-Wilk normality test
C10	-2.0867 **	0.9437	0.1372	0.9882
C11	-3.2053 ***	0.1771	0.3173	0.9547
C13	-5.1132 ***	0.4178	0.4225	0.7758
C14	-2.7157 ***	0.4483	0.2355	0.9835
C15	-2.7628 ***	0.4164	0.1768	0.3945
C16	-4.2104 ***	0.5773	0.7538	0.9902
C17	-3.4786 ***	0.5470	0.1068	0.1051
C18	-2.3990 **	0.7668	0.4048	0.1856
C22	-3.8661 ***	0.8243	0.9339	0.05491
C23	-3.0538 ***	0.6315	0.3588	0.8402
C24	-2.4685 **	0.4385	0.2246	0.6314
C25	-3.2561 ***	0.7247	0.3935	0.3352
C26	-3.7135 ***	0.9014	0.2902	0.7630
C27	-2.7663 ***	0.4712	0.9256	0.6518
C28	-3.0665 ***	0.8051	0.1306	0.2849
C30	-2.7892 ***	0.4251	0.3055	0.2514
C31	-3.3494 ***	0.1444	0.1591	0.7037
C33	-3.2954 ***	0.1662	0.5440	0.9929

Source: author's calculations

3.4. Execution of sensitivity analysis for the Lithuanian manufacturing industry when utilizing agent-based modelling framework

The constructed and verified VAR models were used in the ABM framework to perform sensitivity analysis in order to evaluate how changes in different macroeconomic variables of the sectors operating in the Lithuanian manufacturing industry influence the fluctuations of the measure of technological progress. Furthermore, the extent of the intersectoral technological progress spillover effect in the development of technological progress is also tested.

Firstly, the ABM model was carried out without any changes made to the independent variables in order to assess how closely the technological progress values are recreated by the ABM framework compared to the values estimated with the help of the VAR method. The results of the ABM modelled TFP values are presented in Table 12. These values are used as the reference point in comparison to the TFP measure results obtained when different independent variables are adjusted.

The discrepancy between the TFP values obtained by the VAR models and the ones estimated by using ABM simulation is low. The most prominent difference is witnessed in the case of the electricity equipment sector where the TFP values estimated by using the ABM methodology deviate from the VAR model values by 8 percent. In the case of the other transportation equipment sector, the deviation was 7

Table 12. TFP values of sectors in the Lithuanian manufacturing industry obtained from ABM model

Year	**C10**	**C11**	**C13**	**C14**	**C15**	**C16**	**C17**	**C18**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**	**C30**	**C31**	**C33**
2000	1.07	3.18	1.40	1.95	0.84	1.15	1.17	0.76	1.14	0.87	2.37	1.15	2.00	1.19	1.16	1.32	1.96	1.17
2001	1.22	3.27	1.43	2.12	0.99	1.12	1.44	0.85	1.21	1.19	2.77	1.25	2.21	1.34	1.65	1.50	2.02	1.39
2002	1.20	3.67	1.61	2.21	1.39	1.23	1.20	0.86	1.38	1.30	1.89	1.28	1.76	1.60	2.47	1.33	2.34	1.01
2003	1.42	3.71	1.80	2.29	1.23	1.26	1.66	1.02	1.34	1.48	1.96	1.42	1.60	1.89	2.35	1.25	2.64	1.34
2004	1.41	3.76	2.02	2.42	0.74	1.32	1.64	1.05	1.42	1.65	2.89	1.74	1.46	2.27	2.82	1.64	3.14	1.58
2005	1.54	4.12	2.27	2.45	1.27	1.45	1.53	1.32	1.78	2.05	2.22	1.74	1.33	2.23	3.42	2.89	2.67	1.85
2006	1.54	4.48	2.35	2.59	2.08	1.40	1.82	1.44	1.97	2.63	3.33	2.34	1.69	2.76	4.58	3.14	3.00	2.49
2007	1.93	5.46	2.40	2.52	1.71	1.42	1.91	1.27	2.17	3.30	2.84	2.79	1.59	3.41	4.98	3.21	3.41	2.68
2008	1.73	5.20	2.48	2.75	2.28	1.23	2.02	1.26	2.00	2.69	5.11	2.59	2.70	3.26	5.09	3.19	3.03	2.74
2009	1.95	4.59	2.60	2.44	2.23	1.20	2.16	1.30	1.94	2.03	1.83	2.20	2.42	2.98	4.27	3.42	3.64	2.42
2010	2.07	4.00	3.11	2.77	2.20	1.41	2.13	1.49	2.40	2.22	3.51	2.94	3.30	4.64	5.33	4.77	4.73	2.64
2011	2.25	4.61	3.94	3.20	2.42	1.46	2.51	1.74	2.51	3.16	5.91	3.45	3.04	4.80	5.67	3.38	4.92	3.07
2012	2.41	5.27	4.21	3.09	2.57	1.51	2.72	1.89	2.71	2.86	5.53	3.24	3.36	5.13	6.44	2.52	5.26	3.49
2013	2.54	5.36	4.66	3.43	2.83	1.65	2.93	2.04	2.91	3.42	6.91	3.46	3.19	6.11	7.02	3.84	5.34	3.29
2014	2.58	5.83	4.92	3.70	3.09	1.81	2.97	2.35	3.07	3.67	7.26	3.89	3.16	6.19	7.43	5.89	6.61	3.38
2015	2.72	5.63	5.06	3.77	3.30	1.82	3.21	2.52	3.27	3.81	7.48	4.38	3.55	6.95	8.16	7.27	6.67	3.80
2016	3.10	6.55	5.60	3.75	3.47	1.85	3.22	2.47	3.46	4.44	7.29	4.34	3.49	9.00	8.64	7.26	7.79	4.56
2017	3.17	5.80	5.88	4.00	3.76	1.94	3.35	2.46	3.67	4.90	8.28	4.50	4.11	8.89	10.00	7.71	8.39	5.01
2018	3.25	6.04	6.18	4.02	3.87	2.14	3.74	2.57	3.96	4.97	8.31	4.73	4.03	9.88	10.18	9.14	8.92	5.75

Source: asuthor' s calculations

percent, whereas the machinery repairs and equipment sector deviated by 5 percent. In the case of the other 15 out of the 18 analyzed sectors, the deviation of the TFP values caused by ABM simulation was lower than 5 percent. In the cases of 4 sectors (the food product, apparel, timber product and metal processing sectors), the divergence was even lower than 1 percent. This indicates that the TFP values obtained by the ABM framework were not distorted due to the interactions between the agents in the model.

The variables which were chosen to be used for the sensitivity analysis in the ABM models are the net profit and labor productivity measures. They were selected because, in the constructed VAR models, these variables affected the technological progress values for the largest number of the analyzed sectors. According to Pannell (1997), the ranges for value changes in sensitivity analysis have to reflect the realistically possible variations of the analyzed parameters. In the given case, sensitivity analysis was performed multiple times, thus increasing the variable values between 5 and 30 percent. The obtained results indicated that the relationship of the growth of technological progress among the sectors remained the same, independently of the scope by which the parameters were increased. Thus, in this section of the research, four simulations are analyzed in detail. In each of the simulations, either the net profit or the labor productivity measure is increased by either 5 percent or 10 percent. After each cycle, the effect of the variables on the changes in the technological progress values is measured. The ABM framework will also help to separate the inner effect of the local variable as well as the outer effect of the technological progress spillover effect on the growth of the TFP measure.

Table 13. Growth of the technological progress measure due to the increase of net profit by 5 percent in the Lithuanian manufacturing industry

Sector	TFP growth from internal factors	TFP growth from spillover effect	Sector	TFP growth from internal factors	TFP growth from spillover effect
C10	0.67%	0.33%	**C23**	0.86%	0.85%
C11	0.45%	0.41%	**C24**	1.15%	0.20%
C13	0.81%	0.50%	**C25**	0.77%	0.38%
C14	0.56%	0.00%	**C26**	0.00%	0.15%
C15	1.77%	0.87%	**C27**	1.08%	0.34%
C16	0.57%	0.00%	**C28**	1.30%	0.79%
C17	0.00%	0.44%	**C30**	0.00%	1.15%
C18	0.85%	1.15%	**C31**	1.55%	0.81%
C22	1.04%	0.00%	**C33**	0.47%	0.67%

Source: author's calculations

Table 13 presents the results of a carried-out ABM simulation where the values of the net profit for each sector operating in the Lithuanian manufacturing industry were increased by 5 percent. The information given in the table indicates the extent by which the TFP value grew entirely due to the rise of the net profit independent variable. The TFP increase is also differentiated into growth due to the increase in the internal independent variable and due to the technological spillover effect.

Out of all the analyzed sectors, the leather and leather products sector showed the largest increase of the TFP value. For the given sector, the measure of the technological progress increased at an annual rate of 2.63 percent. There were three other sectors which managed to reach the annual TFP growth rate of 2 percent or higher: the furniture sector with the rate of 2.36 percent, the other machines and equipment sector with 2.09 percent, and the printing and reproduction sector with the 2 percent annual growth rate.

There were 5 sectors whose annual TFP growth during the analyzed period did not manage to reach as little as 1 percent. These sectors include the beverage sector at 0.86 percent, the apparel sector at 0.56 percent, the timber products sector at 0.57 percent, and the paper and paper products sector at 0.44 percent, while the increase in the annual TFP growth rate of the computers, electronics and optical devices sector reached a very modest value of 0.15 percent.

Out of the 18 analyzed sectors, according to the constructed VAR models, the values of technological progress of only 3 sectors operating in the Lithuanian manufacturing industry were not linearly related to the net profit measures. Despite the absence of the linear relationship between the values of technological progress and the net profit measures, an increase of the net profit values by 5 percent for each sector operating in the Lithuanian manufacturing industry resulted in the TFP value increase for these three sectors as well.

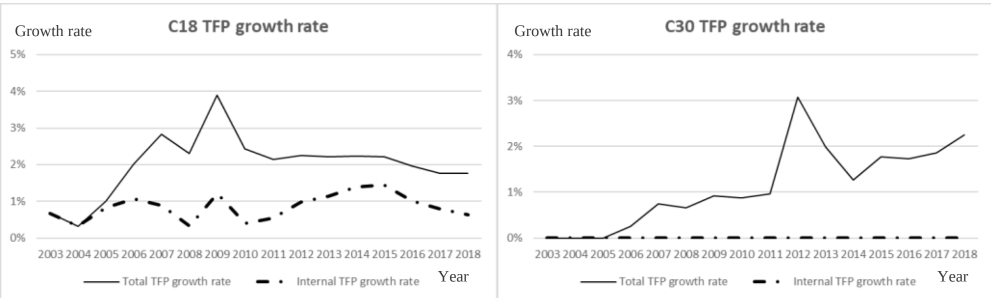


Figure 20. Decomposition of the technological progress annual growth rate due to the increase in net profit measures for the Lithuanian printing and reproduction sector (left) and the other transportation equipment sector (right), 2003–2018. Source: author’s calculations

Two of the sectors were already mentioned (specifically, the paper and paper products; computers, and the electronics and optical devices sectors) as their technological progress values grew at an annual rate of less than 1 percent. Nonetheless, this growth was created from their ability to utilize the technological innovations developed by other sectors operating in the Lithuanian manufacturing industry by reinvesting their earned profits. The third sector whose VAR model does not exhibit linear relationship between technological progress and the measure of net profit is the other transportation equipment sector. The given sector managed to maintain the annual technological progress growth rate of 1.15 percent, all of which stems from the intersectoral technological progress spillover effect. With this behavior, the other transportation equipment sector managed to outgrow 8 other sectors, 6 of which achieved TFP growth due to the internal linear relationship between the measures of technological progress and the net profit.

Out of all the analyzed sectors operating in the Lithuanian manufacturing industry, two managed to utilize the technological progress spillover effect created from the increase in the net profit values most prominently. Specifically, the printing and reproduction, and the other transportation equipment production sectors managed to increase their annual TFP growth values by 1.15 percent from the intersectoral technological progress spillover effect only. Figure 20 presents the decomposition of the technological progress growth rates for the two sectors.

What concerns the printing and reproduction sector, for the first few years, the growth of the measure of the total technological progress coincided with the internal growth as it takes time for the intersectoral technological progress spillover effect to take place and get manifested. Between the years 2004 and 2009, the annual growth rate of the technological progress spillover effect increased rapidly – from 0.5 percent to almost 4 percent. The 3.9 percent annual growth rate, obtained in 2009, is the largest of all throughout the entire analyzed period. The swift growth during the analyzed time frame was not created by the internal variables of the printing and reproduction sector as the TFP growth due to the internal factors between the years 2004 and 2009 never increased by more than 1.2 percent. This means that most of the growth was created by the intersectoral technological spillover effect. From 2009 until the end of the analyzed time period, the annual TFP growth rate started declining. The growth of technological progress due to the internal variables of the printing and reproduction sector, on the contrary, started increasing as, between 2010 and 2015, it grew from 0.4 percent to 1.5 percent. Thus, although the intersectoral technological progress spillover effect after 2009 started withering, between 2011 and 2015, the increasing effect of the internal variables helped to keep the total TFP annual growth rate at a constant level.

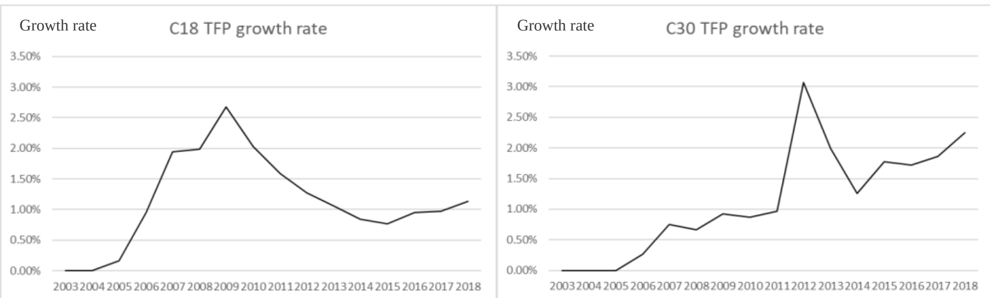


Figure 21. Intersectoral technological spillover effect on the technological progress annual growth rate due to the increase in the net profit measures for the Lithuanian printing and reproduction sector (left) and the other transportation equipment sector (right), 2003–2018. Source: author's calculations

As the internal variables of the other transportation equipment sector throughout the analyzed time frame had no effect on the TFP growth and as the intersectoral technological spillover effect still had not taken place, for the first few years, the increase in the net profit measure did not affect the values of technological progress. After 2005, the annual TFP growth rate started rising, and it sustained a constant increase rate, with the exception for 2012 and 2013, all throughout the analyzed period. In 2012, the annual growth rate of TFP reached 3.1 percent, while, in 2013, the measure was 2 percent.

Figure 21 shows only the part of the technological progress annual growth rate which was induced by the intersectoral technological spillover effect. The intersectoral technological progress spillover effect in the case of the printing and reproduction sector grew rapidly between 2005 and 2009 – by up to 2.7 percent, which was the largest value throughout the entire analyzed period. After that followed a period of decline in the growth rate of the spillover effect. During the time interval of the years 2009–2015, the value of the growth for the annual technological progress spillover effect declined to 0.8 percent, although, until 2018, the value of the measure rebounded and expanded to 1.1 percent.

On the contrary, in the case of the other transportation equipment sector, the annual technological progress spillover effect started increasing at a slow and steady pace. Between 2007 and 2011, the given measure for the analyzed sector increased from 0.7 percent to 1 percent. In 2012 and 2013, the annual growth rate expanded rapidly until reaching the value of 3.1 percent for one year. The annual growth rate of the technological progress spillover effect did not manage to maintain the pace reached in 2012, although the other transportation equipment sector managed to finish the year 2018 with a 2.2 percent growth rate.

Table 14. Growth of the technological progress measure due to the increase of net profit by 10 percent in the Lithuanian manufacturing industry

Sector	TFP growth from internal factors	TFP growth from spillover effect	Sector	TFP growth from internal factors	TFP growth from spillover effect
C10	1.34%	0.67%	**C23**	1.72%	1.70%
C11	1.00%	0.72%	**C24**	2.29%	0.39%
C13	1.61%	1.00%	**C25**	1.60%	0.69%
C14	1.11%	0.00%	**C26**	0.00%	0.30%
C15	3.53%	1.73%	**C27**	2.17%	0.67%
C16	1.14%	0.00%	**C28**	2.60%	1.59%
C17	0.00%	0.88%	**C30**	0.00%	2.30%
C18	1.71%	2.29%	**C31**	3.09%	1.63%
C22	2.09%	0.00%	**C33**	0.95%	1.35%

Source: author's calculations

When comparing the annual growth rate of the technological progress spillover effect which was initiated by the increase in the net profit values and presented in Figure 20, we can see that different sectors can exploit the effect very differently. In the cases of both presented sectors, the average annual growth rate during the analyzed time frame was identical, at 1.15 percent, but the values were attained in different manners. The printing and reproduction sector started with the initially large annual growth rate of the technological progress spillover effect which started declining during the second part of the analyzed time period. In the case of the other transportation equipment sector, the growth rate increased more rapidly during the second part of the evaluated time frame. The printing and reproduction sector also managed to expand the total growth rate of the TFP measure by utilizing the internal effect of the increased net profit, which other transportation equipment sector failed to achieve.

Table 14 presents the same differentiation of the technological progress growth, except that, this time, for sensitivity analysis, the net profit value of the companies operating in the Lithuanian manufacturing industries were increased by 10 percent.

The results presented in Table 14 indicate that the proportion between the growth of technological progress induced by the internal factors and the growth of technological progress caused by the intersectoral spillover effect remained the same as in the previous simulation where the net profit was increased by 5 percent. The only thing that actually changed is the magnitude of the growth of the TFP measure. This time, greater attention was addressed towards two sectors which, in the performed simulation, possessed the largest growth of technological progress: the leather and leather products sector and the furniture sector. Their decomposed annual technological progress growth rates are presented in Figure 22.

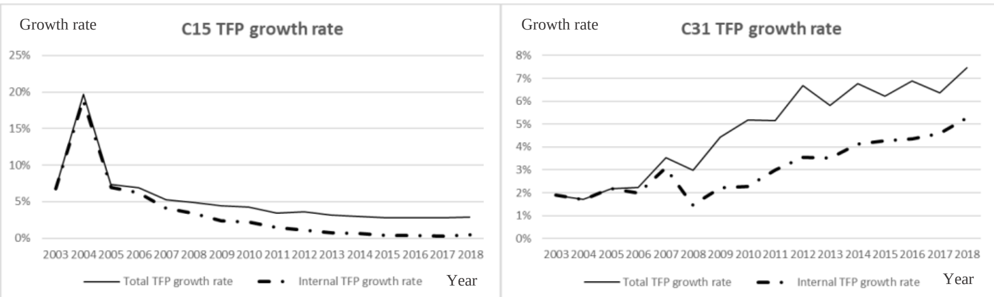


Figure 22. Decomposition of the technological progress annual growth rate due to the increase in the net profit measures for the Lithuanian leather and leather products sector (left) and the furniture sector (right), 2003–2018. Source: author's calculations

The dynamic changes of the annual technological progress growth rates are radically different for the two sectors operating in the Lithuanian manufacturing industry. In the case of the leather and leather products sector, at the beginning of the analyzed period, the TFP measure values increased rapidly, yet, later on, the growth rate gradually diminished. The presently shown trend can be rationally explained. In the year 2004, the leather and leather products sector possessed the lowest technological progress value out of all the 18 analyzed sectors operating in the Lithuanian manufacturing industry. As the base value of the technological progress measure is low, the percentage expression at the early stage appears to be large. As the technological progress values for the leather and leather products sector increased, the effect of the internal parameters diminished. Between the years 2014 and 2018, the technological growth rate due to the internal factors was measured at an average value of 0.4 percent. At the end of the analyzed timeframe, the growth of the TFP measure in the case of the leather and leather products sector was mainly influenced by the intersectoral technological spillover effect due to efficient utilization of the technology developed internally within other sectors of the Lithuanian manufacturing industry. Despite the rapid technological progress growth between the years 2003–2008, the leather and leather products sector finished the year 2018 with the 5th lowest technological progress value out of all the 18 analyzed Lithuanian manufacturing sectors.

The situation with the dynamic changes of the growth of technological progress in the case of the furniture sector was totally different. At the beginning of the researched period, the annual TFP growth rate stayed at a relatively low level. Between the years 2003 and 2005, all the growth of technological progress was created by the internal factors influencing the TFP growth rate as the intersectoral spillover effect took time to take effect. After 2008, the technological progress growth rate started gaining momentum and rising at an increasing rate. In 2008, the annual technological progress growth rate increased from 3 percent to 7.5 percent compared with 2018. The vast majority of the increase in the annual TFP measure growth rate was influenced by the internal factors as, between 2008 and 2018, the technological growth rate due to the spillover effect rose from 1.5 percent to 2.2 percent.

The given example indicates that, even between the largest growing sectors in the Lithuanian manufacturing industry, the means to induce the growth of technological progress can be vastly different. In the case of the leather and leather products sector which exhibited lower values of the TFP measure, it managed to efficiently utilize the intersectoral technological progress spillover effect so that to reinforce its technological progress growth. In the case of the furniture sector which held high TFP measure values at the start of the analyzed time frame, it managed to speed up its technological progress growth through efficient employment of the internal resources. Thus, a wide variety of different methods to further increase the technological progress growth rates can be observed and attained.

Table 15 presents the results of a simulation where the labor productivity of all the sectors operating in the Lithuanian manufacturing industry were increased by 5 percent. The table dissects the increase in the TFP measure values only due to the growth of labor productivity. Out of the 18 analyzed sectors, 8 did not exhibit any internal technological progress growth increase due to the rising labor productivity. This means that the variable of labor productivity was not included into their vector autoregression functions. As additional technological progress growth could not be produced by the internal factors due to the increase in labor productivity, the increase in the TFP measure values could only be anticipated from the intersectoral technological progress spillover effect.

Table 15. Growth of the measure of technological progress due to the increase of labor productivity by 5 percent in the Lithuanian manufacturing industry

Sector	TFP growth from internal factors	TFP growth from spillover effect	Sector	TFP growth from internal factors	TFP growth from spillover effect
C10	1.65%	0.04%	**C23**	0.00%	0.90%
C11	1.02%	0.22%	**C24**	1.66%	0.77%
C13	3.45%	0.43%	**C25**	2.21%	0.01%
C14	3.46%	0.00%	**C26**	4.34%	0.01%
C15	0.00%	2.62%	**C27**	0.00%	0.00%
C16	2.31%	0.00%	**C28**	0.00%	0.29%
C17	1.51%	0.98%	**C30**	0.00%	0.00%
C18	0.00%	1.17%	**C31**	0.00%	0.37%
C22	3.06%	0.00%	**C33**	0.00%	0.00%

Source: author's calculations

Some sectors managed to utilize the effect while others did not. The leather and leather products sector managed to maintain the 2.6 percent annual TFP growth rate due to the intersectoral technological progress spillover effect. In the case of printing and reproduction sector, the annual technological progress growth rate was 1.2 percent, for the non-metal mineral products sector, it was 0.9 percent, for the furniture sector, it was 0.4 percent, and for the other machines and equipment sector, it was 0.3 percent. There were three sectors which did not manage to absorb any intersectoral technological progress spillover effect, and their technological progress values in the performed simulation did not achieve any additional growth. These are the electricity equipment, the other transportation equipment, and the machinery repairs and equipment sectors.

Another insight which could be made from the results of the performed simulation is that internal factor effects on the TFP growth due to the increase in labor productivity are stronger than the intersectoral technological spillover effects. In the simulation that we carried out, out of the 10 fastest growing sectors, only one managed to generate all of the growth through the intersectoral technological spillover effect. This was the leather and leather products sector, and it had the fifth highest annual growth technological progress growth rate. Thus, in order to generate the technological progress growth due to the increase in labor productivity, the effect of internal factors is necessary. The intersectoral technological progress spillover effect cannot be relied on to generate large TFP growth rates in the given scenario.

Figure 23 presents the annual technological progress growth rates of the two fastest growing sectors in the given scenario: the computers, electronics and optical devices sector, and the textile sector. In the case of the computers, electronics and optical devices sector, at the beginning of the analyzed time frame, the annual technological progress growth rate was increasing at a rising pace.

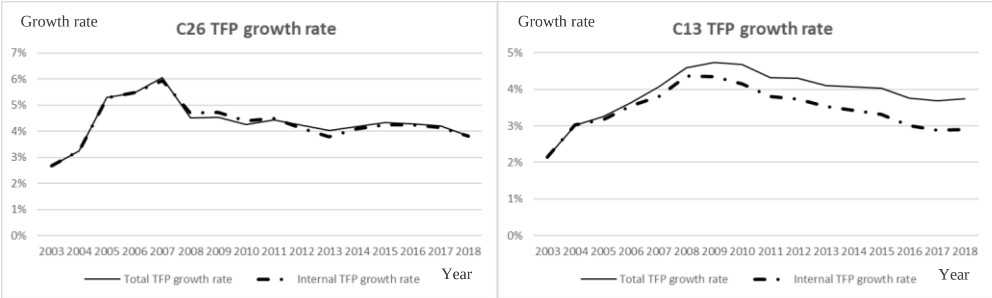


Figure 23. Decomposition of the technological progress annual growth rate due to the increase in labor productivity measures for the Lithuanian computers, electronics and optical devices sector (left) and the textile sector (right), 2003–2018. Source: author's calculations

In 2003, the TFP measure growth rate due to the increased labor productivity was 2.7 percent, while, in 2007, the value reached 6 percent. For the remaining part of the analyzed period, the technological progress value was still growing, although the annual growth rate declined. In 2018, i.e., in the final analyzed time period, the TFP measure annual growth rate was 3.8 percent. Thus, for the entirety of the analyzed time interval, the average annual technological progress growth rate had the value of 4.3 percent. This kind of growth rate was achieved without the help of the intersectoral technological progress spillover effect as the influence of the given effect on the TFP value was barely visible.

The simulation results for the textile sector indicate that the growth rates of the TFP measure due to the increased labor productivity between the years 2003–2009 was growing at an accelerating pace. In 2003, the technological progress growth rate was 2.2 percent, while, in 2009, it reached 4.36 percent. After 2009 until the end of the analyzed time frame, the annual TFP growth rate decreased, although the decrease was mild. In 2018, i.e., in the analyzed year, the annual technological progress growth rate value was 3.7 percent. Thus, the growth rate value was still higher than the measure witnessed at 2006. The main difference between the results of the two sectors presented in Figure 22 is that the TFP growth rate of the textile sector was also influenced by the technological progress spillover effect. We can see that the technological progress spillover effect exerted influence on the TFP measure growth beginning with 2007. Prior to that, the effect of the technological progress spillover effect on the TFP growth was either non-existent or minuscule. From 2007 until 2018, the technological progress spillover effect had an increasingly growing influence on the growth of the TFP measure. In 2007, the growth of technological progress due to the spillover effect was 0.3 percent, while, in 2018, the TFP increase due to the spillover effect was recorded as 0.8 percent. Despite the fact that, during the period of 2009–2018, the effect of internal factors on the TFP growth was declining and the technological progress spillover effect was increasing, in 2018, the spillover effect influenced only around 20 percent of the total annual TFP growth, whereas approximately 80 percent of the TFP growth was still influenced by internal factors.

The results presented in Table 16 were obtained from a sensitivity analysis simulation similar to that of the case of Table 15. The only difference between these two simulations is the labor productivity incrementation rate. In the case of Table 16, labor productivity was increased by 10 percent rather than 5 percent, and the obtained results indicate how labor productivity incrementation affected the growth rate of technological progress.

Table 16. Growth of the measure of technological progress due to the increase of labor productivity by 10 percent in the Lithuanian manufacturing industry

Sector	TFP growth from internal factors	TFP growth from spillover effect	Sector	TFP growth from internal factors	TFP growth from spillover effect
C10	3.30%	0.08%	**C23**	0.00%	1.81%
C11	2.04%	0.44%	**C24**	3.31%	1.54%
C13	6.90%	0.87%	**C25**	4.42%	0.01%
C14	6.93%	0.00%	**C26**	8.68%	0.01%
C15	0.00%	5.23%	**C27**	0.00%	0.00%
C16	4.62%	0.00%	**C28**	0.00%	0.58%
C17	3.01%	1.96%	**C30**	0.00%	0.00%
C18	0.00%	2.34%	**C31**	0.00%	0.75%
C22	6.12%	0.00%	**C33**	0.00%	0.00%

Source: author's calculations

No matter whether labor productivity was increased by 5 percent or by 10 percent, in both cases, the same sectors featured the highest levels of the annual technological progress growth rates. The largest annual increase in the TFP measure was identified in the case of the computers, electronics and optical devices sector where the growth rate reached 8.7 percent. In the case of the textile sector, the annual technological progress growth rate due to the increase in labor productivity was 7.8 percent, for the apparel sector, the score was 6.9 percent, for the rubber and plastic products sector, the rate equaled 6.1 percent, and for the leather and leather products sector, the score of 5.2 percent was obtained.

Internal factors had a significantly stronger effect on the annual TFP growth rates compared to the technological progress spillover effect. Out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry, in the cases of 10 sectors, the internal factors managed to increase the technological progress annual growth rate by more than 2 percent. The technological progress spillover effect managed to increase the annual TFP grow rate by at least 2 percent in the cases of only 2 sectors. These are the leather and leather products sector where the annual technological progress growth due to the intersectoral technological progress spillover effect was determined to be 5.2 percent, and the printing and reproduction sector where the technological progress spillover effect led to the annual TFP measure increase by 2.3 percent. The dynamic changes of the growth rates of the annual technological progress of these two sectors are presented in Figure 24.

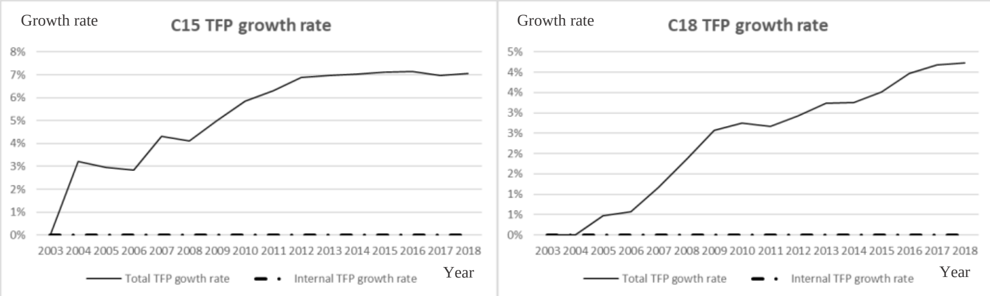


Figure 24. Decomposition of the technological progress annual growth rate due to the increase in labor productivity measures for the Lithuanian leather and leather products sector (left) and the printing and reproduction sector (right), 2003–2018. Source: author's calculations

The two sectors share similarities in the presented figure as the source of growth in either case is due to the technological progress spillover effect, and internal variables have no effect on the TFP annual growth measure. In the case of the leather and leather products sector, the increase in the intersectoral technological progress spillover effect is rapid – in 2003, the spillover effect had no influence on the technological progress growth rate, whereas, in 2004, TFP grew due to the technological progress spillover effect by 3.2 percent. The next jump in the technological progress spillover effect on the annual growth rate of the TFP measure was between 2008 and 2012. In 2008, the technological progress growth rate due to the technological progress spillover effect was 4.1 percent, while, in 2012, it reached 6.9 percent. In 2012, the technological progress spillover effect reached its peak effect, and, between the years 2012–2018, the influence of the spillover effect on the annual growth of the TFP measure settled down at around 7 percent.

In the case of the printing and reproduction sector, the increase in the intersectoral technological progress spillover effect on the annual growth value of the TFP measure was more stable. Between 2006 and 2009, the technological progress spillover effect on the annual TFP growth rate had a steeper increase: from 0.6 percent in 2006 to 2.6 percent in 2009. After 2009, the intersectoral technological progress spillover effect in the TFP measure growth was constantly increasing, albeit at a slow pace. In 2018, i.e., in the final period of the analyzed time frame, the TFP measure grew by 4.2 percent due to the influence of the technological progress spillover effect.

The performed simulation analysis helps to define how changes in the net profit and labor productivity values of the sectors operating in the Lithuanian manufacturing industry influenced the growth of the technological progress measure and defined the extent of the impact which the intersectoral technological progress spillover effect had on the dynamic changes of technological progress. The findings of simulation analysis suggest a few insights.

Firstly, the changes in the net profit and labor productivity had a significantly different effect on the fluctuations of the values of technological progress. Secondly, the changing values of the net profit measure for all the sectors operating in the

Lithuanian manufacturing industry affected the technological progress values of all the 18 analyzed sectors, although to a different extent. An increase of the net profit by 5 percent for all of the sectors led to the average annual technological progress growth rate between 2.6 percent (for the leather and leather products sector) and 0.2 percent (for the computers, electronics and optical devices sector). The next important aspect in analyzing the net profit measure effect in the growth of technological progress is the importance of the intersectoral technological progress spillover effect. Out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry, only 3 sectors did not exhibit the intersectoral technological progress spillover effect related to changes in the net profit measures. When the net profit values for all the sectors in the Lithuanian manufacturing industry were increased by 5 percent, these three sectors possessed the 10th, 17th and 18th largest annual technological progress growth rates due to the increase in the net profit. This means that, in order to fully utilize the effect of the increased net profit value for maximizing the growth rate of the technological progress, the additionally earned profits need to be invested into the technology and methods which would help to absorb the technological advancements which are common in all of the sectors operating in the given industry.

The impact of the labor productivity measure on the changes in the technological progress growth rates exhibited some differences. Firstly, the increasing labor productivity values of all the sectors operating in the Lithuanian manufacturing industry by 5 percent affected the technological progress growth rates of 15 sectors, whereas, in the cases of 3 sectors, no changes in the TFP measure growth rate were witnessed. For the remaining 15 sectors, the annual technological progress growth rate, due to the increase in the productivity measure values by 5 percent, was determined to vary between 4.35 percent (for the computers, electronics and optical devices sector) and 0.3 percent (for the other machines and equipment sector). This suggests that, although the increase in the net profit affects the technological progress growth rates of a higher number of sectors, the corresponding increase in the labor productivity measure values has a stronger effect in the TFP growth rates. When the net profit values of all the sectors operating in the Lithuanian manufacturing industry were increased by 5 percent, the average annual technological progress growth rate for the leather and leather products sector was recorded to be 2.6 percent, which is the largest out of all the analyzed sectors. When the labor productivity measure values for all the sectors operating in the Lithuanian manufacturing industry were increased by 5 percent, the leather and leather products sector again exhibited the 2.6 percent average annual technological progress growth rate, although, this time, it was the 5th largest growth rate out of all the analyzed sectors. Another exclusivity of the labor productivity measure and its influence on the technological progress growth rate is the importance of the internal variable dynamics. In the case of the net profit measure, the sectors demonstrating the highest technological progress growth were the ones best utilizing the intersectoral technological progress spillover effect. In the case of the labor productivity measure, it was not the case. The sectors whose internal factors did not affect the technological progress growth when the labor productivity measure increased had the lowest annual average TFP growth levels of all. The only exception was the above mentioned leather and leather products sector. This suggests that the labor productivity measure is mainly an internal factor, and it does not represent the qualities required to produce the intersectoral technological progress spillover effect thus benefiting the entire manufacturing industry.

The results obtained from the sensitivity analysis coincide with the stipulations of the endogenous growth theory which suggests that the intersectoral technological progress spillover effect is created by reinvesting the generated profits into research and development and thus generating even more innovations, which leads to further improvement of technological progress.

CONCLUSIONS

1. According to the analyzed neoclassical growth theories, there exist two main measures for technological progress evaluation: total factor productivity (TFP) and technological efficiency (TE). TFP depicts the outward shift of the production frontier which is caused by improvements in the technology used in the manufacturing process. In the context of the neoclassical growth theories, the TFP measure can be defined as a multiplicator which depicts the extent of economic growth which is conditioned by the production factors other than capital and labor. The Solow's growth theory suggests that the TFP value can be derived from the Cobb-Douglas production function with the help of the Solow's residual parameter. The measurement technique of the residual parameter needs to be adjusted from the one presented in the Solow's neoclassical growth model as, in its regular form, the estimated measure might potentially suffer from the omitted variable bias, the aggregation bias, or misspecification errors. The TE parameter measures the produced output level towards the production frontier. It specifies the extent by which the actual output and the potential output, presented in the production frontier, differ, thus indicating inefficiencies caused by the underutilization of capital and labor resources. TE can be estimated by using either stochastic frontier analysis or data development analysis methods. The attempt to define the relationship between economic growth and technological development stochastic frontier analysis is preferred as the obtained results when using this method are delivered in their functional form and can be more easily integrated into other statistical methods. The TFP measure was chosen for the estimation of the technological progress values because it is more suitable for reflecting long-term innovations and their effect on economic growth. The TE measure is more appropriate for the depiction of shorter-term discrepancies from the potential production outputs.
2. Analysis of academic literature indicated that the ability to generate profit, the cost of capital, the foreign direct investment, the capital structure, the level of financial liquidity, the increasing competitiveness in foreign markets, and the energy consumption efficiency constitute the list of factors which can strongly influence the dynamics of technological progress fluctuations. Raising profitability measures can potentially lead to the growth of technological progress through the increasing R&D spending and investments directed at more efficient resource utilization. Value creation through reinvestment of the generated profits is assessed by the Economic Value Added measure. Foreign direct investments can initiate a flow of the technological progress spillover effect. Spillover of technological progress can occur at the intra-industry level and at the inter-industry level. The intra-industry level technological progress spillover effect can be achieved through demonstration, training of employees, and competition. Inter-industry foreign direct investment spillovers can happen due to the vertical linkages between sectors. For domestic companies, in order to absorb the foreign direct investment spillover, adequate resources must be

directed into R&D expenditures. The capital structure can also influence the ability to stimulate growth through technological progress as improper debt and equity capital proportions can either lead to hardships when trying to attract funding or to an increase in the price of capital thus preventing the implementation of new projects. The level of financial liquidity can affect the value creation abilities of companies in two main ways. If the financial liquidity measures are too large, this leads to the increasing levels of maintenance costs in the form of opportunity cost, thus suggesting underinvestment and the loss of value. On the contrary, a very low level of financial liquidity can result in decreasing profitability. Another factor affecting technological improvement in the manufacturing industry is the competitiveness in international markets. Increasing exports can influence economic growth in three main ways: by improving the balance of payments, by being a source for job creation, and by utilizing the effect of economies of scale which helps to accelerate the technological advancement in production. Another factor is the increase of efficiency in energy consumption. One of the more systematically examined theories of the relationship between economic development and energy consumption is the environmental Kuznets curve (EKC). This EKC theory suggests that, at initial state of economic growth, environmental degradation follows a linear relationship with the increase in the production output, yet, when the economy matures, the energy consumption efficiency increases, and the energy consumption per unit of the produced output diminishes. All the described variables, in one form or another, are included into the empirical analysis of the technological progress development of the sectors operating in the Lithuanian manufacturing industry.

3. The technological progress values in the carried-out research were estimated on the basis of the Solow's neoclassical growth theory as a measure of the total factor productivity (TFP). In order to evaluate the TFP parameter, the estimation of the output elasticity of capital is required, which was performed by using time series regression. The regression equation was formed with the help of the Cobb-Douglas production function used in the Solow's neoclassical growth model. Some adjustments in the constructed models were made so that to eliminate the possible endogeneity of regression, to maintain the stationarity of the time series data, and to avoid collinearity of the parameters used in the model. In order to eliminate the endogeneity problem, additional explanatory variables were included into the time series regression beside the habitual parameters of capital and labor included into the Cobb-Douglas production function. These explanatory variables include energy consumption in the production process indicating the extent of energy which was used to produce 1 euro worth of goods, the cash ratio presenting the share of the short-term liabilities which is covered by disposable cash and cash equivalents, the leverage ratio estimated by dividing the equity value by the total debt value, the export turnover ratio calculated as a ratio between the export turnover and the total turnover, and, finally, the reinvestment ratio indicating the extent of the value of material assets which was restored by annual investments. In order to satisfy

the stationarity assumption of the constructed regression model, the time trend independent variable was also included into the equation. The time trend was incorporated into the model so that to account for the output growth due to the variables on the demand side as the Cobb-Douglas function displays the supply side variable effects of the produced output. In order to remove the collinearity of the independent variables effect and to prevent any distortion of the results of the time series regression, all the parameters, which were exhibiting linear correlation with the parameter of the capital per unit of labor were removed from the regression. Finally, one parameter cannot represent the output elasticity of capital values of the sectors operating in the Lithuanian manufacturing industry for the period of 19 years as the output elasticity of capital changes with the flow of time. In order to account for that, additional interaction terms between capital and time were incorporated into the model.

4. In order to assess the effect of different variables on the growth of technological progress, the vector autoregression (VAR) model was incorporated into the created evaluation model. While examining the practical applicability of the model, 18 sectors operating in the Lithuanian manufacturing industry were analyzed. Beside the TFP measures, as independent variables, other parameters were also included into the VAR model, specifically, the reinvestment ratio, the labor productivity ratio, the foreign capital structure ratio, the estimated division of the average annual foreign capital value by the value of the total annual capital value employed in the production process, and the annual inflation adjusted net profit measure. The reinvestment ratio was included into the VAR model with lagged values, while other parameters were included into the model with the current time period values. The results of the constructed VAR model suggest that, in the case of 15 out of the 18 analyzed sectors operating in the Lithuanian manufacturing industry, the net profit measure influenced changes in the measure of technological progress, in the case of 10 sectors, the labor productivity measure influenced TFP measure values, in the case of 6 sectors, the foreign capital structure ratio affected the changes in TFP, and, in case of 5 sectors, the reinvestment ratio had a significant effect on the changes in the technological progress values. The results of the constructed VAR model also suggested that only in the case of 3 out of the 18 sectors operating in the Lithuanian manufacturing industry, no intersectoral technological progress spillover effect could be identified. In the case of 10 sectors, the determined intersectoral technological progress spillover effect was one-to-one, where the technological progress value of one sector influenced changes in the TFP values of exactly one other sector. In 5 cases, the relationship was two-to-one, where the TFP values of one sector were influenced by the changes in the technological progress measures of two other sectors operating in the Lithuanian manufacturing industry.
5. In the carried-out sensitivity analysis, two parameters were chosen, which are, specifically, inflation adjusted net profit and labor productivity, in order to measure their effect on the measure of technological progress. They were chosen because the previously performed VAR analysis indicated that they affect the

largest number of the analyzed sectors operating in the Lithuanian manufacturing industry. In total, 4 simulations were performed where the values of both variables were increased by 5 percent and by 10 percent for all the companies operating in the Lithuanian manufacturing industry. The sensitivity analysis indicated that the two variables influence changes of the technological progress values in different ways. The changes in the inflation adjusted net profit values to a varying extent influenced the technological progress growth for all the 18 sectors operating in the Lithuanian manufacturing industry. An increase of the net profit values by 5 percent resulted in the average annual technological progress growth between 2.6 percent and 0.2 percent. The net profit parameter is also a more efficient generator of the intersectoral technological progress spillover effect as the technological progress growth in the cases of 15 sectors was reinforced by the technological progress spillover. On the other hand, the growth in the labor productivity parameter affected the technological progress growth rates of 15 sectors operating in the Lithuanian manufacturing industry. Out of those 15 sectors, only 9 were significantly affected by the intersectoral technological progress spillover effect. Thus, labor productivity influenced the growth of technological progress for a lower number of sectors operating in the Lithuanian manufacturing industry, although the effect itself was stronger. In our simulation where labor productivity was incremented by 5 percent, the average annual technological progress growth rate increased by up to 4.4 percent. Finally, in the simulations where the inflation adjusted net profit values were increased, the technological progress values grew at the fastest pace for those sectors which managed to utilize the intersectoral technological progress spillover effect. In the simulations where labor productivity measures were increased, the technological progress values increased at the most rapid pace for those sectors which managed to induce their own growth internally. These results coincide with the endogenous growth theory which states that innovations along with the technological progress development are accelerated by the spillover effect created from reinvested profits. The results obtained from the sensitivity analysis suggest that the situation perceived in the Lithuanian manufacturing industry is positive. Throughout the analyzed timeframe, the technological progress values of the analyzed sectors were increasing, while the intersectoral technological progress spillover effect significantly influenced the technological progress values for the majority of sectors. Companies operating in the Lithuanian manufacturing industry should continue reinvesting their profits into innovations and further increase their productivity, thus maintaining the growth of the values of technological progress. The constructed model possesses its own shortcomings which could be amended in the future. In the case of the Lithuanian manufacturing industry, these shortages consist of data scarcity in the case of a few variables and a relatively short timeframe for the gathered data. With more data becoming available, the precision of the constructed model can be further improved.

SUMMARY

ĮVADAS

Tyrimo aktualumas

Ekonominis vystymasis yra aktuali, kartu ir labai kompleksiška tema. Augimą vertinanti ekonomikos mokslo šaka ne tik tiria agreguotų pagamintos produkcijos apimčių kitimą, tačiau kartu ir analizuoja svarbius ekonominius reiškinius, tokius kaip sektorių struktūros pokyčiai, demografiniai bei geografiniai veiksniai, bandydama paaiškinti jų sąsają su socialine ir institucine aplinkomis (Acemoglu, 2012). Dėl to, kad ekonominis augimas gali būti vertinamas skirtingais aspektais, egzistuoja galybė įvairiausių metodologijų siekiant atsakyti į svarbius ekonominio vystymosi klausimus. Ekonominio augimo teorijos taip pat padeda analizuoti technologinės pažangos bei kuriamų inovacijų poveikį ekonominiam vystymuisi bei socialinės gerovės raidai.

Ekonominio vystymosi teorijų raida užtruko, kol susiformavo šiuolaikinė ekonominio augimo vertinimo koncepcija. Pačiose ekonomikos teorijos ištakose Adamas Smitas savo knygoje „Tautų turto prigimties ir priežasčių tyrinėjimas“ (angl. *„Wealth of Nations“*) ekonominį augimą analizavo kaip griežtai endogeninį procesą, pabrėždamas kapitalo kaupimo bei darbo produktyvumo svarbą ekonominio vystymosi tęstinumui (Kurz, Salvadori, 2003). Tiesa, pagal Adamą Smitą, jokia viršutinė darbo produktyvumo augimo riba nebuvo apibrėžta, o vienintelės darbo produktyvumo augimą ribojančios priežastys buvo nusakomos kaip nepakankama darbuotojų pasiūla, baigtiniai gamtiniai ištekliai arba nykstanti kapitalo kaupimo motyvacija, neįvertinant laikui bėgant mažėjančios kapitalo grąžos galimybės. Davidas Rikardas, analizuodamas ekonominio vystymosi klausimą, kapitalo kaupimą vertino kaip endogeninį reiškinį, nors, jo požiūriu, pagrindinė pusiausvyros būsenos susiformavimo priežastis buvo ribota žemės kaip ištekliaus pasiūla, kartu darant prielaidą, jog gamybos veiksniai yra nekintami ir per laiką generuoja pastovią grąžą.

Laikui bėgant ekonominio vystymosi teorijos tobulėjo ir ėmė atmesti ekonominės teorijos pradininkų iškeltą pastovios kapitalo grąžos bei potencialiai nenutrūkstamo augimo prielaidą. Neoklasikinės ekonominio augimo teorijos siekia aiškinti ekonominį augimą bei pajamų pasiskirstymo klausimą vertinant gamybos išteklių, tokių kaip kapitalas ar darbas, pakankamumą. Pats svarbiausias neoklasikinių ekonomikos augimo teorijų aspektas yra laikui bėgant mažėjanti investuojamo fizinio kapitalo bei darbo grąža ir jų poveikis struktūrinėms ekonomikos pusiausvyros būsenos charakteristikoms bei asimptotiniam stabilumui (Solow, 1999). Šumpeterinė ekonominio augimo vertinimo koncepcija bandė dar labiau patobulinti ekonominio vystymosi sampratą, bandydama akcentuoti inovacijų svarbą siekiant išlaikyti ekonominį augimą ilguoju laikotarpiu (Aghion, Festre, 2017). Šumpeterio iškelta teorija traktuoja inovacijas kaip investicijų į mokslinius tyrimus ir plėtrą rezultatą. Naujos technologijos, sukurtos pasitelkiant inovacijas, paverčia gamybos procese naudojamas technologijas pasenusiomis bei neefektyviomis. Taip technologinės pažangos veiksnys ekonominio vystymosi kontekste įgyja endogeninį pobūdį, kitaip nei neoklasikiniuose ekonominio augimo modeliuose.

Dar vėliau ekonominio augimo teorija buvo papildyta žmogaus socialinės raidos bei darnaus vystymosi koncepcijomis, taip didesnį dėmesį atkreipiant į natūraliųjų išteklių efektyvesnį panaudojimą bei aplinkosaugos klausimus, žmonių gyvenimo kokybės gerinimo aspektus (Costantini, Monni, 2008). Moderniose ekonominio vystymosi teorijose vis labiau akcentuojamas tvarus ekonominis augimas, siekiant, kad gyvenimo kokybės gerinimas šiandien nebūtų pasiektas ateinančių kartų gerovės sąskaita.

Ši ekonominio vystymosi raidos analizė parodė, kad bėgant laikui ekonominio augimo problema visada išliko aktuali, tačiau pačios augimo vertinimo teorijos vystėsi kartu su besikeičiančiomis skirtingų laikotarpių aktualijomis. Todėl svarbu ir toliau tobulinti ekonominio augimo vertinimo metodiką, derinant ją prie sparčiai kintančios ekonominės aplinkos.

Apdirbamoji pramonė yra ypač svarbi ekonominio augimo analizės dedamoji. Apdirbamosios pramonės sektoriai reikšmingai prisideda prie ekonominės, socialinės, aplinkosauginės bei institucinės aplinkų vystymosi, kurdami pamatus globalizacijos bei tarptautinės prekybos plėtrai, vystydami efektyvesnius žaliavinių išteklių panaudojimo gamybos procese metodus, veikdami žmogiškojo kapitalo vystymąsi bei sukuriamų inovacijų gausėjimą (Behun ir kt., 2018). Istoriniu požiūriu užfiksuota nemažai atvejų, kai technologinės pažangos vystymosi paspartėjimas kilo dėl apdirbamosios pramonės sukurtų inovacijų. Todėl yra svarbu įtraukti apdirbamąją pramonę į ekonominio vystymosi vertinimo procesą ir detaliau išanalizuoti apdirbamosios pramonės veiksnių poveikį technologinės pažangos augimui.

Mokslinės problemos ištirtumas

Kiekviena ekonominio augimo teorija turi teigiamų bei kritikuotinų aspektų. Klasikinės augimo teorijos pagal šių dienų standartus yra pasenusios dėl to meto riboto ekonomikos procesų suvokimo. Klasikinės ekonomikos augimo teorijos vystymosi laikais dominavo agrarinė ekonomika, o radikalių pokyčių produkcijos gamybos procesuose nebuvo pastebima (Harris, 2007). Todėl klasikinės teorijos gerokai nuvertino technologinės pažangos poveikį ekonominiam vystymuisi ir produktyvumo gerinimui apdirbamosios pramonės bei žemės ūkio sektoriuose.

Neoklasikinės ekonominio augimo teorijos turi savų trūkumų, kuriuos galima būtų ištaisyti. Solow neoklasikinio augimo modelyje technologinės pažangos rodiklis yra vertinamas kaip egzogeninis veiksnys, todėl daroma prielaida, kad technologinė pažanga laikui bėgant kinta tam tikru pastoviu tempu (Jones, Vollrath, 2013). Dėl šios priežasties technologinės pažangos rodiklis gali būti klaidinantis vertinant veiksnius, lemiančius ekonominį augimą ilguoju laikotarpiu (Barro, Sala-i-Martin, 2004). Neoklasikiniai ekonominio augimo modeliai taip pat aiškina, kad besiskiriančios investuojamo kapitalo normos tarp skirtingų rinkų lemia ekonominį suartėjimą arba nutolimą, tačiau neanalizuoja kitų veiksnių, lemiančių ekonominės nelygybės susidarymą (Weil, 2013). Galiausiai, ekonominio vystymosi priežastys neoklasikinio ekonominio augimo modeliuose yra aiškinamos pasitelkiant pasiūlai įtaką darančius veiksnius, o paklausą veikiantys veiksniai lieka nenagrinėti (Landreth, Colander, 2001).

Endogeninio augimo teorijos stengiasi pašalinti neoklasikinių ekonomikos augimo modelių trūkumus, tačiau susiduria su jiems būdingomis problemomis. Dažniausia kritika, kurios susilaukia endogeninio augimo modeliai, yra susijusi su ekonomikos dalyvių elgsenos modeliavimu bei pusiausvyros būsenos neigimu vertinant ekonominio vystymosi raidą (Alcouffe, Kuhn, 2004). Endogeninio augimo teorijos taip pat atsisako tobulos konkurencijos rinkos modelio ir žinias laiko visiems rinkoje viešai prieinamu produktu, taip per bendrą inovacijų kūrimo procesą užsitikrinant didėjančią gamybos masto grąžą (Cavusoglu, Tebaldi, 2006).

Vis didesnio populiarumo susilaukiančios darnaus augimo teorijos taip pat nėra atsparios kritikai. Darnaus augimo teorijos dažnai plačiai žvelgia į įvairiuose sektoriuose iškylančias problemas, o jų siūlomi į darnią plėtrą orientuoti sprendimai dažniausiai nukreipti į trumpąjį laikotarpį (Gaziulusoy, 2015). Kad tvaraus augimo rodikliai galėtų būti tinkamiau integruoti į ekonominės plėtros metodologiją, reikia vieningesnio požiūrio dėl tvarų augimą vertinančių rodiklių naudojimo (Moffatt, 2000).

Visos ekonominį augimą analizuojančios teorijos susiduria su tam tikrais neapibrėžtumais, atsirandančiais dėl noro vertinant ekonominę plėtrą pabrėžti tuo metu aktualią savitą problematiką. Populiariausios ekonominio augimo teorijos arba vertina technologinės pažangos rodiklį kaip egzogeninį veiksnį, arba detaliai neanalizuoja, kaip skirtingų veiksnių kaita lemia technologinės pažangos rodiklio pokyčius. Tai apriboja suvokimą, kaip technologinės pažangos rodiklio vertės kinta laike, ir sunkina ekonominio vystymosi analizę. Atliktas tyrimas siekia pašalinti apibūdintus ekonominio vystymosi teorijų trūkumus gerinant technologinės pažangos rodiklio vertinimo metodologiją apdirbamosios pramonės kontekste.

Tyrimo objektas – apdirbamosios pramonės sektorius bei apdirbamosios pramonės sektoriaus technologinės pažangos dinaminė kaita.

Tyrimo tikslas

Sukonstruoti technologinės pažangos veiksnių apdirbamojoje pramonėje vertinimo modelį, kuris padėtų įvertinti, kokią įtaką besikeičiantys apdirbamosios pramonės sektoriaus veiksniai daro technologinės pažangos rodiklių svyravimams.

Tyrimo uždaviniai

1. Išskirti tinkamiausius technologinės pažangos rodiklių skaičiavimo metodus.
2. Pagrįsti veiksnius, darančius stipriausią poveikį apdirbamosios pramonės vystymuisi bei technologinės pažangos rodiklių kaitai.
3. Suformuoti apdirbamosios pramonės sektorių technologinės pažangos rodiklių nustatymo metodologiją.
4. Sukonstruoti modelį, kuris įtrauktų technologinės pažangos rodiklių verčių nustatymą, technologinės pažangos sklaidos efekto apdirbamojoje pramonėje vertinimą bei technologinės pažangos rodiklių funkcinių formų apibrėžimą.
5. Praktiškai pritaikyti sukonstruotą modelį atliekant Lietuvos apdirbamosios pramonės situacijos vertinimą jautrumo analizės metodu.

Tyrimo metodai

Sisteminis mokslinės literatūros analizės metodas buvo pritaikytas atrenkant apdirbamosios pramonės veiksnius, galimai darančius įtaką technologinės pažangos verčių kaitai, išskiriant pagrindinius ekonominio vystymosi teorijų trūkumus ir atrenkant tinkamiausias technologinės pažangos rodiklių reikšmių apskaičiavimo metodikas.

Technologinės pažangos vertėms apskaičiuoti buvo panaudotas laiko eilučių regresijos metodas. Laiko eilučių regresijos modeliai sukonstruoti remiantis Solow neoklasikinio ekonominio augimo modelio pagrindu. Technologinės pažangos sklaidos efektui nustatyti tarp Lietuvos apdirbamosios pramonės sektorių panaudotas Grangerio priežastingumo testas. Funkcijoms, nusakančioms įvairių apdirbamosios pramonės veiksnių poveikį technologinės pažangos kaitai, formuoti naudotas vektorinės autoregresijos modelis. Jautrumo analizė atlikta remiantis agentais grįsto modeliavimo metodologija.

Visi įvardinti ekonometrijos modeliai bei statistinės analizės metodai buvo panaudoti pasitelkiant R programavimo kalbos kodą. Disertacijoje pateiktos lentelės ir grafikai buvo suformatuoti naudojantis *Microsoft Excel* programa.

Mokslinio tyrimo naujumas bei pritaikomumas

Disertacijos metu sukonstruotas modelis paremtas Solow neoklasikine ekonominio augimo teorija. Tyrimo modelis yra praplėsta bei patobulinta Solow ekonominio augimo versija, jame technologinės pažangos parametras yra analizuojamas kaip endogeninis kintamasis. Toks technologinės pažangos rodiklio vertinimas ne tik padeda įvertinti technologinės pažangos poveikį pagaminamos produkcijos apimčiai, bet ir atlikti veiksnių, darančių įtaką technologinės pažangos svyravimams, analizę.

Svarbi sukonstruoto modelio dalis yra galimybė atskirti technologinės pažangos sklaidos efekto įtaką technologinės pažangos rodiklių kaitai nuo kitų vidinių apdirbamosios pramonės veiksnių poveikio. Tai pasiekti padeda į tyrimo modelį integruota agentais grįsto modeliavimo metodologija. Agentais grįsto modeliavimo metodika yra pakankamai nauja ekonomikos mokslo tyrimuose, ypač vertinant ekonominę pažangą, tačiau šios metodikos įtraukimas palieka vietos tolimesniam sukonstruoto modelio tobulinimui.

Teorinė akademinės literatūros analizė bei sistematizavimas buvo pasitelkti siekiant nustatyti ekonominio augimo teorijų aspektus, padedančius atliekant ekonominio vystymosi vertinimą, išskiriant veiksnius, potencialiai darančius stipriausią poveikį technologinės pažangos vystymosi raidai, ir aprašant tinkamiausią technologinės pažangos rodiklių verčių nustatymo metodiką. Atliktos teorinės analizės rezultatai taip pat padėjo išskirti esminius ekonominio augimo teorijų trūkumus, pagal kuriuos metodologinėje tyrimo dalyje buvo priimami unikalūs sprendimai apibrėžtiems trūkumams šalinti technologinės pažangos rodiklio vertinimo kontekste.

Disertacijos metu sukonstruotas technologinės pažangos vertinimo modelis taip pat gali būti personalizuotas skirtingų šalių apdirbamosios pramonės sektoriams vertinti. Tai gali būti atliekama įtraukiant papildomus apdirbamosios pramonės lygmens kintamuosius į lygtis, nusakančias skirtingų veiksnių poveikį technologinės pažangos kaitai, bei papildant modelį elgsenos parametrais, padedančiais geriau apibrėžti konkrečiame apdirbamosios pramonės sektoriuje vykstančius procesus.

Disertacijos struktūra

Disertaciją sudaro 150 lapai, 16 lentelių, 24 paveikslėliai ir 83 formulės, atliekant tyrimą remtasi 125 moksliniais šaltiniais. Disertacijos struktūrą sudaro įvadas, trys dėstymo dalys ir išvados. Įvade pristatomas tyrimo aktualumas, nagrinėjama mokslinė problema, pristatomas tyrimo objektas, tikslas, išvardinami uždaviniai, aprašyti tyrime naudojami metodai, pateikiamas tyrimo naujumas bei praktinis pritaikomumas.

Pirmojoje, teorinėje, disertacijos dėstymo dalyje pristatoma, kaip įvairios ekonominio augimo teorijos vertina bei analizuoja technologinės pažangos rodiklio kaitą, kaip technologinės pažangos svyravimai lemia pagaminamos produkcijos apimčių pokyčius. Šioje dalyje taip pat nagrinėjami rodikliai, kurie pagal įvairias mokslinėje literatūroje aprašytas teorijas gali nulemti technologinės pažangos rodiklio vystymosi raidą. Apibūdinama technologinės pažangos rodiklių įvertinimo bei apskaičiavimo metodika.

Antrojoje, metodologinėje, tyrimo dėstymo dalyje suformuojamas disertacijos modelis. Patį modelį sudaro keturios pagrindinės dalys: technologinės pažangos vertinimas; technologinės pažangos sklaidos efekto nustatymas tarp sektorių, veikiančių apdirbamojoje pramonėje; funkcinio ryšio tarp technologinės pažangos rodiklio bei apdirbamosios pramonės veiksnių nustatymas; jautrumo analizės, kuria įvertinama, kaip skirtingų apdirbamosios pramonės veiksnių kaita veikia technologinės pažangos rodiklių svyravimus, atlikimas.

Trečiojoje, empirinėje, disertacijos dalyje pristatoma Lietuvos apdirbamosios pramonės atvejo analizė, kur sukonstruotas modelis pritaikomas technologinės pažangos reikšmėms nustatyti ir analizuoti. Tyrimo uždavinių sprendimai pateikti išvadose.

Tyrimo rezultatai buvo publikuoti 4 moksliniuose žurnaluose ir pristatyti 4 tarptautinėse mokslinėse konferencijose.

1. TECHNOLOGINĖ PAŽANGA EKONOMINIO AUGIMO TEORIJOSE IR VEIKSNIAI, DARANTYS ĮTAKĄ TECHNOLOGINĖS PAŽANGOS RAIDAI

1.1. Technologinės pažangos svarba ekonominio augimo teorijose

Teorinė disertacijos dalis pradedama ekonomikos augimo teorijų analize. Apžvalgai pasirinktos dvi ekonominio augimo teorijos: neoklasikinė ekonominio augimo teorija bei endogeninė ekonominio augimo teorija. Literatūros analizei pasirinktos būtent šios augimo teorijos, kadangi jose ypatingo dėmesio sulaukia bei svarbų vaidmenį atlieka technologinės pažangos rodikliai.

1.1.1. Technologinės pažangos vertinimas bei analizė Solow neoklasikinio ekonominio augimo teorijoje

Yra kelios pagrindinės savybės, kuriomis turi pasižymėti modelis, kad galėtų būti priskiriamas neoklasikinio ekonominio augimo metodologijai (Barro, Sala-i-Martin, 2004):

- Neoklasikinio ekonominio augimo funkcijos pasižymi stabilia gamybos masto grąža, kaip pavaizduota lygtyje:

$$F(\lambda K, \lambda L, T) = \lambda * F(K, L, T) \qquad \textbf{(1)}$$

1 lygtyje pateikta savybė, dar kitaip vadinama pirmo laipsnio homogeniškumu. Pagrindinis šios savybės akcentas yra koeficientas λ, kuris pateiktas prie kapitalo (K) bei darbo jėgos (L) parametro, tačiau ne prie technologinės pažangos (T). Tai reiškia, kad bet koks kapitalo ir darbo jėgos išteklių padidėjimas, technologinės pažangos parametrui liekant stabiliam, nulemia tokio paties dydžio pagamintos produkcijos apimties padidėjimą.

- Neoklasikinės augimo teorijos modeliuose pastebima mažėjanti pagaminamos produkcijos grąža augant gamybos procese naudojamų išteklių kiekiui:

$$\frac{\partial F}{\partial K} > 0, \quad \frac{\partial^2 F}{\partial K^2} < 0 \quad ; \quad \frac{\partial F}{\partial L} > 0, \quad \frac{\partial^2 F}{\partial L^2} \qquad \textbf{(2)}$$

- Kita neoklasikinės ekonomikos augimo teorijos sąlyga – gamyboje naudojamų išteklių marginalumo efektas, pavaizduotas lygtyje:

$$\lim_{K\to 0}\left(\frac{\partial F}{\partial K}\right) = \lim_{L\to 0}\left(\frac{\partial F}{\partial L}\right) = \infty; \ \lim_{K\to \infty}\left(\frac{\partial F}{\partial K}\right) = \lim_{L\to \infty}\left(\frac{\partial F}{\partial L}\right) = 0 \qquad \textbf{(3)}$$

- Paskutinė neoklasikinėms ekonominio augimo teorijoms būdinga savybė – gamybos funkcijos būtinumo prielaida, pateikta 4 lygtyje:

$$F(0, L) = F(K, 0) = 0 \qquad \textbf{(4)}$$

Neoklasikinėje ekonominio augimo teorijoje vienas iš pagrindinių rodiklių, nusakančių ekonomikos augimo greitį, yra kapitalo prieaugio, tenkančio vienam darbuotojui, rodiklis (Aghion, Garcia-Penalosa, Howitt, 2004). Šį rodiklį galima apibrėžti pateikta lygtimi:

$$\dot{k} = s * F[k, T(t)] - (n + \delta) * k \qquad \textbf{(5)}$$

Pagal pateiktą 5 lygtį, kapitalo apimtys ekonomikoje auga dėl taupymo normos s ir gamybos funkcijos $F[k, T(t)]$ rodiklių kaitos. Svarbi gamybos funkcijos dedamoji yra technologinės pažangos rodiklis $T(t)$, kuris, pagal Solow neoklasikinio augimo teoriją, auga pastoviu tempu laike. O kapitalo, tenkančio vienam darbuotojui, augimo tempą mažina darbo jėgos augimo tempas, pavaizduotas kaip n, ir kapitalo nusidėvėjimo normos rodiklis, pateiktas kaip δ.

Dažniausiai neoklasikiniuose ekonominio augimo modeliuose gamybos funkcija būna pateikiama Cobb-Douglas gamybos funkcijos pagrindu (Aghion, Garcia-Penalosa, Howitt, 2004):

$$Y_t = AK_t^{\alpha} L_t^{\beta} \; ; \; \alpha, \beta \; \geq 0 \qquad \textbf{(6)}$$

Pagal pateiktą 6 lygtį, pagamintos produkcijos apimtis ir jų kaitą laike lemia kapitalo, darbo jėgos bei technologinės pažangos (A) rodikliai. Technologinės pažangos rodiklis yra laikomas darbą taupančiu parametru, kadangi, augant technologinei pažangai, toks pats pagaminamos produkcijos kiekis gali būti pasiekiamas su mažesniais gamybos procese naudojamų ištekių kiekiais (Novales, Fernandez, Ruiz, 2009).

Akademinės literatūros analizė padėjo išskirti dažniausiai minimus neoklasikinės ekonominio augimo teorijos trūkumus:

- Solow neoklasikinėje ekonominio augimo teorijoje vienintelis veiksnys, be darbo jėgos, veikiantis pagamintos produkcijos apimtis, yra kapitalas (Weil, 2013). Kiti pasiūlos veiksniai, kurie galėtų veikti pagaminamos produkcijos apimtis, į neoklasikines ekonominio augimo teorijas neįtraukiami (Aghion, Garcia-Penalosa, Howitt, 2004).
- Technologinės pažangos rodiklis neoklasikinėse ekonominio augimo teorijose yra traktuojamas kaip egzogeninis kintamasis. Vietoje to, kad technologinės pažangos vertės būtų sumodeliuojamos, yra daroma prielaida, kad technologinė pažanga auga tam tikru pastoviu tempu laike (Jones, Vollrath, 2013). Tokio pobūdžio technologinės pažangos rodiklio integravimas į ekonominio augimo modelį gali privesti prie netinkamų išvadų dėl ilgalaikio ekonomikos augimo priežasčių (Barro, Sala-i-Martin, 2004).
- Solow neoklasikinis ekonominio augimo modelis identifikuoja, kad skirtingos investicijų normos rinkose veda arba prie ekonominio augimo normų suartėjimo, arba prie nutolimo, tačiau netiria priežasčių, kurios lemia investicijų normų skirtumus (Weil, 2013).
- Vertinant ekonominę plėtrą, neoklasikinio ekonominio augimo teorijos analizuoja tik pasiūlos veiksnių poveikį. Į ekonominės plėtros vertinimo procesą neįtraukiami skirtumai, susidarę dėl paklausos veiksnių nulemtų skirtingų augimo tempų (Landreth, Colander, 2001).

1.1.2. Technologinės pažangos analizė endogeninio augimo teorijoje

Endogeninio augimo teorijos stengiasi išspręsti dalį neoklasikinių ekonominio augimo modelių problemų. Bazinė endogeninio augimo teorijos versija yra AK modelis, kuris pagamintos produkcijos apimčių augimą aiškina pasitelkęs kapitalo kaupimo ir technologinės pažangos augimo efektus (Aghion, Howitt, 2009). Pagrindinis skirtumas nuo neoklasikinių ekonominio augimo teorijų yra technologinės pažangos rodiklio interpretavimas. Endogeninio augimo teorijose į technologinės pažangos rodiklį įtraukiamas intelektualinio kapitalo veiksnys, kuris leidžia atsisakyti mažėjančios pagaminamos produkcijos grąžos efekto, vyraujančio neoklasikiniuose augimo modeliuose. Investuojant sukauptą kapitalą į technologinės pažangos vystymą, generuojamas intelektualinis kapitalas, kuris skatina tolimesnį technologinės pažangos augimą. AK modelio gamybos funkcija pateikta lygtyje (Aghion, Howitt, 2009):

$$Y = AK \tag{7}$$

Pagal endogeninius ekonominio augimo modelius, ilguoju laikotarpiu technologinės pažangos rodiklio vertė nusistovi ir tampa stabili, kaip pavaizduota 8 lygtyje (Baldwin, Braconier, Foslid, 2005):

$$\gamma_c \sigma + \theta = A - (\delta + n) \tag{8}$$

Šios lygties kairėje pusėje esantys parametrai kartu indikuoja vartojimo augimo tempo kaitą laike, o dešinėje pusėje esantys kintamieji yra perkelti iš neoklasikinės ekonominio augimo teorijos ir atspindi technologinę pažangą A, kapitalo nusidėvėjimo normą δ, bei darbo jėgos augimo tempą n.

Šumpeterio endogeninis augimo modelis į ekonominio augimo analizę įtraukia ir mokslinių tyrimų bei plėtros kintamąjį. Moksliniai tyrimai ir plėtra gali būti išnaudojami efektyvesniam darbo jėgos panaudojimui arba tolimesniam mokslinių tyrimų ir plėtros generavimui (Englmann, 1994). Darbo jėgos poreikis, reikalingas mokslinių tyrimų bei plėtros kūrimui, nusakomas pagal pateiktą lygtį:

$$L^R = s^R * P * \frac{1}{w} \tag{9}$$

Pagal 9 lygtį, $s^R * P$ uždirbta įmonės pelno dalis yra reinvestuojama į tolimesnį mokslinių tyrimų ir plėtros vystymą, siekiant generuoti technologinę pažangą kuriančias inovacijas. Lygtyje w parametras identifikuoja darbo užmokestį, kuris pagal modelį yra laikomas vienodas visiems darbuotojams.

Endogeninio augimo teorijos požiūriu, kiekviename pramonės sektoriuje yra tam tikros įmonės, kurios dėl savo inovacijų yra gaminamos produkcijos kokybės lyderės. Įmonei patapus kokybės lydere, pagamintos produkcijos elastingumo kapitalo atžvilgiu vertė tampa lygi 1. Paskata investuoti į mokslinius tyrimus ir plėtrą bei kurti inovacijas – rinkos kokybės lyderio generuojama monopolistinė pelno norma (Chu, Cozzi, Furukawa, Liao, 2017), pavaizduota lygtyje:

$$\Pi_t(\omega, j_\omega) = [\lambda_t(\omega) - 1] * y_t(\omega, j_\omega) = \left[\frac{\lambda_t(\omega) - 1}{\lambda_t(\omega)}\right] * (1 - \theta) Y_t \tag{10}$$

Pateiktoje 10 lygtyje parametras $y_t(\omega, j_\omega)$ nurodo tarpinės produkcijos gamybos funkciją esant $\lambda_t(\omega)$ pusiausvyros kainai. Lygtyje parametras ω identifikuoja skirtingų sektorių pramonėje skaičių, kurie tarpusavyje dalijasi monopolistinį pelną, taip darant prielaidą, kad per pelną, reinvestuotą į mokslinius tyrimus bei plėtrą, technologinės pažangos sklaidos efektas generuoja technologinę pažangą visai pramonei.

Šumpeterio ekonominio augimo teorija kartu akcentuoja ir gamybos proceso specializaciją. Kai įmonės skaido savo mokslinių tyrimų ir plėtros išlaidas skirtingų produktų technologijos vystymui, tai susilpnina kuriamų inovacijų poveikį technologinės pažangos plėtrai bei sumažina technologinės pažangos augimo tempus (Ha, Howitt, 2007). Visa tai pateikiama lygtyje:

$$g_A = \lambda(\frac{X}{Q})^{\sigma} \quad \textbf{(11)}$$

11 lygtyje rodiklis Q nurodo skirtingų gamybos technologijos gaminamų produktų apimtį, o kintamais σ pateikia technologinės pažangos augimo tempo elastingumą mokslinių tyrimų ir plėtros išlaidoms.

1.2. Technologinės pažangos vertes veikiančių veiksnių identifikavimas

Mokslinės literatūros analizė parodė, kad egzistuoja veiksnių, potencialiai darančių įtaką technologinės pažangos rodiklių kaitai laike, įvairovė. Pirmoje lentelėje pateikiamas šių veiksnių sąrašas.

1 lentelė. Veiksniai, darantys įtaką technologinės pažangos rodiklių kaitai laike

Veiksniai	Šaltiniai
Generuojamas pelnas / Kapitalo kaštai	Grant, 2003; Damodaran, 2012; Rao, Stevens, 2007; Fabozzi, Drake, 2009; Kumar, 2016
Investuojamas kapitalas / Tiesioginės užsienio investicijos	Wang, Wong, 2016; Gugler, Brunner, 2007; Chaudhuri, Mukhopadhyay, 2014; Meon, Sekkat, 2012; Seck, 2012
Kapitalo struktūra	Li, Niskanen, Niskanen, 2018; Miglo, 2011; Rao, Stevens, 2007; Cekrezi, 2013; Leary, Roberts, 2010
Finansinis likvidumas	Nanda, Panda, 2017; Yu-Thompson, Lu-Andrews, 2016; Michalski, 2010; Anderson, Carverhill, 2012; Wang, 2012
Konkurencingumas užsienio rinkose	Raza, Karim, 2017; Fortunato, Razo, 2014; Dreger, Herzer, 2013; Vernon, 2004; Hsu, Li, 2009
Energijos panaudojimo gamybos procese efektyvumas	Ozokcu, Ozdemir, 2017; Cantore, Cali, Velde, 2016; Shahbaz *et al.*, 2013; Ahmed, 2017; Zhang *et al.*, 2013; Feng, Wang, 2017

Toliau apžvelgiamos teorijos, kurios nusako, kaip 1 lentelėje pateikiami veiksniai gali veikti technologinės pažangos rodiklių svyravimus laike.

1.2.1. Generuojamo pelno bei kapitalo kaštų poveikis technologinės pažangos rodiklių kaitai

Anksčiau apibūdinta Šumpeterio endogeninio augimo teorija pabrėžia, jog dėl inovacijų išaugęs generuojamas pelnas gali būti investuojamas į mokslinius tyrimus bei plėtrą, taip spartinant technologinę pažangą bei kuriant naujas inovacijas. Pagrindinis įmonės vertės kūrimo būdas yra gebėjimas atsirinkti investicinius projektus, į kuriuos reinvestuojami įmonės generuojami pinigų srautai gali generuoti grąžą, viršijančią kapitalo kaštų normą (Subramanyam, 2014). Pagrindinis ir dažniausiai naudojamas rodiklis, vertinantis įmonių kuriamą vertę, yra pridėtinė ekonominė vertė, apskaičiuojama pagal pateiktą lygtį (Grant, 2003):

$$EVA = NOPAT - Capital * WACC \quad \textbf{(12)}$$

12 lygtyje *NOPAT* reiškia grynąjį veiklos pelną po mokesčių, o *WACC* – svertinius vidutinius kapitalo kaštus. Bet koks investicinis projektas kuria ekonominę vertę, jeigu $EVA > 0$ sąlyga yra patenkinama. Svertiniai vidutiniai kapitalo kaštai detalizuojami pagal lygtį (Damodaran, 2012):

$$WACC = w_E * r_E + w_D * r_D * (1 - T) \quad \textbf{(13)}$$

1.2.2. Investuojamo kapitalo bei tiesioginių užsienio investicijų poveikis technologinės pažangos kaitai

Vienas iš svarbiausių neoklasikinės ekonominio augimo teorijos rodiklių yra kapitalo kaupimo norma. Per laiką kapitalas nusidėvi, ir yra svarbu reinvestuoti į kapitalo atkūrimą, kad būtų palaikoma pagaminamos produkcijos norma ir nemažėtų ir gamybos veiklos generuojamos pajamos. Investiciniai sprendimai kartu yra svarbūs ir dėl neoklasikinėje ekonominio augimo teorijoje vyraujančio mažėjančios pagaminamos produkcijos grąžos efekto.

Pasinaudojant tiesioginėmis užsienio investicijomis galima perduoti materialų turtą, tokį kaip įrengimai ir technika, ir nematerialų turtą, tokį kaip procesų valdymo metodai bei intelektinis kapitalas, iš vienos rinkos į kitą (Wang, Wong, 2016). Tinkamai įsisavinus tiesioginių užsienio investicijų būdu perduodamą kapitalą, gali vykti technologinės pažangos perdavimas iš labiau technologiškai išsivysčiusios rinkos į mažiau išsivysčiusią rinką. Tarpindustrinis technologinės pažangos sklaidos efektas gali būti pasiektas trimis pagrindiniais būdais: demonstracijos, mokymų, konkurencijos (Gugler, Brunner, 2007). Technologinės pažangos sklaida pramonės viduje gali atsirasti dėl susidariusių vertikalių ryšių tarp sektorių.

Kiti veiksniai, lemiantys technologinės pažangos sklaidos efektą, yra investicijų į žmogiškąjį kapitalą apimtys (Kopf, 2007), institucinė bei politinė aplinka (Belkhir, Boubakri, Grira, 2017), ekonominio ciklo fazės (Crafts, 2017).

1.2.3. Kapitalo struktūros poveikis technologinei pažangai

Esant tobuloms rinkos sąlygoms, kapitalo struktūra neturėtų veikti įmonių pridėtinės vertės kūrimo proceso, tačiau egzistuoja įvairios teorijos, kurios tikina, kad tam tikrais atvejais netinkamas nuosavo bei skolinto kapitalo santykis gali sukurti sunkumų pritraukiant investicinį kapitalą tolimesnei plėtrai arba padidinti kapitalo kainą, dėl ko gali būti atmetami inovacijas kuriantys projektai, kurie kitomis sąlygomis galėtų būti įgyvendinami (Li, Niskanen, Niskanen, 2018).

Kompromiso teorija teikia siūlymą, kad įmonės priima sprendimus dėl kapitalo struktūros nustatymo, laviruodamos tarp skolinto kapitalo didinimo, besistengdamos pasinaudoti mokesčių skydo efektu, tačiau ir per stipriai nesumažindamos nuosavo kapitalo dalies kapitalo struktūroje, taip neiškeldamos skolinto kapitalo kainos dėl potencialiai augančios bankroto rizikos. Kompromiso teoriją nusako pateikta formulė (Miglo, 2011):

$$V_d + V_e = \frac{\bar{R}-D}{\bar{R}} D + \frac{D}{\bar{R}} \frac{D(1-k)}{2} + \frac{\bar{R}-D}{\bar{R}} \left(\frac{\bar{R}+D}{2} - D \right) (1 - T) \qquad \textbf{(14)}$$

14 lygtyje pateiktas įmonės kuriamos vertės skaidymas į vertę, sukurtą dėl nuosavo kapitalo investicijų, bei vertės, sukurtos panaudojant skolintą kapitalą. Šioje lygtyje $\bar{R}$ parametras identifikuoja generuojamus pinigų srautus, T – pelno mokesčio normą, D – įmokas skoliniams įsipareigojimams padengti. Lygties dalis $\frac{\bar{R}-D}{\bar{R}} D + \frac{D}{\bar{R}} \frac{D(1-k)}{2}$ identifikuoja skolinio kapitalo poveikį vertės kūrimo procese, kur $\frac{\bar{R}-D}{\bar{R}}$ yra tikimybė, kad pinigų srautai padengs skolinių įsipareigojimų įmokas, o $\frac{D}{\bar{R}}$ – bankroto patyrimo tikimybė. 15 lygties dalis $\frac{\bar{R}-D}{\bar{R}} \left(\frac{\bar{R}+D}{2} - D \right) (1 - T)$ nurodo, kaip nuosavas kapitalas prisideda prie įmonės vertės kūrimo. Vertę maksimizuojanti skolinto kapitalo dalis visame kapitale gali būti apibrėžta pagal lygtyje pateiktą išraišką (Miglo, 2011):

$$D = \frac{T\bar{R}}{T+1-k} \qquad \textbf{(15)}$$

1.2.4. Finansinio likvidumo poveikis technologinės pažangos plėtrai

Egzistuoja dvi pagrindinės teorijos, grindžiančios, kad likvidumo rodiklių reikšmės daro įtaką įmonių generuojamam pelnui, o per pelną ir įmonių kuriamai vertei (Nanda, Panda, 2017). Pirmosios teorijos teigimu, per didelis neįdarbinto likvidaus turto kiekis mažina įmonės kuriamą pridėtinę vertę dėl didelių alternatyviųjų kaštų. Tai gali lemti per žemo investicijų lygio bei potencialios kuriamos vertės praradimą. Kita teorija teigia, kad per žemas disponuojamo likvidaus turto lygis gali lemti prarandamą pelną.

Priimami likvidaus turto valdymo sprendimai veikia įmonių generuojamus grynuosius pinigų srautus, taip darydami įtaką vertės kūrimo procesui, kaip pavaizduota lygtyje (Michalski, 2010) :

$$\Delta V_p = \sum_{t=1}^{n} \frac{\Delta FCFF_t}{(1+k)^t} \qquad \textbf{(16)}$$

16 lygtyje pateiktas parametras $\Delta FCFF_t$ identifikuoja grynųjų pinigų srautų pokytį, kuris gali susidaryti dėl besikeičiančių rinkos veiksnių arba priimamų strateginių sprendimų įmonės lygmeniu. Rodiklis k nurodo investuojamų pinigų srautų kapitalo kaštus.

Pagal Wang (2002), sprendimai dėl disponuojamo likvidaus kapitalo apimčių įmonės lygmeniu gali veikti įmonės vertę dviem būdais. Visų pirmiausia, įmonės privalo palaikyti pakankamą likvidaus turto rezervą, kad nekiltų rizikos dėl galimo skolinių įsipareigojimų nevykdymo. Auganti potencialaus bankroto rizika gali didinti ateities investicijų kapitalo kaštus bei apsunkinti tolimesnei plėtrai reikiamų finansų lėšų pritraukimą.

1.2.5. Konkurencingumo užsienio rinkose didinimo poveikis technologinės pažangos raidai

Vertindami skirtingas teorijas, analizuojančias eksporto poveikį ekonominiam augimui, mokslininkai nesutaria, kuris veiksnys daro reikšmingesnį poveikį kitam veiksniui. Vienos teorijos teigia, kad eksporto pajamų augimas bei konkurencinės padėties gerėjimas tarptautinėse rinkose lemia technologinės pažangos augimą, kitos siūlo, kad išaugęs konkurencingumas tarptautinėse rinkose yra augančios technologinės pažangos rezultatas, tačiau nėra jokių ginčų dėl egzistuojančio ryšio tarp šių reiškinių (Sathyamoorthy, Tang, 2018). Eksporto veiklos produktyvumui vertinti naudojamas rodiklis, pateiktas lygtyje (Fortunato, Razo, 2014):

$$PRODY_k = \sum_j \frac{\frac{x_{kj}}{X_j}}{\sum_j \frac{x_{kj}}{X_j}} Y_j \qquad \textbf{(17)}$$

Pateikiamoje 17 lygtyje X_{kj} parametras nurodo eksportuojamą produkto k apimtį į šalį j, o Y_j nurodo bendro nacionalinio produkto reikšmę šalies, į kurią vykdoma eksporto veikla. Šis rodiklis vertina, ar šalys, į kurias eksportuojama didžiausia dalis pagaminamos produkcijos, yra vargingesnės, ar turtingesnės. Kuo šalis yra turtingesnė ir labiau technologiškai pažengusi, tuo eksportuojamos produkcijos kokybės rodiklis yra aukštesnis, nurodantis stipresnę konkurencinę padėtį tarptautinėje rinkoje. Eksporto rafinuotumo rodiklį galima įvertinti tokiu būdu (Fortunato, Razo, 2014):

$$EXPY_{jt} = \sum_k \frac{x_{kjt}}{X_{jt}} PRODY_k \qquad \textbf{(18)}$$

Atlikti tyrimai parodė, kad didesnės eksporto rafinuotumo reikšmės koreliuoja su technologinio intensyvumo rodiklių reikšmėmis, identifikuojant teigiamą ryšį tarp eksporto veiklos efektyvumo bei įmonių kuriamos pridėtinės vertės (Fortunato, Razo, 2014).

1.2.6. Energijos panaudojimo efektyvumo poveikis technologinei pažangai

Viena pagrindinių teorijų, grindžianti energijos panaudojimo efektyvumo gamybos procese poveikį ekonominiam augimui bei technologinei pažangai, yra aplinkos apsaugos Kuznetso kreivė (Shahbaz et al., 2013). Pagal Kuznetso kreivės teoriją, pradiniuose ekonominio vystymosi etapuose ryšys tarp pagaminamos produkcijos apimčių bei anglies dioksido emisijų yra linijinis. Vėliau, padidinus apimtis bei pagerinus gamybos proceso efektyvumą dėl sukuriamų inovacijų, anglies dioksido emisijų kiekis, tenkantis pagaminto produkto vienetui, ima mažėti. Pagal Ahmed (2017) atliktą tyrimą, ekonominis augimas, finansinio sektoriaus išsivystymo lygis bei prekybos atvirumas, pasiekus tam tikrą generuojamų pajamų lygį, sumažina neigiamą gamybos proceso poveikį aplinkai.

Pakankamai populiarus rodiklis, vertinantis energijos išteklių panaudojimo efektyvumą, vadinamas energijos intensyvumo rodikliu. Jis įvertinamas pagal pateiktą lygtį (Cantore *et al.*, 2016):

$$EI = \frac{EC}{TS} \quad \textbf{(19)}$$

Pateiktoje 19 lygtyje energijos efektyvumas apskaičiuojamas padalijus gamybos procese suvartotą energiją *EC* iš bendrų pajamų, gautų už parduotą produkciją *TS*. Zhang et al. (2013) siūlo kelis alternatyvius energijos efektyvumo vertinimo rodiklius. Vienas iš jų – atsinaujinančiais ištekliais ir neatsinaujinančiais ištekliais pagaminamos energijos santykis.

1.3. Technologinės pažangos matavimo rodikliai

Akademinės literatūros analizė leido išskirti du pagrindinius technologinės pažangos vertinimo rodiklius: technologinio efektyvumo bei technologinės pažangos. Šiame poskyryje aptariama abiejų rodiklių skaičiavimo metodika ir šių rodiklių ekonominė interpretacija.

1.3.1. Technologinio efektyvumo rodiklis

Technologinio efektyvumo rodiklis gali būti įvertinamas stochastinės ribinės analizės metodu pagal pateiktą lygtį (Nguyen, 2010):

$$TE_i = \frac{y_i}{f(x_i;\beta) * e^{V_i}} \quad \textbf{(20)}$$

20 lygtyje pateikta išraiška $f(x_i;\beta) * e^{V_i}$ identifikuoja reikšmes, esančias ant gamybos galimybių kreivės, čia β reprezentuoja gamybos funkcijoje esančius parametrus, o V_i – paklaidos veiksnį. Technologinio efektyvumo rodiklis nurodo visiškai efektyvų gamybinių išteklių panaudojimą esant $TE_i = 1$, o, egzistuojant $TE_i < 1$ sąlygai, egzistuoja potencialas gamybos išteklių efektyviam panaudojimui gerinti.

Technologinio efektyvumo rodiklis gali būti nustatytas ir duomenų gaubtinės analizės metodu, pagal pateiktą lygtį (Yu, 2008):

$$T = \{(x,y): \sum_{j=1}^{J} z_j y_{jm} \geq y_{km},\ m = 1,\dots,M,\ \sum_{j=1}^{J} z_j x_{jn} \leq (1-\beta)x_{kn},\ n = 1,\dots,M,\ z_j \geq 0,\ j = 1,\dots,J\} \quad \textbf{(21)}$$

Duomenų gaubtinės analizės metodu įvertinami z_j parametrai, kurie identifikuoja visus galimus pagamintos produkcijos kiekius esant tam tikroms gamybos žaliavų apimtims, išvestus pagal į modelį įvestus faktinius duomenis. Atliekant duomenų gaubtinę analizę sukonstruojama gamybos galimybių kreivė ir apskaičiuojami technologinio efektyvumo rodiklių koeficientai.

1.3.2. Technologinės pažangos rodiklis

Technologinės pažangos reikšmės gali būti apskaičiuojamos remiantis Solow neoklasikinio augimo modeliu, išreiškiant per bendros gamybos veiksnių produktyvumo parametrą. Bendras gamybos veiksnių produktyvumas gali būti išreikštas dviem būdais: kaip technologinės pažangos indeksas arba Solow likučio parametras (Ondrej, Jiri, 2012). Technologinės pažangos rodiklis, toks kaip indeksas, gali būti apskaičiuojamas remiantis pateikta lygtimi (Rabbani, 2006):

$$Y = AK^{\alpha}L^{1-\alpha} \quad \textbf{(22)}$$

22 lygtyje technologinės pažangos rodiklis yra pavaizduotas kaip parametras *A*. Pagal lygtyje pateiktą išraišką technologinės pažangos rodiklis yra multiplikatorius, kuris nurodo, kaip stipriai ekonominį augimą veikia veiksniai, nesusiję su kapitalo bei darbo jėgos ištekliais. Modeliuose technologinės pažangos rodiklis dažnai išreiškiamas ir kaip Solow likučio parametras (Hulten, 2001):

$$R_t = \frac{\dot{Q}_t}{Q_t} - s_t^K \frac{\dot{K}_t}{K_t} - s_t^L \frac{\dot{L}_t}{L_t} = \frac{\dot{A}_t}{A_t} \qquad \textbf{(23)}$$

23 lygtyje pateikti parametrai s^K bei s^L nurodo atitinkamai ribinio kapitalo produkto bei ribinio darbo produkto koeficientus, kurie pakeičia 23 lygtyje pavaizduotą pagamintos produkcijos elastingumo kapitalo atžvilgiu parametrą α. Taip išvestas Solow likučio rodiklis identifikuoja technologinės pažangos augimo tempą laike. Norint nustatyti pagamintos produkcijos elastingumą kapitalo atžvilgiu, reikia kintamuosius konvertuoti į jų logaritminę formą, kaip pateikta lygtyje (Erken, Donselaar, Thurik, 2018):

$$\ln(TFP) = \ln\left(Y/_L\right) - \alpha \ln\left(K/_L\right) = (1 - \alpha - \beta)\ln(A) + \beta \ln\left(H/_L\right) \qquad \textbf{(24)}$$

Logaritmine forma išreikšta 24 lygtis leidžia, naudojantis tiesinės regresijos modeliu, nustatyti tiek technologinės pažangos, tiek pagamintos produkcijos elastingumo kapitalo atžvilgiu vertes. Kai kurie tyrėjai į regresijos modelius, skirtus technologinės pažangos vertėms nustatyti, įtraukia ir žmogiškojo kapitalo parametrą *H*.

2. TECHNOLOGINĖS PAŽANGOS VEIKSNIŲ APDIRBAMOJOJE PRAMONĖJE VERTINIMO MODELIO METODOLOGIJA

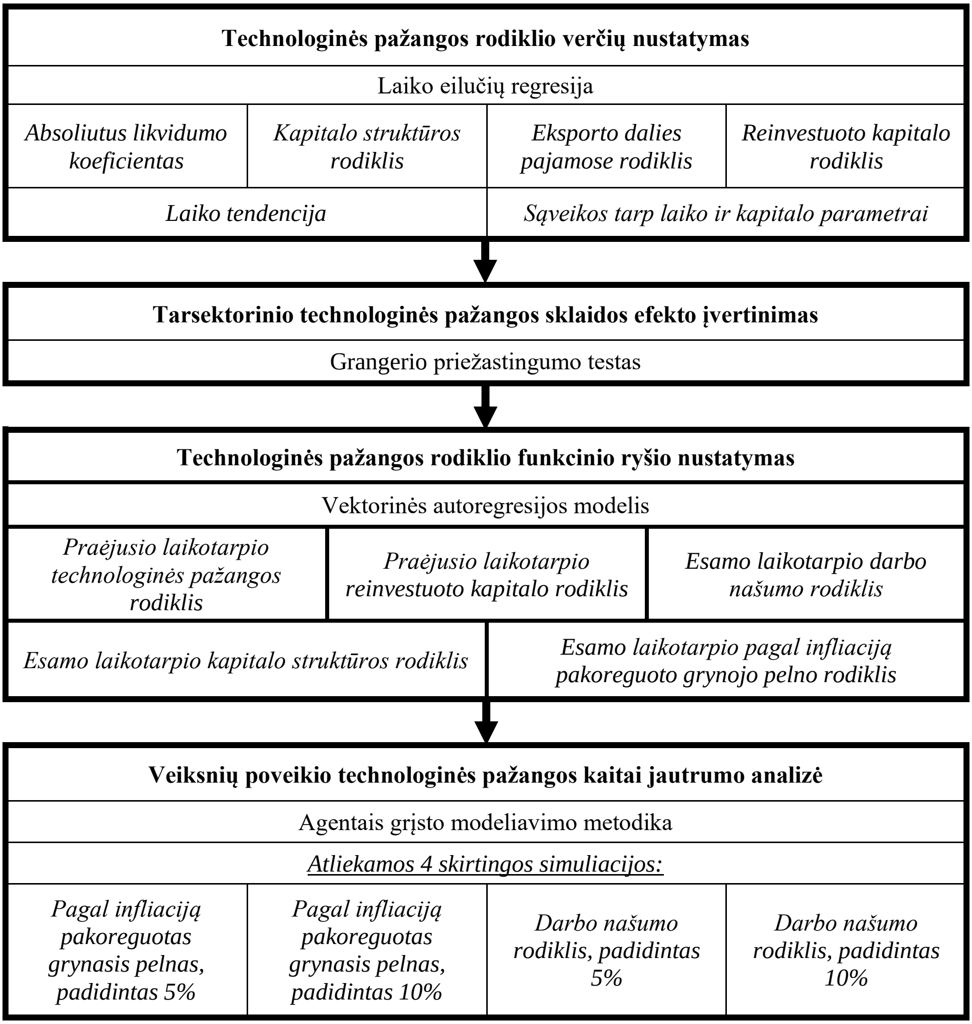
Technologinės pažangos veiksnių apdirbamojoje pramonėje vertinimo modelio schema pateikta 1 paveiksle. Pats tyrimo modelis sudarytas iš keturių dalių. Pirmoje dalyje atliekamas technologinės pažangos rodiklių verčių nustatymas. Tam konstruojami laiko eilučių regresijos modeliai. Antroje dalyje atliekamas tarpsektorinio technologinės pažangos sklaidos efekto vertinimas panaudojant Grangerio priežastingumo testą. Trečioje dalyje sudaromos funkcijos, kuriomis galima įvertinti, kaip skirtingi apdirbamosios pramonės veiksniai lemia technologinės pažangos rodiklių reikšmes. Funkciniam ryšiui nustatyti sudaromas vektorinės autoregresijos modelis. Paskutinėje dalyje atliekama jautrumo analizė, kuri leidžia įvertinti, kaip skirtingų rodiklių reikšmių kaita veikia technologinės pažangos reikšmių pokyčius. Empirinėje dalyje sukonstruoto modelio faktinis pritaikymas atliktas Lietuvos apdirbamosios pramonės sektorių atveju.

Visi duomenys, panaudoti atliekant praktinę Lietuvos apdirbamosios pramonės atvejo analizę, buvo surinkti iš Lietuvos statistikos departamento.

2.1. Technologinės pažangos verčių nustatymas panaudojant laiko eilučių regresiją

Sukonstruotas laiko eilučių regresijos modelis, pagal kurį atliekamas pagamintos produkcijos elastingumo kapitalo atžvilgiu nustatymas, reikalingas technologinės pažangos rodikliui apskaičiuoti, pateiktas lygtyje:

$$\ln(Y_t) = \beta_1 + \beta_2 * \ln(K_t) + \beta_3 * \ln(EN_t) + \beta_4 * \ln(CASH_t) + \beta_5 * \ln(ETD_t) + \beta_6 * \ln(EXP_t) + \beta_7 * \ln(INV_t) + \beta_8 * T + \sum_{i=1}^{4} \beta_i * \ln(K_{t+i}) * Year_{t+i} + \varepsilon_t, \quad \forall\, i, Year_{t+2,i} < Year_{t,i+1} \qquad \textbf{(25)}$$



1 pav. Technologinės pažangos veiksnių apdirbamojoje pramonėje vertinimo modelis

25 lygtyje kaip priklausomas kintamasis Y_t pateiktas pagamintos produkcijos vienam darbuotojui rodiklis. Modelio nepriklausomi kintamieji – kapitalo, tenkančio vienam darbuotojui, rodiklis K_t, energijos panaudojimo efektyvumo koeficientas,

apibrėžtas energijos intensyvumo rodikliu EN_t, absoliutus likvidumo koeficientas $CASH_t$, kapitalo struktūros rodiklis ETD_t, eksporto dalies generuojamose pajamose rodiklis EXP_t ir reinvestuoto kapitalo rodiklis INV_t.

Išvardinti kintamieji buvo pasirinkti įtraukti į laiko eilučių regresijos modelį, pavaizduotą 25 lygtyje, kadangi iš visų 1.2 skyriuje analizuotų kintamųjų šie veiksniai veikia technologinės pažangos vertes per poveikį sukaupto kapitalo apimtims bei pagamintos produkcijos elastingumo kapitalui vertes. Į 25 lygtį taip pat įtrauktas ir parametras T, nusakantis tendenciją. Laiko eilučių regresijos modelyje svarbų vaidmenį atlieka parametras β_2, identifikuojantis pagamintos produkcijos elastingumą kapitalui. Tiesa, jeigu modelis sudarytas ilgalaikei gamybos veiksnių analizei, vienas parametras yra nepakankamas pagamintos produkcijos elastingumui kapitalo atžvilgiu nusakyti, kadangi šis rodiklis kinta laike. Todėl į 25 lygtyje pateiktą modelį įtraukti sąveikos parametrai, identifikuojantys besikeičiančias pagamintos produkcijos elastingumo kapitalui vertes.

$$A_{i,t} = \frac{Y_{i,t}}{K_{i,t}^{\alpha_{i,t}} * L_{i,t}^{(1-\alpha)_{i,t}}} \quad \textbf{(26)}$$

Įvertinus pagamintos produkcijos elastingumo kapitalui reikšmes bei įrašius į 26 lygtį, galima apskaičiuoti technologinės pažangos rodiklių reikšmes skirtingiems apdirbamosios pramonės sektoriams.

2.2. Tarpsektorinio technologinės pažangos sklaidos efekto nustatymas

Tarpsektoriniam technologinės pažangos sklaidos efektui nustatyti panaudotas Grangerio priežastingumo testas, kurį galima atlikti remiantis dviem pateiktomis lygtimis (Tuppura et al., 2016):

$$Y_t = \alpha_0 + \sum_{j=1}^{n} \alpha_j Y_{t-j} + \sum_{k=1}^{n} \beta_k X_{t-k} + e_{1t} \quad \textbf{(27)}$$

$$X_t = \gamma_0 + \sum_{j=1}^{n} \gamma_j Y_{t-j} + \sum_{k=1}^{n} \delta_k X_{t-k} + e_{2t} \quad \textbf{(28)}$$

Pagal pateiktas 27 ir 28 lygtis Grangerio priežastingumas yra tiriamas tarp dviejų kintamųjų: *X* ir *Y*. Konstruojamame modelyje *X* ir *Y* reikšmes pakeis dviejų analizuojamų apdirbamosios pramonės sektorių technologinės pažangos rodikliai. Yra laikoma, kad kintamasis *X* Granger daro įtaką kintamajam *Y*, jeigu grupinės koeficientų β_k reikšmės yra reikšmingai didesnės už 0, o kintamasis *Y* Granger daro įtaką kintamajam *X*, jeigu grupinės koeficientų δ_k reikšmės yra reikšmingai didesnės už 0.

Svarbus kintamasis, galintis nulemti Grangerio priežastingumo testo reikšmes, yra *t*, identifikuojantis lagų skaičių. Lietuvos apdirbamosios pramonės sektorių analizės atveju pasirinktas lagų skaičius yra 3. Pagal Verspagen ir Loo (1998) atliktą tyrimą, technologinės pažangos sklaidos efektas, nulemtas mokslinių tyrimų ir plėtros išlaidų augimo, pasiekia didžiausią poveikį praėjus 3 metams po patirtų išlaidų, o vėliau pradeda mažėti. Dėl šios priežasties 3 lagai turėtų būti pakankami Granger priežastingumui tarp apdirbamosios pramonės sektorių technologinės pažangos verčių identifikuoti.

2.3. Apdirbamosios pramonės veiksnių poveikio technologinės pažangos rodikliams funkcinio ryšio nustatymas

Funkcinio ryšio tarp technologinės pažangos rodiklių bei apdirbamosios pramonės sektorių lygmens veiksniams nustatyti panaudotas vektorinės autoregresijos modelis. Vektorinė autoregresija funkciniam ryšiui nustatyti pasirinkta todėl, kad šis modelis padeda įvertinti analizuojamų veiksnių tarpusavio dinaminį poveikį, išreikštą per tiesinio ryšio sąveikas tarp kintamųjų (Damasio, Mendonca, 2019). Bendrinė vektorinės autoregresijos modelio forma pateikta lygtyje (Zhou, Luo, 2018):

$$y_t = \phi_1 y_{t-1} + \cdots + \phi_p y_{t-p} + Hx_t + \varepsilon_t,\ t = 1,2,\ldots,T \quad \textbf{(29)}$$

Pateiktoje 29 lygtyje kintamasis y_t nurodo endogeninių kintamųjų, įtrauktų į vektorinės autoanalizės modelį, vektorių, parametras x_t identifikuoja egzogeninių kintamųjų vektorių, o ε_t – modelio paklaidą. Į lygtį taip pat įtrauktas kintamasis p, nurodantis maksimalų modelio lagų skaičių.

Atliekant Lietuvos apdirbamosios pramonės sektorių analizę, naudojama pateikta vektorinio autoregresijos modelio forma:

$$A_{i,t} = \alpha_i + \sum_{k=1}^{3} \beta_{i,t-k} A_{i,t-k} + \sum_{k=1}^{3} \gamma_{j,t-k} A_{j,t-k} + \sum_{k=1}^{3} \delta_{i,t-k} INV_{i,t-k} + \theta_{i,t} LP_{i,t} + \rho_{i,t} CR_{i,t} + \varphi_{i,t} NP_{i,t} + \varepsilon_{i,t} \quad \textbf{(30)}$$

Į 30 lygtyje pateiktą modelį įtrauktus endogeninius kintamuosius sudaro analizuojamo sektoriaus technologinės pažangos rodiklio vertės $A_{i,t-k}$, kitų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos vertės $A_{j,t-k}$ bei reinvestuoto kapitalo rodiklio vertės $INV_{i,t-k}$. Kaip egzogeniniai vektorinės autoregresijos modelio kintamieji įtraukti darbo našumo rodiklis $LP_{i,t}$, užsienio kapitalo struktūros rodiklis $CR_{i,t}$, identifikuojantis, kurią sektoriaus disponuojamo kapitalo dalį sudaro užsienio investicijomis pritrauktas kapitalas, ir metinis pagal infliaciją pakoreguotas grynasis pelnas $NP_{i,t}$. Išvardinti kintamieji įtraukti į 31 lygtį, kadangi iš visų 1.2 skyriuje analizuotų veiksnių būtent jie daro tiesioginį poveikį technologinės pažangos rodiklių kaitai.

Siekiant nustatyti tinkamas vektorinio autoregresijos modelio endogeninių kintamųjų lagų vertes, galima pasinaudoti Akaitės bei Švarco kriterijais, kurių vertės apskaičiuojamos pagal pateiktas lygtis (Xu, Lin, 2016):

$$AIC = -\frac{2l}{n} + \frac{2k}{n} \quad \textbf{(31)}$$

$$SC = -\frac{2l}{n} + \frac{k \log(n)}{n} \quad \textbf{(32)}$$

Lietuvos apdirbamosios pramonės sektorių atvejo analizei atlikti buvo pasirinktas 3 lagų skaičius. Visų pirma, tai buvo atlikta dėl jau anksčiau minėto Verspagen ir Loo (1998) tyrimo, kuris nustatė, kad maksimalus tarpsektorinės technologinės pažangos sklaidos efekto poveikis atsiranda būtent praėjus 3 metams. Antra, Lietuvos apdirbamosios pramonės atveju duomenys surinkti 19 metų laikotarpiui. Pasirinktus didesnį nei 3 lagų skaičių vektorinės autoregresijos modeliui, liks nepakankamas laisvės laipsnių skaičius. Todėl, kol disponuojamų duomenų intervalas neprasiplės, yra apsiribojama 3 lagais.

2.4. Technologinės pažangos veiksnius analizuojančio simuliacinio modelio jautrumo analizė

Jautrumo analizės, kuri padeda nustatyti veiksnių poveikį apdirbamosios pramonės sektorių technologinės pažangos kaitai bei tarpsektorinės technologinės pažangos sklaidos efekto mastą, įgyvendinimui buvo pasirinkta naudoti agentais grįsto modeliavimo metodiką. Agentais grįsto modeliavimo metodologija išsiskiria tuo, kad kiekvienas modelio dalyvis yra išskirtas kaip atskiras objektas, kuris gali reaguoti į aplinką bei priimti atitinkamus individualius sprendimus (Darley, Outkin, 2007). Paprasčiausiu būdu agentais grįsto modeliavimo metodiką galima apibūdinti kaip sistemą, kurioje apibūdintos objektų charakteristikos bei apibrėžti jų tarpusavio santykiai.

Kiekvieno iš objektų, veikiančių pagal agentais grįsto modeliavimo principus, vidinių savybių kaita gali būti apibūdinta pateikta lygtimi (Richiardi, 2012):

$$x_{i,t+1} = f_i(x_{i,t}, x_{-i,t}, \alpha_i) \quad \textbf{(33)}$$

33 lygtyje pateikta informacija nurodo, kad būsimo laikotarpio agentų parametrų vertės $x_{i,t+1}$ priklauso nuo esamo laikotarpio agento parametro verčių $x_{i,t}$, kitų agentų, veikiančių toje pačioje aplinkoje, esamo laikotarpio verčių $x_{-i,t}$ bei analizuojamo agento parametrų verčių α_i. Taip per laiką, priklausomai nuo agentų parametrų verčių, susidaro pusiausvyros būsena, kurią galima apibūdinti pateikta lygtimi (Richiardi, 2012):

$$Y^e = \lim_{t \to n} Y_t \equiv g(x_{1,0}, \ldots, x_{n,0}; \alpha_1, \ldots, \alpha_n) \quad \textbf{(34)}$$

Jeigu rinkoje sumodeliuotomis sąlygomis gali susidaryti pusiausvyros būsena, tuomet 34 lygtyje parametro n vertė nusako tam tikrą realų laiko momentą ateityje. Jeigu rinkoje pusiausvyros būsena susidaryti negali ir vyksta pastovūs svyravimai, tuomet $n = \infty$. Lietuvos apdirbamosios pramonės sektorių atvejo analizėje agentais grįsto modelio lygtis gali būti atvaizduota tokia funkcija:

$$\ln(Y_t) = \beta_1 + \beta_2 * A_t(\mathrm{x}) + \beta_3 * \ln(K_t) + \beta_4 * \ln(EN_t) + \beta_5 * \ln(CASH_t) + \beta_6 * \ln(ETD_t) + \beta_7 * \ln(EXP_t) + \beta_8 * \ln(INV_t) + \varepsilon_t \quad \textbf{(35)}$$

Pagrindinis skirtumas tarp 25 ir 35 lygčių yra tas, jog 35 lygtyje yra išskirtas technologinės pažangos kintamasis A_t(x), kuris pateiktas funkcine forma, apibrėžta pasinaudojant vektorinės autoregresijos modeliu. Taip technologinės pažangos rodiklis kartu gali būti analizuojamas ir kaip priklausomas kintamasis, ir kaip nepriklausomas kintamasis. Tai suteikia daugiau lankstumo analizuojant technologinės pažangos rodiklio įtaką apdirbamosios pramonės sektorių augimui.

3. EMPIRINIO MODELIO PRITAIKYMAS VERTINANT VEIKSNIŲ POVEIKĮ TECHNOLOGINĖS PAŽANGOS KAITAI: LIETUVOS APDIRBAMOSIOS PRAMONĖS ATVEJO ANALIZĖ

Praktinis sukonstruoto modelio pritaikymas atliktas Lietuvos apdirbamosios pramonės atvejui, tiriant Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodiklių vertės bei veiksnius, veikiančius technologinės pažangos verčių svyravimus. Atvejo analizėje tiriama 18 Lietuvos apdirbamosios pramonės sektorių 2000–2018 m. laiko intervalu. Lietuvos apdirbamosios pramonės sektorių sąrašas bei atitinkami kodai, identifikuojantys atskirus sektorius, pateikti 2 lentelėje.

2 lentelė. Lietuvos apdirbamosios pramonės sektoriai bei jų identifikaciniai kodai

Kodas	Pavadinimas	Kodas	Pavadinimas
C10	Maisto produktų gamyba	C23	Kitų nemetalo mineralinių produktų gamyba
C11	Gėrimų gamyba	C24	Pagrindinių metalų gamyba
C13	Tekstilės gaminių gamyba	C25	Metalo gaminių, išskyrus mašinas ir įrenginius, gamyba
C14	Drabužių siuvimas	C26	Kompiuterinių, elektroninių ir optinių gaminių gamyba
C15	Odos ir odos dirbinių gamyba	C27	Elektros įrangos gamyba
C16	Medienos bei medienos ir kamštienos gaminių, išskyrus baldus, gamyba	C28	Niekur kitur nepriskirtų mašinų ir įrangos gamyba
C17	Popieriaus ir popieriaus gaminių gamyba	C30	Kitų transporto priemonių ir įrangos gamyba
C18	Spausdinimas ir įrašytų laikmenų tiražavimas	C31	Baldų gamyba
C22	Guminių ir plastikinių gaminių gamyba	C33	Mašinų ir įrangos remontas ir įrengimas

Šioje dalyje aprašomi praktinio modelio pritaikymo Lietuvos apdirbamosios pramonės atveju rezultatai.

3.1. Technologinės pažangos verčių nustatymas Lietuvos apdirbamosios pramonės sektorių atveju

3 lentelėje pateiktos Lietuvos apdirbamosios pramonės sektorių nustatytos technologinės pažangos rodiklių vertės. Pateikti rezultatai parodo, kad visų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodikliai auga laike. Tai reiškia, kad bėgant metams Lietuvoje veikiančios apdirbamosios pramonės įmonės geba pagaminamos produkcijos apimtis didinti greičiau, nei auga kapitalo bei darbo jėgos ištekliai, naudojami gamybos procese. Esant skirtingam gaminamos produkcijos pobūdžiui bei dėl apdirbamos produkcijos specifikos technologinės pažangos rodiklio vertės laike tarp sektorių keičiasi skirtingai.

3 lentelė. Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodiklių vertės

Sektorius	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Vidurkis
C10	1,07	1,22	1,20	1,31	1,40	1,44	1,62	2,06	1,76	2,13	2,02	2,26	2,46	2,52	2,46	2,80	3,08	3,19	3,17	2,06
C11	3,18	3,27	3,67	3,37	3,98	3,92	4,42	5,80	5,07	4,64	4,41	4,40	4,93	4,84	6,26	6,40	6,22	6,18	5,63	4,77
C13	1,40	1,43	1,61	1,80	2,10	2,26	2,27	2,44	2,51	2,52	3,04	3,90	4,24	4,56	4,87	4,98	5,69	5,96	6,19	3,36
C14	1,95	2,12	2,21	2,18	2,34	2,48	2,56	2,70	2,66	2,40	2,89	3,22	3,16	3,43	3,81	3,77	3,83	3,95	3,87	2,92
C15	0,84	0,99	1,39	1,49	0,52	1,46	1,66	1,64	2,49	2,13	2,18	2,15	2,51	2,69	3,17	3,47	3,62	3,83	3,78	2,21
C16	1,15	1,12	1,23	1,28	1,31	1,46	1,42	1,41	1,29	1,12	1,36	1,47	1,51	1,75	1,76	1,75	1,88	1,98	2,14	1,50
C17	1,17	1,44	1,20	1,66	1,59	1,68	1,85	1,89	2,03	2,12	2,14	2,42	2,60	2,90	2,99	3,20	3,16	3,41	3,88	2,28
C18	0,76	0,85	0,86	1,06	0,95	1,44	1,57	1,39	1,27	1,16	1,41	1,88	1,87	1,89	2,09	2,31	2,52	2,60	2,69	1,61
C22	1,14	1,21	1,38	1,71	1,27	1,62	2,22	1,90	2,16	1,95	2,36	2,46	2,81	2,77	3,14	3,21	3,59	3,61	3,96	2,34
C23	0,87	1,19	1,30	1,54	1,78	1,91	2,76	3,35	2,60	2,04	2,21	2,84	3,12	3,36	3,72	3,58	4,94	5,11	5,49	2,83
C24	2,37	2,77	1,89	2,07	2,16	2,06	3,04	3,71	4,66	1,89	3,42	5,56	5,20	7,18	6,45	7,15	7,81	9,12	8,60	4,59
C25	1,15	1,25	1,28	1,46	1,70	1,99	2,22	2,65	2,85	2,31	2,83	3,31	3,41	3,46	4,19	4,50	4,57	4,57	4,42	2,85
C26	2,00	2,21	1,76	1,61	1,70	1,40	1,46	1,55	2,72	2,28	2,98	3,04	3,05	3,29	3,14	3,65	3,52	4,51	3,97	2,62
C27	1,19	1,34	1,60	1,85	2,24	2,53	2,86	3,15	3,39	2,75	4,50	5,73	5,21	6,66	6,62	7,35	9,56	9,69	9,40	4,61
C28	1,16	1,65	2,47	2,37	2,60	3,31	4,40	5,04	4,91	4,26	5,41	5,98	6,88	7,40	7,34	8,21	8,45	9,88	10,41	5,38
C30	1,32	1,50	1,33	1,23	1,86	2,03	2,29	2,67	3,12	4,52	6,55	3,53	2,49	3,88	6,00	7,15	7,12	8,96	9,87	4,07
C31	1,96	2,02	2,34	2,76	2,82	2,60	2,79	3,66	2,86	3,82	4,59	5,12	5,20	5,61	6,47	6,93	7,75	8,49	8,68	4,55
C33	1,17	1,39	1,01	1,07	1,72	1,95	2,44	2,47	2,53	2,37	2,83	3,36	3,80	3,49	3,46	3,96	4,53	5,15	6,08	2,88

Technologinės pažangos rodiklių kaita taip pat parodė, kad atskiri sektoriai skirtingai veikė prasidėjus 2008–2009 m. finansų ir ekonominei krizei. Kitų nemetalo mineralinių produktų gamybos sektoriaus technologinės pažangos vertė tarp 2007 ir 2009 m. smuko 39 procentais. Prireikė 6 metų, kol sektoriaus technologinės pažangos rodiklio vertė pasiekė ikikrizinį lygį. O kompiuterinių, elektroninių ir optinių gaminių gamybos sektoriaus technologinės pažangos rodiklio vertės net kriziniu laikotarpiu toliau augo: nuo 1,55 vertės 2007 m. pakilo iki 2,28 reikšmės 2009 metais.

4 lentelė pateikia kitus veiksnius, be kapitalo, kurie pagal laiko eilučių regresijos modelį daro įtaką pagaminamos produkcijos apimtims Lietuvos apdirbamosios pramonės sektorių atveju.

4 lentelė. Laiko eilučių regresijos modelių nepriklausomų kintamųjų koeficientų reikšmės, nurodančios poveikį pagaminamos produkcijos apimtims

Sector	log (EN_t)	log ($CASH_t$)	Log (ETD_t)	Log (EXP_t)	Log (INV_t)	Trend	$CASH_t$	ETD_t	EXP_t
C10	-	-	-	-	-	0,073 (0,000)	-	-	-
C11	0,340 (0,001)	-	-	-	-	0,049 (0,000)	-	-	-
C13	-	-	-	-	-	0,077 (0,000)	0,008 (0,034)	0,295 (0,000)	-
C14	0,074 (0,010)	-	-	-	0,126 (0,000)	0,043 (0,000)	-	-	-
C15	-	-	-	-	-	0,080 (0,000)	-	0,420 (0,000)	-0,265 (0,014)
C16	-	0,126 (0,000)	-	-	0,144 (0,001)	0,029 (0,000)	-	-	-
C17	-	-	-	-	-	0,059 (0,000)	-	0,158 (0,042)	-
C18	-	0,378 (0,000)	-	0,4306 (0,000)	-	-	-	-	-
C22	-	-	-0,261 (0,033)	-	-	0,084 (0,001)	-	-	-
C23	-	-	0,925 (0,025)	-	-	0,115 (0,000)	-	-	-
C24	-	-	-0,070 (0,038)	-	0,285 (0,000)	0,073 (0,000)	-	-	-
C25	-	-	-0,417 (0,000)	-	-	0,098 (0,000)	-	-	-
C26	-	0,269 (0,018)	-	-	-	-	-	-	-
C27	-	-	-	-	-	0,156 (0,000)	-	-	-
C28	-	-	-0,072 (0,000)	-	-	0,127 (0,000)	-	-	-
C30	-	0,2040 (0,006)	-	-0,1796 (0,019)	-0,192 (0,043)	0,122 (0,000)	-	-	-
C31	0,2351 (0,005)	-	0,525 (0,013)	-	-	0,098 (0,000)	-	-	-
C33	-	-	0,0668 (0,001)	-	-	0,0916 (0,000)	-	-	-

5 lentelė. Grangerio priežastingumo testo rezultatai

Sector	C10	C11	C13	C14	C15	C16	C17	C18	C22	C23	C24	C25	C26	C27	C28	C30	C31	C33
C10	-	0,857	0,771	0,339	0,661	0,697	0,389	0,085	**0,034**	0,503	0,879	**0,044**	0,809	0,732	0,444	0,492	0,607	0,078
C11	0,374	-	0,190	0,274	0,408	0,218	0,153	0,185	0,135	**0,001**	0,400	0,327	0,666	0,300	0,241	0,995	0,277	0,318
C13	0,539	0,598	-	0,949	0,330	0,058	0,370	0,525	0,897	0,148	**0,032**	0,675	0,151	0,107	0,104	0,347	0,497	0,430
C14	0,186	0,190	0,482	-	0,787	0,251	0,110	0,329	0,889	0,091	0,443	0,699	0,189	0,663	0,903	0,897	0,357	0,955
C15	0,104	0,073	0,122	0,097	-	0,340	**0,004**	0,121	**0,041**	0,305	0,237	**0,022**	0,839	0,326	0,066	0,926	0,490	0,097
C16	0,262	0,089	0,138	0,131	0,148	-	0,359	0,476	0,462	0,795	0,214	0,184	**0,043**	0,115	0,226	0,122	0,058	0,466
C17	0,337	0,273	**0,023**	0,721	0,531	0,226	-	0,876	0,655	0,254	0,473	0,800	0,193	0,070	0,267	0,138	0,203	0,335
C18	0,489	0,498	**0,031**	**0,016**	0,075	0,493	**0,008**	-	0,076	0,390	0,363	0,249	0,278	**0,047**	**0,039**	0,200	0,089	0,575
C22	0,421	0,864	0,245	0,372	0,471	0,496	**0,024**	0,100	-	0,830	0,998	0,649	0,539	0,353	0,414	0,755	0,258	0,437
C23	0,534	0,839	0,095	0,187	0,535	0,092	0,061	**0,015**	0,340	-	0,194	0,299	0,240	0,099	0,077	0,406	0,146	0,331
C24	0,098	0,210	**0,014**	**0,027**	0,635	0,465	0,106	0,059	0,073	0,114	-	0,210	0,283	**0,030**	**0,045**	0,397	**0,042**	0,171
C25	0,129	0,323	0,677	0,562	0,186	0,886	0,158	0,841	0,336	0,340	0,945	-	0,254	0,684	0,908	0,615	0,071	0,931
C26	**0,018**	**0,036**	0,133	0,118	**0,020**	0,350	0,186	0,217	0,074	**0,045**	0,545	**0,017**	-	0,270	0,089	0,262	0,055	0,080
C27	0,384	0,665	0,292	0,878	0,594	0,762	0,463	0,150	0,909	0,075	0,124	0,893	0,347	-	0,492	0,238	**0,028**	0,503
C28	0,282	0,221	0,230	0,744	0,772	0,614	0,321	**0,028**	0,615	**0,047**	0,727	0,372	0,092	0,226	-	0,502	0,158	0,239
C30	0,128	**0,032**	**0,045**	**0,004**	**0,048**	0,052	0,148	**0,047**	0,132	**0,013**	**0,022**	**0,001**	0,221	0,108	**0,010**	-	**0,012**	0,277
C31	0,298	0,404	0,578	0,777	0,139	0,587	0,445	0,818	0,230	0,053	0,263	0,451	0,243	0,396	0,551	0,452	-	0,187
C33	0,080	0,595	0,459	0,623	0,104	0,656	**0,024**	0,117	0,480	0,780	0,453	0,175	0,662	0,220	0,708	**0,049**	0,072	-

Iš visų veiksnių, įtrauktų į laiko eilučių regresijos modelius, kapitalo struktūros rodiklis darė reikšmingą įtaką 10 iš 18 analizuotų sektorių pagaminamos produkcijos apimtims. Absoliutus likvidumo rodiklis turėjo reikšminį poveikį pagaminamos produkcijos apimtis 5 sektorių atveju, reinvestuojamo kapitalo koeficientas – 4 sektorių atveju, eksporto dalies generuojamose pajamose rodiklis ir energijos panaudojimo efektyvumo koeficientas – 3 sektorių atveju. Laikas turėjo reikšminį poveikį pagaminamos produkcijos apimčių kaitai 16 iš 18 analizuotų Lietuvos apdirbamosios pramonės sektorių atveju.

3.2. Tarpsektorinio technologinės pažangos sklaidos efekto nustatymas Lietuvos apdirbamosios pramonės sektorių atveju

5 lentelėje pateikiami Grangerio priežastingumo testo rezultatai Lietuvos apdirbamosios pramonės sektorių atveju. Grangerio priežastingumo testas tiria, ar egzistuoja Grangerio priežastingumo ryšys tarp atskirų sektorių, taip identifikuojant galimą tarpsektorinį technologinės pažangos sklaidos efektą. Lentelėje pateiktos p-reikšmių vertės, nurodančios, ar Lietuvos apdirbamosios pramonės sektoriaus, pateikto lentelės stulpelyje, technologinės pažangos rodiklio kaita Granger daro įtaką eilutėje pateikto sektoriaus technologinės pažangos vertėms. Egzistuojant Grangerio priežastingumui, lentelėje pateiktos vertės yra paryškintos.

Atlikus Grangerio priežastingumo testo analizę nustatyta, kad iš 18 tirtų apdirbamosios pramonės sektorių 4 sektoriai Granger veikė kitų 4 Lietuvos apdirbamosios pramonės sektorių technologinės pažangos vertes. Dar 4 Lietuvos apdirbamosios pramonės sektorių technologinės pažangos verčių kaita Granger veikė kitų 3 sektorių technologinės pažangos verčių kaitą. 5 ištirtų Lietuvos apdirbamosios pramonės sektorių atveju jų technologinės pažangos vertės Granger turėjo įtakos kitų 2 sektorių technologinės pažangos vertėms. 3 Lietuvos apdirbamosios pramonės sektorių atveju jų technologinės pažangos vertės Granger veikė vieno kito sektoriaus technologinės pažangos kaitą. Galiausiai, buvo nustatyta, kad tik 2 analizuotų Lietuvos apdirbamosios pramonės sektorių atvejais iš 18 tirtų technologinės pažangos rodiklių kaita Granger neveikė nė vieno kito sektoriaus technologinės pažangos rodiklių pokyčių. Šie sektoriai yra medienos bei medienos ir kamštienos gaminių, išskyrus baldus, gamyba bei mašinų ir įrangos remontas ir įrengimas.

Grangerio priežastingumo testo rezultatai rodo, kad tarpsektorinis technologinės pažangos sklaidos efektas Lietuvos apdirbamosios pramonės atveju potencialiai egzistuoja, todėl, nustatant technologinės pažangos rodiklių funkcinį ryšį, reikia įtraukti parametrus, vaizduojančius technologinės pažangos sklaidos efektą. Tolimesnė analizė taip pat parodė, kad reikšmingas tiesinis ryšys tarp technologinės pažangos rodiklių dydžio bei Granger paveiktų Lietuvos apdirbamosios pramonės sektorių skaičiaus neegzistuoja.

3.3. Funkcinio ryšio tarp Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodiklių bei rodiklius veikiančių veiksnių nustatymas

6 lentelė. Vektorinės autoregresijos modelio rezultatai

P,K,	Nepriklausomi kintamieji					P,K,	Nepriklausomi kintamieji				
AC10, t	AC28, t-2	CR10, t	NP10, t	LP10, t		AC23, t	AC23, t-2	AC14, t-2	AC27, t-1	NP23, t	
	0,0794 (0,02)	2,451 (0,00)	0,0004 (0,01)	19,42 (0,00)			0,297 (0,03)	0,2546 (0,03)	0,2905 (0,00)	0,0014 (0,00)	
AC11, t	AC23, t-1	NP11, t	LP11, t			AC24, t	AC16, t-3	CR24, t	NP24, t	LP24, t	
	0,4385 (0,01)	0,0013 (0,01)	26,45 (0,03)				1,5075 (0,00)	3,4435 (0,00)	0,0366 (0,00)	42,3761 (0,01)	
AC13, t	AC13, t-1	AC15, t-2	INV13, t-2	NP13, t	LP13, t	AC25, t	AC33, t-3	NP25, t	LP25, t		
	0,4961 (0,00)	0,2161 (0,01)	0,0394 (0,00)	0,0032 (0,00)	77,675 (0,00)		0,5251 (0,00)	0,0019 (0,00)	64,78 (0,00)		
AC14, t	CR14, t	NP14, t	LP14, t			AC26, t	AC26, t-2	AC30, t-3	CR26, t	LP26, t	
	2,723 (0,00)	0,0026 (0,00)	275,1 (0,00)				0,4445 (0,00)	0,1238 (0,02)	-0,9669 (0,00)	49,7702 (0,00)	
AC15, t	AC15, t-2	AC13, t-1	CR15, t	NP15, t		AC27, t	AC27, t-3	AC30, t-2	NP27, t		
	0,5614 (0,01)	0,3089 (0,01)	4,4561 (0,00)	0,0109 (0,00)			0,9756 (0,00)	0,3543 (0,00)	0,0033 (0,00)		
AC16, t	AC16, t-1	INV16, t-2	NP16, t	LP16, t		AC28, t	AC28, t-2	AC18, t-1	AC30, t-1	AC30, t-3	NP28, t
	0,3103 (0,05)	0,008 (0,02)	0,0006 (0,00)	24,84 (0,00)			0,3731 (0,00)	0,7995 (0,01)	0,2096 (0,00)	0,1059 (0,01)	0,0067 (0,00)
AC17, t	AC17, t-3	AC23, t-1	AC26, t-1	INV17, t-3	LP17, t	AC30, t	AC30, t-1	AC27, t-3	INV30, t-2		
	0,4844 (0,00)	0,1519 (0,00)	0,1264 (0,04)	-0,018 (0,00)	15,1487 (0,00)		0,4871 (0,01)	0,7977 (0,00)	0,087 (0,01)		
AC18, t	AC18, t-1	AC11, t-2	AC15, t-3	NP18, t		AC31, t	AC31, t-2	AC23, t-3	CR31, t	NP31, t	
	0,3154 (0,03)	0,1294 (0,01)	0,2278 (0,01)	0,0028 (0,00)			0,6625 (0,00)	0,6107 (0,00)	-5,0794 (0,00)	0,0026 (0,00)	
AC22, t	AC22, t-3	NP22, t	LP22, t			AC33, t	AC33, t-1	AC27, t-2	AC30, t-1	INV33, t-2	NP33, t
	0,6164 (0,00)	0,0012 (0,01)	21,59 (0,01)				0,4335 (0,01)	0,1779 (0,02)	0,139 (0,00)	-0,012 (0,03)	0,0011 (0,01)

Veiksnių poveikio technologinės pažangos rodiklių funkciniam ryšiui nustatyti panaudotas vektorinės autoregresijos modelis. 6 lentelėje pateikti VAR modelio rezultatai, kur *P.K.* stulpeliuose nurodomi sektorių technologinės pažangos rodiklių kodai, identifikuojantys priklausomus kintamuosius. Stulpeliuose pavadinimu *Nepriklausomi kintamieji* pateikiamos veiksnių, veikiančių sektorių technologinės pažangos rodiklius, koeficientų vertės bei p-reikšmės.

Pasinaudojant vektorinės autoregresijos modeliu buvo identifikuota, kad iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių 5 technologinės pažangos vertės buvo paveiktos kitų dviejų sektorių technologinės pažangos rodiklių pokyčių. Didžiosios dalies atveju, 10 sektorių iš 18 tirtų, sektoriaus technologinės pažangos vertėms daro įtaką vieno kito sektoriaus technologinės pažangos rodiklio pokyčiai. Vos 3 sektoriams iš 18 tarpsektorinis technologinės pažangos sklaidos efektas neužfiksuotas. Tai reiškia, kad sektoriaus technologinės pažangos verčių kaita neveikiama jokio kito sektoriaus technologinės pažangos rodiklių pokyčių. Vektorinės autoregresijos modelio rezultatai rodo, kad tarpsektorinės technologinės pažangos sklaidos Lietuvos apdirbamosios pramonės atveju egzistuoja ir daro poveikį ekonominio vystymosi raidai.

Vertinant veiksnius, veikiančius technologinės pažangos rodiklių kaitą laike, sudarytas vektorinės autoregresijos modelis labiausiai išskiria pagal infliaciją pakoreguotą grynojo pelno rodiklį. Grynasis pelnas, pagal modelį, daro reikšminę įtaką 15 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodiklių kaitai. Kitas svarbus veiksnys – darbo našumo rodiklis. Šis rodiklis darė reikšminę įtaką 10 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos verčių. Iš kitų kintamųjų užsienio kapitalo struktūros rodiklis turėjo reikšminį poveikį 6 sektorių atveju, reinvestuoto kapitalo rodiklis – 5 sektorių technologinės pažangos rodiklių atveju.

7 lentelėje pateikiama informacija apie tarpsektorinės technologinės pažangos sklaidos efekto poveikį Lietuvos apdirbamosios pramonės sektorių technologinės pažangos kaitai, remiantis sukonstruotu vektorinės autoregresijos modeliu.

7 lentelė. Metinio technologinės pažangos rodiklio augimo dalis dėl tarpsektorinio technologinės pažangos sklaidos efekto

Sektorius	**Augimo tempas**	**Sektorius**	**Augimo tempas**
C10	17%	C23	66%
C11	24%	C24	52%
C13	12%	C25	41%
C14	0%	C26	14%
C15	44%	C27	26%
C16	0%	C28	41%
C17	31%	C30	66%
C18	61%	C31	30%
C22	0%	C33	39%

Pagal sudarytą modelį 4 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių atvejais daugiau nei pusė technologinės pažangos prieaugio susidarė dėl tarpsektorinio technologinės pažangos sklaidos efekto. Šie sektoriai yra spausdinimas ir įrašytų laikmenų tiražavimas, kitų nemetalo mineralinių produktų gamyba, pagrindinių metalų gamyba bei kitų transporto priemonių ir įrangos gamyba. Tai parodo, kad Lietuvos pramonėje yra sektorių, kurių vystymuisi tarpsektorinės technologinės pažangos sklaidos efektas daro didelį poveikį.

3.4. Technologinės pažangos veiksnius vertinančio modelio jautrumo vertinimas panaudojant agentais grįsto modeliavimo metodologiją

Atliekant jautrumo analizę pasirinkti du kintamieji, kurių vertes keičiant analizuojamas jų poveikis Lietuvos apdirbamosios pramonės sektorių technologinės pažangos raidai. Šie kintamieji yra pagal infliaciją pakoreguotas grynojo pelno rodiklis bei darbo našumo rodiklis. Remiantis Pannell (1997) rekomendacijomis bei atlikus duomenų vertinimą, buvo pasirinkta tyrime aprašyti 4 skirtingų simuliacijų rezultatus, kurių metu kiekvieno iš kintamųjų vertės visiems Lietuvos apdirbamosios pramonės sektoriams padidintos 5 ir 10 procentų, stebint, kaip tai paveiks technologinės pažangos augimo tempą. Jautrumo analizėje naudojamos taikant vektorinės autoregresijos modelį gautos technologinės pažangos funkcinio ryšio lygtys.

8 lentelė. Technologinės pažangos rodiklio pokytis dėl grynojo pelno augimo 5 procentais Lietuvos apdirbamosios pramonės sektorių atveju

Sektorius	T. P. augimas dėl vidinių veiksnių	T. P. augimas dėl sklaidos efekto	Sektorius	T. P. augimas dėl vidinių veiksnių	T. P. augimas dėl sklaidos efekto
C10	0,67%	0,33%	**C23**	0,86%	0,85%
C11	0,45%	0,41%	**C24**	1,15%	0,20%
C13	0,81%	0,50%	**C25**	0,77%	0,38%
C14	0,56%	0,00%	**C26**	0,00%	0,15%
C15	1,77%	0,87%	**C27**	1,08%	0,34%
C16	0,57%	0,00%	**C28**	1,30%	0,79%
C17	0,00%	0,44%	**C30**	0,00%	1,15%
C18	0,85%	1,15%	**C31**	1,55%	0,81%
C22	1,04%	0,00%	**C33**	0,47%	0,67%

8 lentelėje pateikti pirmosios simuliacijos rezultatai, kai pagal infliaciją pakoreguoto grynojo pelno rodiklio vertės visiems sektoriams buvo padidintos 5 procentais. Lentelėje taip pat išskiriamas technologinės pažangos prieaugis dėl vidinių veiksnių bei dėl tarpsektorinio technologinės pažangos sklaidos efekto. Iš visų sektorių odos ir odos dirbinių gamybos vidutinis metinis technologinės pažangos prieaugis siekė didžiausią vertę – 2,63 procentus. Mažiausia vertė užfiksuota kompiuterių, elektroninių ir optinių gaminių gamybos sektoriaus atveju – 0,15

procento. Labiausiai 8 lentelėje aprašyta situacija išsiskiria tuo, kad visų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos rodikliai augo, net ir tų, kurių vidiniai grynojo pelno rodikliai technologinės pažangos pokyčiams įtakos neturėjo. Tokie sektoriai yra popieriaus ir popieriaus gaminių gamyba, kompiuterinių, elektroninių ir optinių gaminių gamyba bei kitų transporto priemonių ir įrangos gamyba. Visas šių sektorių technologinės pažangos augimo pokytis simuliacijos metu buvo nulemtas tarpsektorinės technologinės pažangos sklaidos efekto, atsiradusio dėl kitų sektorių tinkamo grynojo pelno prieaugio įsisavinimo.

9 lentelėje pateikiami kitos simuliacijos rezultatai, kai vietoje grynojo pelno 5 procentais yra padidinamos visų Lietuvos apdirbamosios pramonės sektorių darbo našumo rodiklių vertės. Darbo našumo augimo atveju tarpsektorinio technologinės pažangos sklaidos efekto poveikis apima mažiau sektorių nei grynojo pelno padidėjimo atveju. Padidinus grynojo pelno reikšmes 5 procentais, iš 18 Lietuvos apdirbamosios pramonės sektorių tik 3 sektorių atveju vidutinis metinis technologinės pažangos prieaugis dėl sklaidos efekto buvo mažesnis nei 0,1 procento. Padidinus darbo našumą 5 procentais, net 9 sektorių atveju technologinės pažangos prieaugis dėl sklaidos efekto buvo mažesnis nei 0,1 procento.

Nepaisant silpnesnio sklaidos efekto poveikio, vidinių veiksnių poveikis technologinės pažangos augimui užfiksuotas didesnis darbo našumo padidėjimo atveju. Didžiausias vidutinis metinis technologinės pažangos prieaugis 9 lentelėje aprašytos simuliacijos atveju siekia 4,35 procento kompiuterių, elektroninių ir optinių gaminių gamybos sektoriaus atveju. Augant darbo našumo rodikliui 5 procentais, vidutinis metinis technologinės pažangos prieaugis viršijo 3 procentų reikšmę 4 sektorių atveju, kai, padidinus grynojo pelno vertę 5 procentais, didžiausias vidutinis metinis technologinės pažangos prieaugis užfiksuotas kaip 2,63 procentai. Tai parodo, kad darbo našumo poveikis technologinės pažangos rodiklio augimui stipresnis nei grynojo pelno.

9 lentelė. Technologinės pažangos rodiklio pokytis dėl darbo našumo augimo 5 procentais Lietuvos apdirbamosios pramonės sektorių atveju

Sektorius	T. P. augimas dėl vidinių veiksnių	T. P. augimas dėl sklaidos efekto	Sektorius	T. P. augimas dėl vidinių veiksnių	T. P. augimas dėl sklaidos efekto
C10	1,65%	0,04%	**C23**	0,00%	0,90%
C11	1,02%	0,22%	**C24**	1,66%	0,77%
C13	3,45%	0,43%	**C25**	2,21%	0,01%
C14	3,46%	0,00%	**C26**	4,34%	0,01%
C15	0,00%	2,62%	**C27**	0,00%	0,00%
C16	2,31%	0,00%	**C28**	0,00%	0,29%
C17	1,51%	0,98%	**C30**	0,00%	0,00%
C18	0,00%	1,17%	**C31**	0,00%	0,37%
C22	3,06%	0,00%	**C33**	0,00%	0,00%

Simuliacijos, kai jautrumo analizės metu grynojo pelno bei darbo našumo vertės buvo padidintos 10 procentų, struktūriškai davė tokius pačius rezultatus, kaip ir rodikliams didėjant 5 procentais. Technologinės pažangos prieaugis dėl vidinių veiksnių bei sklaidos efekto padidėjo, tačiau išlaikė tokias pačias proporcijas.

Jautrumo analizės metu gauti rezultatai sutampa su endogeninio augimo teorijos įžvalgomis. Pagal šią teoriją, tarpsektorinis technologinės pažangos sklaidos efektas kuriamas reinvestuojant uždirbtą pelną į mokslinius tyrimus ir plėtrą, taip kuriant naujas inovacijas bei skatinant tolimesnį technologinės pažangos vystymąsi.

IŠVADOS

1. Atlikus ekonominio augimo teorijų analizę, nustatyti du pagrindiniai rodikliai, matuojantys technologinę pažangą: technologinio efektyvumo rodiklis bei technologinės pažangos rodiklis. Technologinės pažangos rodiklis matuoja gamybos galimybių kreivės persistūmimą, susijusį su technologijų, naudojamų gamybos procese, tobulėjimu. Neoklasikinių ekonominio augimo teorijų kontekste technologinės pažangos rodiklis gali būti apibrėžtas kaip multiplikatorius, parodantis, kuri ekonominio augimo dalis yra nulemta veiksnių, nesusijusių su gamybos procese naudojamais kapitalo bei darbo jėgos ištekliais. Tiesa, technologinės pažangos rodiklio apskaičiavimas, aprašytas Solow neoklasikinėje augimo teorijoje, turi būti patobulintas, kad būtų panaikintas rezultatų šališkumas dėl galimai praleistų kintamųjų, netinkamo kintamųjų grupavimo ar modelio matavimo paklaidų. Technologinio efektyvumo rodiklis matuoja skirtumus tarp faktinių pagamintos produkcijos apimčių bei gamybos galimybių kreivėje atvaizduojamų potencialių apimčių. Technologinio efektyvumo rodiklis gali būti apskaičiuotas stochastinės ribinės analizės metodu arba duomenų gaubtinės analizės metodu. Iš šių dviejų rodiklių atliekamam tyrimui buvo pasirinktas technologinės pažangos rodiklis, kadangi jis tinkamiau perteikia kuriamų inovacijų poveikį technologinės pažangos raidai ilguoju laikotarpiu. Technologinio efektyvumo rodiklis yra tinkamesnis vertinant trumpuoju laikotarpiu atsirandančius pagaminamos produkcijos nukrypimus nuo potencialiai galimos vertės.
2. Mokslinės literatūros analizė padėjo identifikuoti veiksnius, galimai veikiančius technologinės pažangos rodiklių verčių svyravimus. Dažniausiai minimi veiksniai yra įmonių gebėjimas generuoti pelną, investuojamo kapitalo kaštai, tiesioginės užsienio investicijos bei jų įsisavinimas, kapitalo struktūra, finansinio likvidumo lygis, konkurencingumas užsienio rinkose, energijos panaudojimo efektyvumas. Augančios uždirbamo pelno apimtys gali padidinti investicijas į mokslinius tyrimus ir plėtrą, taip kuriant inovacijas, skatinant gamybos procese naudojamo kapitalo efektyvumo augimą bei didinant įmonės kuriamą vertę. Įsisavinant tiesiogines užsienio investicijas inicijuojamas technologinės pažangos sklaidos efektas. Technologinės pažangos sklaidos efektas gali susidaryti tarp atskirų pramonės šakų bei pramonės viduje (tarpsektorinė sklaida). Tarpsektorinė technologinės pažangos sklaida atsiranda dėl susidariusių vertikalių ryšių tarp sektorių. Kad tiesioginės užsienio investicijos sklaidos efekto pagrindu būtų įsisavintos, pakankamas kiekis investicijų turi būti nukreiptas į mokslinius tyrimus ir plėtrą. Priimti tinkami sprendimai, susiję su kapitalo struktūros pokyčiais, taip pat gali skatinti augimą per technologinę pažangą. Netinkamos nuosavo bei skolinto kapitalo proporcijos gali sudaryti sunkumų bandant pritraukti kapitalą naujiems investiciniams projektams arba padidinti kapitalo kainą, taip ribojant investicijas į technologijų vystymąsi. Įmonei susiduriant su per dideliu finansiniu likvidumu, didėja alternatyvieji kaštai, susiję su sukaupto kapitalo lygio palaikymu, o per žemas likvidumo lygis įmonėse gali privesti prie

nepakankamo investicijų lygio, nukreipto į technologinės pažangos vystymą. Dar vienas svarbus technologinės pažangos augimo veiksnys yra konkurencingumas tarptautinėse rinkose. Didėjantis pramonės konkurencingumo lygis gali gerinti šalies mokėjimo balansą, kurti darbo vietas bei vystyti žmogiškąjį kapitalą, sukurti masto ekonomijos efektą. Galiausiai, energijos išteklių panaudojimo efektyvumas taip pat svarbi ilgalaikio technologinės pažangos vystymo dalis. Pagal Kuznetso kreivės teoriją, ankstyvoje ekonominio augimo stadijoje neigiamas poveikis aplinkai dėl neefektyvaus energijos išteklių panaudojimo auga kartu su pagaminamos produkcijos apimtimis, tačiau, pasiekus tam tikrą gamybos lygį, energijos panaudojimo efektyvumas ima augti, o tai mažina neigiamą poveikį aplinkai, kartu mažinamos ir gamybos procese patiriamos išlaidos.

3. Technologinės pažangos rodiklis šiame tyrime apskaičiuojamas remiantis Solow neoklasikinio augimo modeliu. Norint nustatyti technologinės pažangos reikšmes, privalu įvertinti pagamintos produkcijos elastingumą kapitalo atžvilgiu. Tam naudojamas laiko eilučių regresijos metodas, sudarytas Cobb-Douglas gamybos funkcijos pagrindu. Laiko eilučių regresija, palyginti su Solow neoklasikiniu modeliu, buvo pakoreguota, kad būtų galima išvengti endogeniškumo, išlaikyti laiko eilučių duomenų stacionarumą, išvengti modelyje naudojamų nepriklausomų kintamųjų kolinearumo. Siekiant išvengti endogeniškumo, į laiko eilučių regresijos modelį buvo įtraukti papildomi nepriklausomi kintamieji, tokie kaip gamybos procese naudojamos energijos efektyvumas, absoliutaus likvidumo rodiklis, kapitalo struktūros rodiklis, eksporto dalis generuojamose pajamose, reinvestuoto kapitalo rodiklis. Siekiant išlaikyti likutinių paklaidų stacionarumą, į lygtį įtrauktas tendencijos parametras. Jis įtrauktas todėl, kad neoklasikinės augimo teorijos aiškina gamybos apimčių kaitą per pasiūlos veiksnius. Šiuo parametru siekiama įvertinti pagamintos produkcijos kitimą dėl paklausos veiksnių pokyčio bėgant laikui. Nepriklausomų kintamųjų kolinearumui išvengti į laiko eilučių regresijos lygtis įtraukiami tik tie kintamieji, kurie nepasižymi stipria tiesine koreliacija su kapitalo parametru. Galiausiai, vienu parametru neįmanoma nusakyti pagaminamos produkcijos elastingumo kapitalo atžvilgiu parametro, kadangi ilguoju laikotarpiu rodiklio vertės kinta. Lietuvos apdirbamosios pramonės sektorių atveju analizuojamas 19 metų laikotarpis, todėl į laiko regresijos lygtį įtraukti ir trys sąveikos tarp kapitalo bei laiko parametrai.
4. Siekiant įvertinti atskirų veiksnių poveikį technologinės pažangos rodiklių kaitai, buvo sukonstruotas vektorinės autoregresijos (VAR) modelis. Siekiant įvertinti modelio praktinį pritaikomumą, atlikta 18 Lietuvos apdirbamosios pramonės sektorių analizė. Be skirtingų sektorių technologinės pažangos rodiklių, į VAR modelį buvo įtraukti reinvestuoto kapitalo rodiklis, darbo našumo rodiklis, užsienio kapitalo struktūros rodiklis, pagal infliaciją pakoreguoto grynojo pelno rodiklis. Technologinės pažangos rodikliai bei reinvestuoto kapitalo rodiklis buvo įtraukti su lago vertėmis, o kiti kintamieji į VAR modelį įtraukti esamomis vertėmis. Sudaryto VAR modelio rezultatai rodo, kad 15 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių atveju pagal

infliaciją pakoreguoto grynojo pelno rodiklis turėjo reikšminį poveikį technologinės pažangos verčių kaitai. 10 sektorių atveju darbo našumas pasižymėjo reikšmingu poveikiu technologinės pažangos rodiklių kaitai, užsienio kapitalo struktūros rodiklis – 6 sektorių atveju, reinvestuoto kapitalo rodiklis – 5 sektorių atveju. VAR modelių rezultatai taip pat nurodo, kad tik 3 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių atvejais tarpsektorinis technologinės pažangos sklaidos efektas nebuvo užfiksuotas. 10 sektorių atveju technologinės pažangos sklaidos efektas turėjo vienas-prie-vieno ryšį, kai vieno sektoriaus technologinės pažangos rodiklio kaita darė įtaką vieno kito sektoriaus technologinės pažangos rodiklio verčių svyravimams. 5 sektorių atveju nustatytas du-prie-vieno ryšys, kai vieno sektoriaus technologinės pažangos rodiklio vertėms turi įtakos dviejų kitų sektorių technologinės pažangos rodiklių pokyčiai.

5. Atliekant sukonstruoto modelio jautrumo analizę, buvo pasirinktu du kintamieji, darantys technologinės pažangos rodiklio poveikį didžiausiam skaičiui Lietuvos apdirbamosios pramonės sektorių. Šie rodikliai – pagal infliaciją pakoreguoto grynojo pelno rodiklis bei darbo našumo rodiklis. Iš viso atliktos 4 simuliacijos – abiejų rodiklių vertės visų sektorių atžvilgiu buvo padidintos 5 procentais bei 10 procentų, stebint, kaip tai paveikė technologinės pažangos rodiklių vertes. Atliktos jautrumo analizės rezultatai parodė, kad analizuotų dviejų kintamųjų poveikis Lietuvos apdirbamosios pramonės sektorių technologinės pažangos vystymosi raidai yra skirtingas. Pagal infliaciją pakoreguoto grynojo pelno augimas pakoregavo visų 18 tirtų apdirbamosios pramonės sektorių technologinės pažangos vertes. Grynojo pelno padidinimas 5 procentais išaugino vidutinį metinį technologinės pažangos augimo tempą tarp 2,.6 procentų ir 0,2 procentų, priklausomai nuo sektoriaus. Pagal infliaciją pakoreguoto grynojo pelno rodiklis taip pat labiau skatina tarpsektorinės technologinės pažangos sklaidos efekto plitimą. 15 iš 18 ištirtų atvejų technologinės pažangos sklaidos efektas paspartino vidutinius technologinės pažangos rodiklio augimo tempus. O darbo našumo rodiklio padidinimas 5 procentais paveikė 15 iš 18 tirtų Lietuvos apdirbamosios pramonės sektorių technologinės pažangos augimo tempus. Iš šių 15 sektorių tik 9 buvo reikšmingai paveikti tarpsektorinės technologinės pažangos sklaidos efekto. Nors darbo našumo rodiklio didinimas padarė poveikį mažesniam skaičiui sektorių, pats poveikis technologinės pažangos rodiklių kaitai buvo stipresnis, palyginti su pagal infliaciją pakoreguoto grynojo pelno rodiklio poveikiu. Darbo našumą padidinus 5 procentais, vidutiniai metiniai technologinės pažangos augimo tempai augo iki 4,4 procento. Galiausiai, padidinus grynojo pelno vertes, technologinės pažangos rodikliai labiausiai augo tų sektorių, kurie sugebėjo įsisavinti technologinės pažangos sklaidos efektą. Darbo našumo atžvilgiu labiausiai augo sektoriai, kurie sugebėjo technologinę pažangą vystyti remdamiesi vidiniais veiksniais. Gauti rezultatai, rodantys, kad tarpsektorinės technologinės pažangos sklaidos efektas yra paskatinamas reinvestuojant uždirbamą pelną į naujų inovacijų kūrimą, sutampa su endegeninio ekonominio augimo teorijomis. Jautrumo analizės rezultatai rodo, kad Lietuvos

apdirbamosios pramonės situaciją per paskutinius 20 metų galima vertinti teigiamai. Analizuotų sektorių technologinės pažangos rodiklių vertės vertinamuoju laikotarpiu reguliariai augo, o tarpsektorinės technologinės pažangos sklaidos efektas turėjo reikšminį poveikį technologinės pažangos vystymosi raidai daugumos tirtų sektorių atveju. Įmonės, veikiančios Lietuvos apdirbamojoje pramonėje, turėtų ir toliau reinvestuoti uždirbamą pelną į inovacijų kūrimą bei pažangiausių gamybos metodų įsisavinimą, taip tęsdamos technologinės pažangos vystymą bei gamybos proceso produktyvumo gerinimą. Sukonstruotas modelis pasižymi ir tam tikrais apribojimais, į kuriuos vertėtų atkreipti dėmesį. Lietuvos apdirbamosios pramonės atveju pagrindiniai trikdžiai yra tam tikrų apibrėžtų kintamųjų duomenų stoka bei sąlyginai trumpas analizės laikotarpis. Praplėtus tiriamojo laikotarpio intervalą bei surinkus didesnį kiekį duomenų, atliktos analizės tikslumas padidėtų.

MOKSLO STRAIPSNIAI DISERTACIJOS TEMA

Rezultatų sklaida: disertacijos tema buvo paskelbti 4 moksliniai straipsniai. Tyrimų rezultatai pristatyti 3 tarptautinėse mokslinėse konferencijose.

MOKSLO IR KITŲ DARBŲ SĄRAŠAS

Humanitariniai, socialiniai mokslai ir menai (HSM)

STRAIPSNIAI RECENZUOJAMUOSE MOKSLO LEIDINIUOSE

Web of Science duomenų bazėje indeksuotuose leidiniuose be cituojamumo rodiklio (JCR SCIE)

Nacionalinėse leidyklose

1.**Markauskas, Mantas**; Saboniene, Asta. Evaluation of capital cost: long run evidence from manufacturing sector // Inžinerinė ekonomika = Engineering economics. Kaunas : KTU. ISSN 1392-2785. eISSN 2029-5839. 2020, vol. 31, iss. 2, p. 169-177. DOI: 10.5755/j01.ee.31.2.21439. [Social Sciences Citation Index (Web of Science); Scopus] [M.kr.: S 004] [Indėlis: 0,500]

Kituose recenzuojamuose mokslo leidiniuose
Tarptautinėse leidyklose

2.**Markauskas, Mantas**; Baliute, Asta. Modelling technological progress evaluation: case of Lithuanian manufacturing industry // Mediterranean journal of social sciences. London : Richtmann publishing. ISSN 2039-9340. eISSN 2039-2117. 2020, vol. 11, iss. 6, p. 1-11. DOI: 10.36941/mjss-2020-0058. [DOAJ; Index Copernicus] [M.kr.: S 004] [Indėlis: 0,500]

Recenzuojamoje konferencijų pranešimų medžiagoje
Tarptautinėse leidyklose

3.**Markauskas, Mantas**; Saboniene, Asta. Intersectoral spillover effect of technical progress: case study of Lithuanian manufacturing industry // Proceedings of ISERD international conference, Barcelona, Spain, 11-12 May, 2020 / organized by ISERD. Bhubaneswar : Institute for Technology and Research (ITRESEARCH), 2020. ISBN 9789389732924. p. 44-52. [M.kr.: S 004] [Indėlis: 0,500]

4. **Markauskas, Mantas**; Sabonienė, Asta. Evaluation of technological progress measures: case of Lithuanian manufacturing industry // Proceedings of IAC 2019 in Budapest : international academic conference on Teaching, learning and e-learning, international academic conference on Management, economics and marketing, international academic conference on Transport, logistics, tourism and sport science, March 15-16, 2019, Budapest, Hungary. Prague : Czech Technical University in Prague, 2019. ISBN 9788088203100. p. 104-111. [M.kr.: S 004] [Indėlis: 0,500]

MOKSLINIŲ TYRIMŲ REZULTATŲ SKELBIMAS KONFERENCIJOSE

1. Markauskas, Mantas; Sabonienė, Asta. *Evaluation of Technological Progress Measures: Case of Lithuanian Manufacturing Industry.* International Academic Conference on Management, Economics and Marketing in Budapest 2019, Hungary (IAC-MEM 2019 in Budapest), March 15 - 16, 2019.

2. Markauskas, Mantas; Sabonienė, Asta. *Cost of Capital Changes in Lithuanian Manufacturing Industry.* 17th International Scientific Conference "Perspective of Business and Entrepreneurship Development in Digital Transformation of Corporate Business" Brno University of Technology, April 30, 2019 Brno, Czech Republic.

3. Markauskas, Mantas; Sabonienė, Asta. *Intersectorial Spillover Effect of Technical Progress: Case Study of Lithuanian Manufacturing Industry*. International Conference on Economics, Management and Social Study (ICEMSS) organised by ISERD, Barselona, Spain, May 11-12, 2020.

4. Markauskas, Mantas; Baliutė, Asta. *Intersectoral technological progress spillover effect measurement using agent-based modelling: case of Lithuanian manufacturing industry.* 11th International Conference on Applied Economics: Contemporary Issues in Economy. Poland, Online Conference, June 17-18, 2021.

CURRICULUM VITAE

Išsilavinimas

2017 – dabar	**Ekonomikos mokslo krypties doktorantūra** *Kauno technologijos universitetas*
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REFERENCES

1. Abdallah, W., Georgen, M., & O'Sullivan, N. (2015). Endogeneity: How Failure to Correct for it can Cause Wrong Inferences and Some Remedies. *British Journal of Management*, 26, 791-804.
2. Acemoglu, D. (2012). Introduction to economic growth. *Journal of Economic Theory*, 147, 545-550.
3. Aghion, P., & Festre, A. (2017). Schumpeterian growth theory, Schumpeter, and growth policy design. *Journal of Evolutionary Economics*, 27, 25-42.
4. Aghion, P., & Howitt, P. (2009). *The Economics of Growth*. Cambridge, London: The MIT Press.
5. Aghion, P., Garcia-Penalosa, C., & Howitt, P. (2004). Knowledge and Development: A Schumpeterian Approach. In Dowrick, S., Pitchford, R., & Turnovski, S. J. (Ed.) *Economic Growth and Macroeconomic Dynamics: Recent Developments in Economci Theory*. Cambridge: Cambridge University Press.
6. Ahmed, K. (2017). Revisiting the role of financial development for energy-growth-trade nexus in BRICS economies. *Energy*, 128, 487-495.
7. Albanez, T. (2015). Impact of the cost of capital on the financing decisions of Brazilian companies. *International Journal of Management Finance*, 11 (3), 285-307.
8. Alcouffe, A., & Kuhn, T. (2004). Schumpeterian endogenous growth theory and evolutionary economics. Journal of Evolutionary Economics, 14, 223-236.
9. Alvarez, I., & Marin, R. (2013). FDI and Technology as Levering Factors of Competitiveness in Developing Countries. Journal of International Management, 19, 232-246.
10. Anderson, R. W., & Carverhill, A. (2012). Corporate Liquidity and Capital Structure. The Review of Financial Studies, 25 (3), 797-837.
11. Arthur, W. B. (2005). Out-of-Equilibrium Economics and Agent-Based Modeling. *Interim Report, IR-05-046.* International Institute for Applied Systems Analysis.
12. Baharadwaj, S., Clark, T., & Kulviwat, S. (2005). Marketing, Market Growth, an Endogenous Growth Theory: Inquiry Into the Causes of Market Growth. *Journal of the Academy of Marketing Science*, 33 (3), 347-359.
13. Bayarcelik, E. B., & Tasel, F. (2012). Research and Development: Source of Economic Growth. *Procedia - Social and Behavioral Sciences,* 58, 744-753.
14. Baldwin, R., Braconier, H., & Forslid, R. (2005). Multinationals, Endogenous Growth, and Technological Spillovers: Theory and Evidence. *Review of International Economics*, 13(5), 945–963.
15. Barro, R. J., & Sala-i-Martin, X. (2004). *Economic Growth* (2nd ed.). Cambridge, London: The MIT Press.
16. Batabyal, A. A., & Nijkamp, P. (2012). A Schumpeterian Model of Entrepreneurship, Innovation, and Regional Economic Growth. *International Regional Science Review*, 35, 339–361.
17. Beag, F. A., & Singla, N. (2014). Cointegration, Causality and Impulse Response Analysis in Major Apple Markets of India. *Agricultural Economics Research Review*, 27 (2), 289-298.
18. Becerra, M. (2009). *Theory of the Firm for Strategic Management: Economic Value Analysis*. Cambridge: Cambridge University Press.
19. Behun, M., Gavurova, B., Tkacova, A., & Kotaskova, A. (2018). The Impact of the Manufacturing Industry on the Economic Cycle of European Union Countries. *Journal of Competitiveness*, 10 (1), 23-39.

20. Belkhir, M., Boubakri, N., & Grira, J. (2017). Political risk and the cost of capital in the MENA region. *Emerging Markets Review*, 33, 155-172.
21. Belotti, F., Daidone, S., Ilardi, G., & Atella, V. (2013). Stochastic frontier analysis using Stata. *The Stata Journal*, 13 (4), 719-758.
22. Bolton, P., & Freixas, X. (2000). Equity, Bonds, and Bank Debt: Capital Structure and Financial Market Equilibrium under Asymmetric Information. *Journal of Political Economy*, 108 (2), 324-351.
23. Braunerhjelm, P., Acs, Z. J., Audretsch, D. B., & Carlsson, B. (2010). The missing link: knowledge diffusion and entrepreneurship in endogenous growth. *Small Business Economics*, 34, 105-125.
24. Bressler, S. L., & Seth A. K. (2011). Wiener–Granger Causality: A well established methodology. *NeuroImage*, 58, 323-329.
25. Brischetto, A., & Voss, G. (1999). A Structural Vector Autoregression Model of Monetary Policy in Australia. *RBA Research Discussion Papers*, 1999-11, Reserve Bank of Australia.
26. Britzelmaier, B., Kraus, P., Haberle, M., & Mayer, B. (2013). Cost of Capital in SMEs: Theoretical considerations and practical implications of a case study. *EuroMed Journal of Business*, 8 (1), 4-16.
27. Candemir, M., Ozcan, M., Gunes, M, & Deliktas, E. (2011). Technical Efficiency and Total Factor Productivity Growth in the Hazelnut Agricultural Sales Cooperatives Unions in Turkey. *Mathematical and Computational Applications*, 16 (1), 66-76.
28. Cantore, N., Cali, M., & te Velde, D. W. (2016). Does energy efficiency improve technological change and economic growth in developing countries? *Energy Policy*, 92, 279-285.
29. Cavusoglu, N., & Tebaldi, E. (2006). Evaluating growth theories and their empirical support: An assessment of the convergence hypothesis. *Journal of Economic Methodology*, 13 (1), 49-75.
30. Cekrezi, A. (2013). A literature review of the trade‒off theory of capital structure. *ILIRIA International Review*, 3 (1), 125-134.
31. Charoenrat, T., & Harvie, C. (2014). The efficiency of SMEs in Thai manufacturing: A stochastic frontier analysis. *Economic Modelling*, 43, 372-393.
32. Chaudhuri, S., & Mukhopadhyay, U. (2014). *Foreign Direct Investment in Developing Countries: A Theoretical Evaluation*. New Delhi: Springer.
33. Chen, Y., & Fang, Z. (2018). Industrial electricity consumption, human capital investment and economic growth in Chinese cities. *Economic Modelling*, 69, 205-219.
34. Chen, L., Gao, J., Vahid, F., & Harris, D. (2015). *Linear Regression for Trending Time Series with Endogeneity*. 61 p.
35. Chen, L.-J., & Chen, S.-Y. (2011). How the Pecking-Order Theory Explain Capital Structure. *Journal of International Management Studies*, 6 (2).
36. Chen, S.-H. (2012). Varieties of agents in agent-based computational economics: A historical and an interdisciplinary perspective. *Journal of Economic Dynamics & Control*, 36, 1-25.
37. Chu, A. C., Cozzi, G., Furukawa, Y., & Liao C.-H. (2017). Inflation and economic growth in a Schumpeterian model with endogenous entry of heterogeneous firms. *European Economic Review*, 98, 392-409.
38. Comin, D. (2010). Total Factor Productivity. *Economic Growth*, 260-263.
39. Costantini, V., & Monni, S. (2008). Environment, human development and economic growth. *Ecological Economics*, 64, 867-880.
40. Crafts, N. (2017). Is Slow Economic Growth the 'New Normal' for Europe? *Atlantic Economic Journal*, 45, 283-297.

41. D'Agata, A., & Freni, G. (2003). The structure of growth models: a comparative survey. In Salvadori, N. (Ed.) *The Theory of Economic Growth: a 'Classical' Perspective*, (p.p. 23-41). Cheltenham, Northampton MA: Edward Elgar.
42. Damasio, B., & Mendonca, S. (2019). Modelling insurgent-incumbent dynamics: Vector autoregressions, multivariate Markov chains, and the nature of technological competition. *Applied Economics Letters*, 26 (10), 843-849.
43. Damodaran, A. (2012). *Investment Valuation: Tools and Techniques for Determining the Value of any Asset* (3rd ed.). New Jersey: John Wiley & Sons, Inc.
44. Daoud, J. I. (2017). Multicollinearity and Regression Analysis. *Journal of Physics, Conference Series*, 949.
45. Darley, V., & Outkin, A. V. (2007). *A Nasdaq Market Simulation: Insights on a Major Market from the Science of Complex Adaptive Systems. Vol. 1*. Singapore: World Scientific Publishing Co. Pte. Ltd.
46. Dawid, H. (2006). Agent-Based Models of Innovation and Technological Change. In Tesfatsion, L, & Judd, K. L. (Ed.) *Handbook of Computational Economics: Agent-Based Computational Economics. Vol 2*. Amsterdam: North-Holland, imprint of Elsevier.
47. Di Vita, G. (2006). Natural resources dynamics: Exhaustible and renewable resources, and the rate of technical substitution. *Resources policy*, 31, 172-182.
48. Dolado, J. J., Gonzalo, J., & Marmol, F. (2003). Cointegration. In Baltagi B. H. (Ed.) *A Companion to Theoretical Econometrics*. New Jersey: Blackwell Publishing Ltd.
49. Dreger, C., & Herzer, D. (2013). A further examination of the export-led growth hypothesis. *Empirical Economics*, 45, 39-60.
50. Ehramann, M., Ellison, M., & Valla, N. (2003). Regime-dependent impulse response functions in a Markov-switching vector autoregression model. *Economics Letters*, 78, 295-299.
51. Eichler, M. (2011). Causal Inference in Time Series Analysis. *Causality*, 6-28.
52. Enders, W. (2015). *Applied Econometric Time Series* (4th ed.). New Jersey: John Wiley & Sons, Inc.
53. Englmann, F. C. (1994). A Schumpeterian model of endogenous innovation and growth. *Journal of Evolutionary Economics*, 4, 227-241.
54. Enns, P. K., Masaki, T., & Kelly, N. J. (2014). *Time Series Analysis and Spurious Regression: An Error Correction*. Cornell University.
55. Erken, H., Donselaar, P., & Thurik, R. (2018). Total factor productivity and the role of entrepreneurship. *The Journal of Technology Transfer*, 43, 1493-1521.
56. Fabozzi, F. J., & Drake, P. P. (2009). *Finance: Capital Markets, Financial Management, and Investment Management*. New Jersey: John Wiley & Sons, Inc.
57. Feng, C., & Wang, M. (2017). Analysis of energy efficiency and energy savings potential in China's provincial industrial sectors. *Journal of Cleaner Production*, 164, 1531-1541.
58. Fortunato, P., & Razo, C. (2014). Export sophistication, growth and the middle-income trap. In Salazar-Xirinachs, J. M., Nubler, I., & Kozul-Wright, R. (Ed.). *Transforming Economies: Making industrial policy work for growth, jobs and development*. Geneva: International Labor Organization.
59. Frank, M. Z., & Goyal, V. K. (2003). Testing the pecking order theory of capital structure. *Journal of Financial Economics*, 67, 217-248.
60. Gaziulusoy, A. I. (2015). A critical review of approaches available for design and innovation teams through the perspective of sustainability science and system innovation theories. *Journal of Cleaner Production*, 107, 366-377.
61. Grant, J. L. (2003). *Foundations of Economic Value Added* (2nd ed.). New Jersey: John Wiley & Sons, Inc.

62. Gugler, P., & Brunner, S. (2007). FDI Effects on National Competitiveness: A Cluster Approach. *International Advances in Economic Research*, 13, 268-284.
63. Ha, J., & Howitt, P. (2007). Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory. *Journal of Money, Credit and Banking*, 39 (4), 733-774.
64. Harris, D. J. (2007). The Classical Theory of Economics Growth. *The New Palgrave Dictionary of Economics* (2nd ed.). London: Macmillan.
65. He, Z., & Maekawa, K. (2001). On spurious Granger causality. *Economics Letters*, 73, 307-313.
66. Hong, Y., Liu, Y., & Wang S. (2009). Granger causality in risk and detection of extreme risk spillover between financial markets. *Journal of Econometrics*, 2009, 271-287.
67. Hsu, C.-I., & Li H.-C. (2009). An integrated plant capacity and production planning model for high-tech manufacturing firms with economies of scale. *International Journal of Production Economics*, 118, 486-500.
68. Hulten, C. R. (2001). Total Factor Productivity. A Short Biography. In Dean, E. R., & Harper, M. J. (2001). *New Developments in Productivity Analysis*. University of Chicago Press.
69. Yu, M.-M. (2008). Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world's railways through NDEA analysis. *Transportation Research Part A*, 42, 1283-1294.
70. Yu-Thompson, Y., Lu-Andrews, R., & Fu L. (2016). Liquidity and corporate governance: evidence from family firms. *Review of Accounting and Finance*, 15 (2), 144-173.
71. Jarreau, J., & Poncet, S. (2012). Export sophistication and economic growth: Evidence from China. Journal of Development Economics, 97, 281-292.
72. Jones, C. I., & Vollrath, D. (2013). *Introduction to Economic Growth* (3rd ed.). New York, London: W. W. North & Company.
73. Karlsson, S. (2013). Forecasting with Bayesian Vector Autoregressions. *Handbook of Economic Forecasting*, 2, 791-897.
74. Kilian L., & Lutkepohl, H. (2017). *Structural Vector Autoregression Analysis*. Cambridge: Cambridge University Press.
75. Kopf, D. A. (2007). Endogenous growth theory applied: Strategies for university R&D. *Journal of Business Research*, 60, 975-978.
76. Kumar, R. (2016). *Valuation: Theories and Concepts*. London: Academic Press, an imprint of Elsevier.
77. Kumbhakar, S. C., & Lovell, C. A. K. (2003). *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press.
78. Kurz, H. D., & Salvadori, N. (2003). Theories of Economic Growth – Old and New. *The Theory of Economic Growth: A 'Classical' Perspective*. Cheltenham: Edward Elgar.
79. Landreth, H., & Colander, D. C. (2001). *History of Economic Thought* (4th ed.). Boston, Toronto: Houghton Mifflin Company.
80. Leary, M. T., & Roberts, M. R. (2010). The pecking order, debt capacity, and information asymmetry. *Journal of Financial Economics*, 95, 332-355.
81. Li, K., Niskanen, J., & Niskanen, M. (2018). Capital structure and firm performance in European SMEs. Does credit risk make a difference? *Managerial Finance*, 45 (5), 582-601.
82. Lu, W.-C., Chen, J.-R., & Wang, C.-L. (2006). Granger causality test on R&D spatial spillovers and productivity growth. *Applied Economics Letters*, 13 (13), 857-861.
83. Macal, C. M., & North, M. J. (2006). Tutorial on Agent-Based Modeling and Simulation Part 2: How to Model with Agents. *Proceedings of the 2006 Winter Simulation Conference*.

84. Machek, O., & Hnilica, J. (2012). Total Factor Productivity Approach in Competitive and Regulated World. *Procedia – Social and Behavioral Sciences*, 57, 223-230.
85. Meon, P.-G., & Sekkat, K. (2012). FDI Waves, Waves of Neglect of Political Risk. *World Development*, 40 (11), 2194-2205.
86. Michalski, G. (2010). Planning Optimal From The Firm Value Creation Perspective. Levels Of Operating Cash Investments. *Romanian Journal of Economic Forecasting*, 13 (1), 198-214.
87. Michelfelder, R. A. (2015). Empirical analysis of the generalized consumption asset pricing model: Estimating the cost of capital. *Journal of Economics and Business*, 80, 37-50.
88. Miglo, A. (2011). Trade-Off, Pecking Order, Signaling, and Market Timing Models. In Baker, H. K., Martin, G. S. (Ed.) *Capital Structure and Corporate Financing Decisions: Theory, Evidence and Practice*. New Jersey: John Wiley & Sons, Inc.
89. Moffatt, I. (2000). Ecological footprints and sustainable development. *Ecological Economics*, 32, 359-362.
90. Monostori, L., Vancza, J., & Kurama, S. R. T. (2006). Agent-Based Systems for Manufacturing. *CIRP Annals*, 55 (2), 697-720.
91. Nanda, S., & Panda, A. K. (2017). The determinants of corporate profitability: an investigation of Indian manufacturing firms. *International Journals of Emerging Markets*, 13 (1), 66-86.
92. Nguyen, N. B. (2010). Estimation of Technological Efficiency in Stochastic Frontier Analysis. Dissertation, Graduate College of Bowling Green State University.
93. Novales, A., Fernandez, E., & Ruiz, J. (2009). *Economic Growth. Theory and Numerical Solution Methods.* Berlin: Springer.
94. Odeck, J. (2007). Measuring technical efficiency and productivity growth: a comparison of SFA and DEA on Norwegian grain production data. *Applied Economics*, 39 (20), 2617-2630.
95. Odeck, J., & Brathen, S. (2012). A meta-analysis of DEA and SFA studies of the technical efficiency of seaports: A comparison of fixed and random-effects regression models. *Transportation Research Part A*, 46, 1574-1585.
96. Ozokcu, S., & Ozdemir, O. (2017). Economic growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews*, 72, 639-647.
97. Pannell, D. J. (1997). Sensitivity analysis of normative economic models: theoretical framework and practical strategies. *Agricultural Economics*, 16 (2), 139-152.
98. Peseran, M. H. (2015). *Time Series and Panel Data Econometrics*. Oxford: Oxford University Press.
99. Rabbani, S. (2006). Derivation of Constant Labor and Capital Share from the Cobb-Douglas Production Function. Access via internet: https://srabbani.com/cobb_douglas.pdf
100. Rao, R. K. S., & Stevens, E. C. (2007). *A Theory of the Firm's Cost of Capital: How Debt Affects the Firm's Risk, Value, Tax Rate and the Government's Tax Claim*. Singapore: World Scientific Publishing Co. Pte. Ltd.
101. Raza, S. A., & Karim, M. Z. A. (2017). Influence of systemic banking crisis and currency crisis on the relationship of export and economic growth. Evidence from China. *Journal of Chinese Economic and Foreign Trade Studies*, 10 (1), 82-110.
102. Richiardi, M. G. (2012). Agent-based computational economics: a short introduction. *The Knowledge Engineering Review*, 27 (2), 137-149.
103. Roberts, M., & Setterfield, M. (2007). What is endogenous growth theory? In Arestis, P., Baddeley, M., & McCombie, J. S. L. (Ed.) *Economic Growth: New Directions in Theory and Policy*. Cheltenham, Northampton MA: Edward Elgar.

104. Sathyamoorty, V., & Tang, T. C. (2018). Institutional quality and export-led growth: an empirical study. *Journal of Economic Studies*, 45 (1), 193-208.
105. Seck, A. (2012). International technology diffusion and economic growth: Explaining the spillover benefits to developing countries. *Structural Change and Economic Dynamics*, 23, 437-451.
106. Sener, S., & Saridogan, E. (2011). The Effects Of Science-Technology-Innovation On Competitiveness And Economic Growth. *Procedia - Social and Behavioral Sciences*, 24, 815-828.
107. Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitao, N. C. (2013). Economic growth, energy consumption, financial development, international trade andCO2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews*, 25, 109-121.
108. Shukur, G., & Mantalos, P. (2000). A simple investigation of the Granger-causality test in integrated-cointegrated VAR systems. *Journal of Applied Statistics*, 27 (8), 1021-1031.
109. Solow, R. M. (1999). Neoclassical Growth Theory. *Handbook of Macroeconomics 1*. 637-667.
110. Sorrell, S. (2010). Energy, Economic Growth and Environmental Sustainability: Five Propositions. *Sustainability*, 2, 1784-1809.
111. Subramanyam, K. R. (2014). *Financial Statement Analysis* (11th ed.). New York: McGraw-Hill Education.
112. Tesfatsion, L. (2002). Agent-based computational economics: modeling economies as complex adaptive systems. *Information Sciences*, 149, 263-269.
113. Tuppura, A., Arminen, H., Patari, S., & Jantunen, A. (2016). *Social Responsibility Journal*, 12 (4), 672- 686.
114. Vernon, V. (2004). Food Expenditure, Food Preparation Time and Household Economies of Scale. *EconWPA, Labor and Demography*, 47 pages.
115. Verspagen, B., & Loo, I. D. (1998). Technology Spillovers Between Sectors and Over Time. *Technological Forecasting and Social Change*, 60 (3), 215-235.
116. Vilcu, A. D., & Vilcu, G. E. (2013). On Homogeneous Production Functions with Proportional Marginal Rate of Substitution. *Mathematical Problems in Engineering*, Volume 2013, 5 pages.
117. Wahlen, J. M., Baginski, S. P., & Bradshaw, M. T. (2010). *Financial Reporting, Financial Statement Analysis, and Valuation: A Strategic Perspective* (7th ed.). Mason: South-Western Cengage Learning.
118. Wang, Y.-J. (2002). Liquidity management, operating performance, and corporate value: evidence from Japan and Taiwan. *Journal of Multinational Financial Management*, 12, 159-169.
119. Wang, M., & Wong, M. C. S. (2016). Effects of Foreign Direct Investment on Firm-level Technical Efficiency: Stochastic Frontier Model Evidence from Chinese Manufacturing Firms. *Atlantic Economic Journal*, 44 (3), 335-361.
120. Weil, D. N. (2013). *Economic Growth* (3rd ed.). Brown University, Rhode Island: Pearson.
121. Wooldridge, J. M. (2012). *Introductory Econometrics: A Modern Approach* (5th ed.). Mason: South-Western, Cengage Learning.
122. Xu, B., & Lin B. (2016). Reducing carbon dioxide emissions in China's manufacturing industry: a dynamic vector autoregression approach. *Journal of Cleaner Production*, 131, 594-606.
123. Zhang, R., & Kanazaki, Y. (2007). Testing static tradeoff against pecking order models of capital structure in Japanese firms. *International Journal of Accounting and Information Management*, 15 (2), 24-36.

124. Zhang, X., Wu, L., Zhang, R., Deng, S., Zhang, Y., Wu, J., Li, Y., Lin, L., Li, L., Wang, Y., & Wang, Y. (2013). Evaluating the relationships among economic growth, energy consumption, air emissions and air environmental protection investment in China. *Renewable and Sustainable Energy Reviews*, 18, 259-270.
125. Zhou, G., & Luo, S. (2018). Higher Education Input, Technological Innovation, and Economic Growth in China. *Sustainability*, 10 (8), 2615.

APPENDIX. DATA USED IN RESEARCH AND ITS CHARACTERISTICS.

Table A.1. Capital employed in the production process, thousands of euros per worker

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	10.02	9.34	9.61	9.83	10.68	11.75	12.72	13.82	16.45	17.21	16.87	17.78	18.87	20.23	21.29	21.78	22.60	24.34	27.32
C11	29.15	32.51	32.67	36.34	38.53	40.88	41.18	41.41	46.18	51.39	55.92	55.59	55.98	57.13	53.03	66.36	78.95	79.14	113.16
C13	9.83	10.05	10.83	9.75	9.97	9.90	11.00	13.12	15.98	19.94	19.38	15.72	14.54	12.04	11.48	10.96	11.21	11.70	12.32
C14	2.55	2.50	2.31	1.99	2.39	2.46	2.66	3.05	3.51	3.50	3.07	2.99	3.01	3.05	3.23	3.48	3.89	4.11	4.74
C15	8.84	8.94	7.55	6.78	7.03	7.66	9.07	9.18	7.79	8.95	11.04	12.24	11.24	10.34	7.96	7.83	7.38	7.44	6.80
C16	5.03	5.18	5.43	6.23	6.96	7.42	9.34	11.43	13.56	18.23	16.52	15.03	13.22	13.56	14.00	14.04	14.29	14.88	17.05
C17	24.60	25.82	29.13	21.84	24.26	26.20	26.74	26.86	31.44	36.52	40.44	38.41	36.83	38.54	39.38	41.94	44.88	44.71	42.78
C18	16.63	15.71	19.71	15.31	16.31	12.42	12.35	17.60	22.45	27.70	26.96	25.70	21.38	19.72	17.99	16.94	15.79	16.39	17.27
C22	10.59	11.00	10.66	11.49	16.80	15.59	16.67	18.29	24.93	33.27	29.19	26.24	24.86	24.43	24.73	25.95	26.27	27.06	28.74
C23	16.75	18.62	19.03	17.53	17.79	18.96	20.80	23.09	26.53	36.97	38.64	35.59	34.78	35.02	34.89	34.39	34.90	34.93	35.55
C24	10.33	10.08	16.90	23.55	22.04	22.09	20.90	18.23	20.84	31.06	30.81	14.56	11.37	8.70	10.96	13.63	9.27	8.26	8.06
C25	7.61	7.48	8.76	8.41	7.99	8.63	9.76	10.43	10.41	13.62	13.73	13.02	13.02	14.18	12.06	12.70	13.26	14.69	17.01
C26	9.82	12.34	14.27	16.22	16.39	17.75	23.29	38.50	11.82	11.37	10.89	10.90	12.79	12.06	12.36	15.69	13.18	11.81	13.49
C27	9.54	10.11	9.39	8.57	8.78	8.30	8.51	9.71	9.84	13.14	12.08	10.79	11.83	11.67	12.77	13.14	13.54	13.84	14.59
C28	13.20	13.22	11.71	10.34	10.44	10.47	11.50	12.37	13.48	18.80	19.85	18.78	16.81	16.26	16.20	17.72	17.90	17.13	16.92
C30	10.95	11.51	12.04	13.68	12.65	12.71	12.53	11.44	11.89	14.03	22.70	16.81	8.79	11.46	12.23	9.62	8.52	7.63	7.69
C31	5.35	5.06	5.33	5.35	5.93	6.56	7.57	8.95	11.34	11.10	9.72	9.27	9.88	9.64	9.33	8.85	8.86	9.32	12.34
C33	6.17	5.80	6.85	6.40	5.05	5.14	5.15	6.68	8.01	8.18	8.09	7.90	8.43	8.38	8.22	8.23	7.86	7.29	7.05

Table A.2. Characteristics of capital employed in production process data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	9.34	27.32	16.45	5.54
C11	29.15	113.16	52.92	20.49
C13	9.75	19.94	12.62	3.11
C14	1.99	4.74	3.08	0.69
C15	6.78	12.24	8.63	1.59
C16	5.03	18.23	11.65	4.38
C17	21.84	44.88	33.75	7.78
C18	12.35	27.70	18.65	4.42
C22	10.59	33.27	21.41	7.17
C23	16.75	38.64	28.15	8.35
C24	8.06	31.06	16.40	7.34
C25	7.48	17.01	11.41	2.80
C26	9.82	38.50	15.00	6.50
C27	8.30	14.59	11.06	2.04
C28	10.34	19.85	14.90	3.20
C30	7.63	22.70	12.05	3.44
C31	5.06	12.34	8.41	2.23
C33	5.05	8.43	7.10	1.19

Table A.3. Gross domestic product, thousands of euros per worker

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	5.00	5.41	5.42	6.03	6.82	7.49	8.87	11.92	10.17	12.62	11.81	13.70	13.66	14.61	14.68	16.95	17.61	19.04	20.15
C11	13.75	14.84	16.67	16.03	19.45	21.99	24.87	32.76	30.07	28.93	25.31	25.23	28.33	28.07	35.14	39.60	36.34	36.15	38.00
C13	4.28	4.41	5.15	5.46	6.46	6.56	6.92	8.10	9.12	9.15	10.87	12.78	12.33	12.29	12.89	12.25	14.12	15.03	15.92
C14	3.56	3.81	3.78	3.39	4.21	4.53	4.93	5.70	5.95	5.35	5.95	7.14	7.06	7.72	8.08	8.39	9.17	9.79	10.49
C15	2.59	3.09	3.96	4.03	1.43	4.18	5.20	5.17	7.23	5.88	6.65	6.86	7.69	7.94	7.41	8.06	8.20	8.72	8.28
C16	3.73	3.70	4.21	4.57	5.05	5.89	6.73	7.67	7.59	8.10	9.21	9.66	9.08	10.72	12.01	11.96	13.00	14.08	16.85
C17	7.35	9.35	8.35	10.64	10.86	12.03	13.58	13.87	16.43	18.24	19.63	21.50	22.50	25.82	26.95	27.45	28.17	30.28	33.61
C18	6.58	7.01	8.51	8.62	8.06	9.93	10.84	12.60	13.80	9.59	11.48	14.90	15.69	15.00	15.57	16.50	16.18	17.08	18.31
C22	7.38	8.06	9.01	9.61	9.31	11.24	16.22	14.76	13.89	14.82	16.64	16.26	20.26	19.71	22.54	21.27	23.95	24.50	27.85
C23	4.28	6.23	6.85	7.78	9.05	10.10	15.37	19.76	16.61	9.50	10.52	13.05	15.25	16.47	18.21	17.40	19.02	19.68	21.26
C24	5.33	6.16	5.03	6.18	6.30	6.02	8.70	9.32	12.22	5.63	10.13	14.04	12.06	15.17	12.81	15.12	14.79	16.69	15.64
C25	4.14	4.45	5.05	5.61	6.29	7.76	9.34	11.63	12.47	9.05	11.13	12.65	13.05	13.82	15.15	16.72	17.35	18.28	19.09
C26	8.74	11.18	9.74	9.71	10.30	7.25	8.83	12.49	17.96	14.58	18.44	19.26	21.89	22.57	21.91	30.62	31.53	36.84	36.35
C27	5.10	5.96	6.79	7.43	9.13	9.94	9.40	11.12	12.08	7.87	12.47	15.14	14.30	15.50	15.90	17.80	18.83	19.20	18.88
C28	2.63	3.75	5.39	5.99	6.60	8.40	12.23	14.46	14.59	12.16	15.73	17.07	18.86	20.05	19.86	20.48	21.15	24.39	25.60
C30	7.51	8.83	8.08	8.21	11.72	12.84	14.35	15.65	18.81	17.16	31.68	14.65	5.50	9.41	14.92	18.65	17.64	21.17	23.40
C31	4.41	4.41	5.24	5.83	6.24	6.00	6.88	9.72	7.01	9.30	10.64	11.66	12.12	11.75	13.41	14.10	14.51	16.14	17.88
C33	4.14	4.68	3.84	5.42	7.06	8.12	10.20	12.98	15.57	10.17	12.06	14.06	16.63	15.22	14.89	17.05	18.88	20.40	23.53

Table A.4. Characteristics of gross domestic product data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	5.00	20.15	11.68	4.84
C11	13.75	39.60	26.92	8.20
C13	4.28	15.92	9.69	3.76
C14	3.39	10.49	6.26	2.21
C15	1.43	8.72	5.92	2.19
C16	3.70	16.85	8.62	3.77
C17	7.35	33.61	18.77	8.21
C18	6.58	18.31	12.43	3.74
C22	7.38	27.85	16.17	6.15
C23	4.28	21.26	13.49	5.28
C24	5.03	16.69	10.39	4.15
C25	4.14	19.09	11.21	4.82
C26	7.25	36.84	18.43	9.59
C27	5.10	19.20	12.26	4.66
C28	2.63	25.60	14.18	7.10
C30	5.50	31.68	14.75	6.46
C31	4.41	17.88	9.86	4.16
C33	3.84	23.53	12.36	5.79

Table A.5. Capital reinvestment ratio

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	18.73	22.49	22.20	25.20	29.70	22.30	24.71	24.12	24.85	12.89	11.79	19.61	20.29	19.70	17.62	16.72	18.11	19.05	20.10
C11	18.56	15.06	14.81	16.86	13.66	9.90	13.25	25.16	21.93	9.37	8.61	12.43	13.31	13.37	12.18	13.11	13.16	20.37	17.44
C13	10.89	22.66	17.39	16.25	19.22	24.53	18.29	16.27	13.80	6.42	6.09	16.21	14.25	12.48	16.68	19.81	18.25	17.98	17.60
C14	21.64	27.86	21.07	21.70	16.07	21.28	23.16	19.33	12.25	7.63	11.88	16.30	12.03	13.86	20.46	25.11	16.97	16.05	12.03
C15	76.54	117.30	98.96	124.72	97.16	125.44	121.65	112.69	95.12	54.20	64.60	77.56	64.30	78.27	153.85	214.98	166.70	168.26	156.71
C16	22.30	27.38	33.39	38.22	26.68	33.50	46.46	30.53	22.32	7.27	13.07	19.16	19.08	23.45	20.82	19.35	18.74	18.02	29.87
C17	6.16	15.32	18.59	20.23	23.55	20.38	22.56	26.33	21.06	18.93	10.14	19.49	15.36	23.80	25.80	21.77	27.76	20.15	21.57
C18	12.76	19.16	13.31	21.65	30.53	14.07	41.75	70.37	20.13	5.37	6.46	8.69	13.59	8.61	23.36	14.25	26.64	26.21	46.43
C22	24.45	39.48	38.56	31.65	58.68	51.01	30.87	46.35	31.99	8.38	13.82	19.65	22.93	20.65	30.58	27.82	21.61	27.14	29.26
C23	10.67	10.09	13.73	16.31	26.24	31.39	29.52	38.80	33.57	22.90	5.89	14.34	14.93	11.71	9.64	11.87	17.61	17.20	9.43
C24	10.22	8.28	10.31	3.69	2.70	4.73	12.64	25.31	19.08	1.79	4.76	8.10	8.75	10.18	6.64	11.19	7.17	12.58	33.94
C25	15.19	21.59	18.17	26.08	24.19	30.76	32.30	34.26	22.42	12.70	9.29	20.40	16.87	20.73	22.81	23.48	29.59	35.94	30.34
C26	31.13	43.28	31.48	27.24	26.84	8.71	7.48	5.46	18.65	12.55	25.73	62.50	25.19	36.75	35.31	27.19	21.88	29.35	71.35
C27	15.77	18.13	17.63	26.65	19.81	14.00	40.75	29.90	18.76	9.83	6.61	15.28	14.79	16.30	13.99	20.43	17.50	23.69	17.59
C28	6.21	6.92	13.87	15.06	15.93	22.23	26.23	23.74	21.73	19.34	13.72	19.32	16.39	22.14	25.87	26.80	21.61	22.95	28.05
C30	9.96	18.03	21.63	31.44	24.55	20.56	20.22	18.14	26.47	4.19	4.71	9.46	24.31	25.56	8.74	13.23	20.17	12.89	34.64
C31	18.16	26.82	31.16	33.59	32.76	29.58	36.70	30.65	18.23	7.32	19.97	26.84	17.51	20.19	20.22	25.36	25.00	27.10	41.38
C33	13.19	14.81	19.33	15.79	18.21	19.67	39.73	40.29	22.67	12.52	8.54	25.12	25.69	31.73	18.31	23.48	18.25	34.83	18.60

Table A.6. Characteristics of capital reinvestment ratio data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	11.79	29.70	20.54	4.32
C11	8.61	25.16	14.87	4.30
C13	6.09	24.53	16.06	4.70
C14	7.63	27.86	17.72	5.30
C15	54.20	214.98	114.16	42.82
C16	7.27	46.46	24.72	9.19
C17	6.16	27.76	19.94	5.32
C18	5.37	70.37	22.28	16.12
C22	8.38	58.68	30.26	12.45
C23	5.89	38.80	18.20	9.45
C24	1.79	33.94	10.63	7.96
C25	9.29	35.94	23.53	7.36
C26	5.46	71.35	28.85	16.87
C27	6.61	40.75	18.81	7.52
C28	6.21	28.05	19.37	6.27
C30	4.19	34.64	18.36	8.61
C31	7.32	41.38	25.71	8.04
C33	8.54	40.29	22.15	8.94

Table A.7. Capital equity to debt ratio

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	1.01	1.10	1.17	1.09	1.03	0.75	0.71	0.72	0.63	0.78	0.81	0.80	0.79	0.76	0.80	0.85	0.88	0.91	0.85
C11	2.08	3.04	3.11	2.27	1.74	1.45	1.52	1.29	1.25	1.28	1.09	0.99	1.00	0.98	1.12	1.56	1.74	1.99	1.69
C13	0.70	0.75	0.66	0.87	0.99	1.10	1.00	0.85	0.84	0.90	1.04	1.46	1.80	1.63	1.63	1.63	1.72	1.83	1.55
C14	0.55	0.59	0.99	1.05	1.19	1.07	0.96	0.83	0.83	0.92	0.90	0.97	1.12	1.10	1.14	1.40	1.36	1.46	1.30
C15	-0.08	-0.16	0.73	0.71	0.23	0.12	0.23	0.26	0.79	0.47	0.60	0.76	0.75	0.78	1.12	0.92	1.01	0.71	0.79
C16	0.51	0.57	0.58	0.69	0.67	0.61	0.46	0.36	0.25	0.32	0.36	0.35	0.45	0.48	0.53	0.58	0.71	0.84	0.86
C17	0.72	0.79	0.72	1.29	0.41	0.97	0.82	0.71	0.54	0.54	0.63	0.74	0.77	0.92	1.00	1.15	1.17	1.18	1.44
C18	0.62	0.63	0.30	0.55	0.46	0.85	0.81	0.53	0.50	0.37	0.43	0.47	0.78	0.94	1.11	1.14	1.18	1.11	1.09
C22	0.91	0.84	0.76	0.46	1.05	0.80	0.73	0.56	0.54	0.59	0.76	0.82	0.92	0.99	0.67	0.91	0.99	1.07	1.14
C23	0.85	0.88	0.89	0.93	1.07	1.04	1.19	1.11	1.05	1.07	0.86	0.99	0.92	0.90	0.87	0.86	1.07	1.07	1.14
C24	0.60	0.48	0.96	1.11	1.54	1.37	1.04	0.57	0.55	0.41	0.23	0.09	0.06	0.06	-0.06	-0.08	-0.05	0.11	0.09
C25	0.94	1.06	0.96	1.03	0.87	0.79	0.72	0.66	0.69	0.82	0.68	0.70	0.78	0.89	1.10	1.17	1.05	0.91	0.84
C26	0.57	0.82	0.87	0.84	0.90	0.73	0.60	0.70	0.92	1.05	0.91	0.79	0.89	1.05	0.93	1.07	1.26	1.29	1.52
C27	0.36	0.30	0.43	0.71	0.98	0.97	0.77	0.94	0.96	0.80	0.86	1.21	1.48	1.44	1.71	1.71	1.93	1.59	1.68
C28	0.48	0.02	-0.04	1.45	1.44	1.43	0.98	0.98	1.08	1.32	1.37	1.40	1.45	1.39	1.33	1.38	1.26	1.17	1.03
C30	2.26	2.35	2.40	1.63	1.43	1.66	1.53	1.50	1.30	1.68	2.93	1.34	0.02	-0.06	-0.14	0.91	1.09	1.04	0.89
C31	0.59	0.57	0.66	0.71	0.65	0.58	0.48	0.54	0.52	0.67	0.74	0.72	0.80	0.78	0.80	0.87	0.81	0.86	0.86
C33	0.90	1.01	0.72	-0.12	1.22	1.11	1.36	0.99	0.82	1.07	1.14	0.82	1.06	0.90	0.90	0.76	0.92	0.86	0.93

Table A.8. Characteristics of equity to debt ratio data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	0.63	1.17	0.87	0.15
C11	0.98	3.11	1.64	0.63
C13	0.66	1.83	1.21	0.41
C14	0.55	1.46	1.04	0.25
C15	-0.16	1.12	0.57	0.36
C16	0.25	0.86	0.54	0.17
C17	0.41	1.44	0.87	0.28
C18	0.30	1.18	0.73	0.29
C22	0.46	1.14	0.82	0.19
C23	0.85	1.19	0.99	0.11
C24	-0.08	1.54	0.48	0.51
C25	0.66	1.17	0.88	0.16
C26	0.57	1.52	0.93	0.24
C27	0.30	1.93	1.10	0.49
C28	-0.04	1.45	1.10	0.46
C30	-0.14	2.93	1.36	0.83
C31	0.48	0.87	0.70	0.12
C33	-0.12	1.36	0.91	0.30

Table A.9. Export to turnover ratio

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	0.22	0.25	0.27	0.29	0.31	0.34	0.37	0.38	0.37	0.38	0.41	0.39	0.40	0.39	0.39	0.38	0.38	0.37	0.42
C11	0.02	0.03	0.04	0.04	0.04	0.08	0.08	0.09	0.09	0.10	0.13	0.16	0.19	0.24	0.26	0.25	0.27	0.32	0.35
C13	0.80	0.82	0.90	0.89	0.88	0.88	0.92	0.96	0.83	0.80	0.80	0.80	0.80	0.75	0.75	0.70	0.76	0.75	0.68
C14	1.71	1.64	1.51	1.39	1.29	1.13	1.12	1.03	0.93	0.95	1.00	0.96	0.92	0.88	0.86	0.86	0.79	0.79	0.81
C15	0.69	0.80	0.93	0.67	0.57	0.62	0.58	0.68	0.66	0.50	1.02	1.20	1.18	1.26	1.09	1.03	0.85	0.90	1.01
C16	0.53	0.52	0.54	0.50	0.49	0.50	0.48	0.45	0.44	0.49	0.51	0.50	0.47	0.49	0.52	0.54	0.59	0.57	0.55
C17	0.27	0.28	0.27	0.31	0.38	0.40	0.42	0.44	0.40	0.39	0.48	0.49	0.35	0.41	0.41	0.42	0.40	0.45	0.45
C18	0.07	0.11	0.10	0.11	0.10	0.12	0.18	0.17	0.18	0.17	0.24	0.28	0.29	0.31	0.33	0.33	0.35	0.37	0.39
C22	0.22	0.19	0.23	0.26	0.35	0.45	0.44	0.44	0.45	0.51	0.56	0.55	0.56	0.57	0.58	0.59	0.60	0.62	0.64
C23	0.26	0.21	0.20	0.16	0.15	0.14	0.15	0.13	0.15	0.18	0.23	0.24	0.32	0.31	0.29	0.32	0.31	0.33	0.27
C24	0.96	0.73	0.58	0.51	0.56	0.56	0.57	0.49	0.65	0.59	0.64	0.68	0.64	0.70	0.67	0.71	0.67	0.70	0.68
C25	0.21	0.25	0.24	0.25	0.36	0.39	0.37	0.35	0.32	0.43	0.49	0.46	0.48	0.46	0.49	0.50	0.52	0.50	0.53
C26	0.70	0.70	0.71	0.74	0.74	0.83	0.90	0.79	0.74	0.86	0.82	0.90	0.77	0.74	0.78	0.73	0.74	0.80	0.67
C27	0.60	0.65	0.68	0.66	0.75	0.72	0.70	0.72	0.68	0.70	0.71	0.67	0.71	0.72	0.74	0.78	0.77	0.74	0.71
C28	0.47	0.44	0.41	0.57	0.53	0.74	0.64	0.78	0.93	1.04	0.79	0.67	0.64	0.62	0.63	0.68	0.70	0.71	0.70
C30	0.78	0.87	4.34	4.74	1.08	1.19	1.11	1.00	1.02	1.14	1.04	0.82	0.86	0.77	0.95	0.76	0.69	0.76	0.71
C31	0.55	0.60	0.63	0.65	0.47	0.50	0.47	0.45	0.47	0.52	0.62	0.60	0.63	0.64	0.63	0.63	0.61	0.62	0.77
C33	0.52	0.41	0.36	0.29	0.73	0.39	0.45	0.31	0.11	0.28	0.39	0.19	0.18	0.12	0.08	0.09	0.11	0.13	0.13

Table A.10. Characteristics of export to turnover ratio data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	0.22	0.42	0.35	0.06
C11	0.02	0.35	0.15	0.11
C13	0.68	0.96	0.81	0.07
C14	0.79	1.71	1.08	0.29
C15	0.50	1.26	0.85	0.24
C16	0.44	0.59	0.51	0.04
C17	0.27	0.49	0.39	0.07
C18	0.07	0.39	0.22	0.11
C22	0.19	0.64	0.46	0.15
C23	0.13	0.33	0.23	0.07
C24	0.49	0.96	0.65	0.10
C25	0.21	0.53	0.40	0.11
C26	0.67	0.90	0.77	0.07
C27	0.60	0.78	0.71	0.04
C28	0.41	1.04	0.67	0.16
C30	0.69	4.74	1.30	1.15
C31	0.45	0.77	0.58	0.08
C33	0.08	0.73	0.28	0.18

Table A.11. Cash ratio

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	8.86	12.40	12.49	17.63	18.84	7.18	6.64	8.12	6.59	12.27	13.23	7.00	9.21	8.76	12.81	16.28	18.86	19.68	11.45
C11	10.36	20.01	51.95	16.46	15.87	20.21	10.26	9.74	6.28	4.21	5.45	6.71	11.80	25.42	28.76	21.73	29.10	27.80	38.59
C13	5.53	3.61	3.07	4.74	6.43	9.42	8.75	9.35	6.32	12.80	15.38	22.09	19.22	24.23	27.06	22.95	25.39	22.80	25.26
C14	10.03	10.37	16.97	16.10	23.45	17.35	19.24	17.95	15.07	19.27	24.19	22.45	29.10	32.96	35.66	40.93	41.41	43.89	33.22
C15	1.56	3.53	3.44	3.98	8.67	4.81	13.14	11.54	14.13	11.48	13.91	12.65	14.14	16.06	21.74	14.15	12.20	9.99	14.51
C16	9.61	8.78	9.30	12.55	13.75	18.61	11.58	9.94	8.21	8.32	12.09	12.91	13.46	18.82	14.47	19.66	25.95	24.73	17.96
C17	12.92	6.09	7.64	19.20	12.41	13.45	19.00	8.70	7.59	14.99	16.63	13.90	20.75	12.56	13.70	16.26	17.44	14.26	28.67
C18	9.38	10.13	8.30	12.31	12.80	24.61	25.15	19.08	14.90	18.61	22.28	20.62	26.80	22.39	30.41	38.82	50.28	49.17	45.03
C22	10.26	10.60	14.07	6.60	10.40	9.54	8.28	8.85	9.82	15.09	11.43	15.87	16.10	18.45	17.50	19.40	19.56	14.82	15.90
C23	5.06	5.52	6.42	9.73	11.30	13.48	12.49	13.46	27.84	20.20	21.93	17.30	28.66	23.82	24.03	10.54	19.95	21.61	32.70
C24	6.86	9.15	13.28	9.36	4.37	18.82	33.54	7.78	8.52	6.07	3.81	7.33	10.52	11.46	11.65	9.87	12.75	13.58	17.53
C25	10.06	11.07	11.83	13.05	11.77	14.21	12.71	14.63	10.73	18.44	17.74	22.35	28.85	31.11	25.80	29.61	28.27	25.35	22.83
C26	14.36	11.54	7.01	10.98	6.54	5.84	6.28	8.95	21.38	19.74	20.33	28.17	35.09	37.40	41.36	67.29	62.11	53.24	57.61
C27	7.44	8.04	6.67	11.67	10.77	9.06	6.93	9.16	6.43	13.74	11.69	20.86	24.38	24.17	46.75	60.86	45.38	31.29	35.51
C28	4.03	4.34	3.11	9.91	13.37	15.72	15.48	13.12	11.89	22.74	24.06	16.60	27.17	25.93	25.09	23.26	38.30	32.99	23.55
C30	11.73	39.99	38.78	31.69	13.09	23.71	23.41	18.38	18.77	36.99	146.53	19.15	3.04	13.16	37.69	30.96	47.99	33.58	26.96
C31	7.80	6.72	41.57	9.62	7.92	9.16	11.40	9.52	7.59	11.49	13.99	12.06	12.41	12.10	12.25	15.40	15.51	16.05	13.32
C33	5.95	9.36	9.02	3.93	20.53	18.56	27.37	24.30	11.51	14.93	26.51	23.92	15.29	19.21	18.55	22.10	27.26	28.01	30.90

Table A.12. Characteristics of cash ratio data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	6.59	19.68	12.02	4.44
C11	4.21	51.95	18.98	12.51
C13	3.07	27.06	14.44	8.67
C14	10.03	43.89	24.72	10.55
C15	1.56	21.74	10.82	5.25
C16	8.21	25.95	14.25	5.34
C17	6.09	28.67	14.53	5.33
C18	8.30	50.28	24.27	13.13
C22	6.60	19.56	13.29	4.03
C23	5.06	32.70	17.16	8.23
C24	3.81	33.54	11.38	6.66
C25	10.06	31.11	18.97	7.41
C26	5.84	67.29	27.12	20.64
C27	6.43	60.86	20.57	16.26
C28	3.11	38.30	18.46	9.75
C30	3.04	146.53	32.40	30.00
C31	6.72	41.57	12.94	7.48
C33	3.93	30.90	18.80	8.02

Table A.13. Energy intensity ratio, monetary energy expenses/value of created products

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	0.03	0.03	0.03	0.03	0.02	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04
C11	0.05	0.05	0.04	0.04	0.04	0.06	0.05	0.04	0.04	0.07	0.07	0.06	0.07	0.06	0.04	0.05	0.03	0.06	0.04
C13	0.09	0.09	0.09	0.08	0.07	0.09	0.09	0.08	0.07	0.07	0.07	0.06	0.10	0.07	0.06	0.06	0.05	0.04	0.05
C14	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.04	0.03	0.06	0.03	0.02	0.03	0.03	0.03	0.04
C15	0.04	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.06	0.06	0.06	0.04	0.07	0.05	0.05	0.04	0.04	0.05	0.05
C16	0.06	0.06	0.04	0.04	0.04	0.09	0.08	0.07	0.07	0.08	0.08	0.08	0.06	0.07	0.06	0.08	0.05	0.06	0.06
C17	0.07	0.07	0.07	0.06	0.08	0.09	0.08	0.09	0.04	0.09	0.13	0.10	0.10	0.08	0.05	0.05	0.04	0.04	0.14
C18	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.03
C22	0.03	0.03	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.03	0.04	0.04
C23	0.08	0.08	0.07	0.06	0.05	0.12	0.10	0.09	0.06	0.10	0.12	0.14	0.15	0.16	0.13	0.11	0.09	0.09	0.10
C24	0.09	0.09	0.09	0.08	0.13	0.10	0.11	0.08	0.03	0.05	0.04	0.04	0.04	0.03	0.05	0.04	0.01	0.03	0.01
C25	0.06	0.06	0.04	0.04	0.02	0.04	0.03	0.03	0.02	0.04	0.05	0.03	0.04	0.04	0.03	0.02	0.03	0.02	0.02
C26	0.04	0.04	0.04	0.04	0.03	0.05	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.02
C27	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02
C28	0.06	0.06	0.05	0.04	0.03	0.04	0.03	0.02	0.02	0.04	0.03	0.03	0.03	0.02	0.03	0.02	0.03	0.02	0.01
C30	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.02	0.03	0.04	0.03	0.01	0.02	0.02	0.01	0.01	0.02	0.01	0.01
C31	0.03	0.03	0.03	0.03	0.02	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02
C33	0.04	0.04	0.04	0.03	0.02	0.05	0.02	0.02	0.01	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02

Table A.14. Characteristics of energy intensity data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	0.02	0.05	0.04	0.01
C11	0.03	0.07	0.05	0.01
C13	0.04	0.10	0.07	0.02
C14	0.02	0.06	0.03	0.01
C15	0.03	0.07	0.05	0.01
C16	0.04	0.09	0.07	0.02
C17	0.04	0.14	0.08	0.03
C18	0.02	0.04	0.03	0.01
C22	0.02	0.05	0.03	0.01
C23	0.05	0.16	0.10	0.03
C24	0.01	0.13	0.06	0.03
C25	0.02	0.06	0.04	0.01
C26	0.01	0.05	0.02	0.01
C27	0.02	0.04	0.02	0.01
C28	0.01	0.06	0.03	0.01
C30	0.01	0.04	0.02	0.01
C31	0.02	0.04	0.03	0.01
C33	0.01	0.05	0.02	0.01

Table A.15. Labor productivity, eur/h

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	15.89	15.89	15.48	16.13	16.79	21.37	24.35	30.22	35.89	32.16	38.21	46.83	48.79	51.85	51.57	47.51	47.23	52.41	54.59
C11	15.14	15.14	18.36	18.21	18.06	20.42	24.20	31.07	32.15	27.30	34.01	45.06	50.64	58.75	61.01	54.06	52.61	53.62	56.04
C13	8.42	8.42	9.08	9.93	10.77	11.19	11.92	13.24	15.10	15.16	19.20	22.00	21.22	21.85	22.17	21.46	22.13	22.45	24.84
C14	4.06	4.06	3.58	4.32	5.07	5.28	6.04	6.71	7.02	6.72	7.04	7.67	7.67	9.03	9.63	9.86	10.53	11.27	12.09
C15	9.12	9.12	8.73	9.98	11.24	8.62	8.88	8.76	8.08	8.58	11.08	11.75	12.41	11.99	10.78	13.03	12.73	14.86	11.14
C16	4.61	4.61	9.54	10.42	11.31	13.52	14.33	18.11	17.94	18.15	21.08	24.63	22.68	24.29	26.62	26.30	27.85	29.43	32.74
C17	13.81	13.81	16.16	16.32	16.48	20.56	24.14	25.67	26.62	26.11	35.05	41.25	40.36	44.90	42.20	44.41	43.82	48.06	51.32
C18	11.08	11.08	10.79	11.19	11.60	12.61	17.40	19.29	18.54	17.15	19.53	22.36	24.47	25.02	24.07	23.46	23.11	23.01	24.86
C22	16.76	16.76	16.86	20.36	23.85	29.66	35.07	39.00	37.83	34.24	43.22	49.89	52.13	50.04	51.48	51.39	49.50	54.64	59.07
C23	9.14	9.14	11.48	12.13	12.78	16.62	21.81	26.42	28.22	18.84	25.14	30.37	31.07	31.45	32.20	31.80	32.92	35.57	36.88
C24	14.04	14.04	12.68	10.78	8.89	10.93	12.60	16.97	33.12	32.76	45.65	54.34	51.62	51.57	58.61	59.69	52.07	60.02	66.67
C25	7.41	7.41	7.96	9.64	11.31	13.15	16.67	21.17	20.52	15.66	20.27	23.17	22.01	23.09	23.46	26.56	25.36	30.99	32.28
C26	13.54	13.54	15.48	17.25	19.02	20.62	28.61	26.01	32.47	27.11	34.56	34.50	32.03	27.44	27.56	39.04	36.69	41.88	34.98
C27	12.48	12.48	13.99	14.64	15.29	19.47	23.03	25.32	25.22	18.47	23.82	25.52	28.96	29.41	29.40	31.71	32.59	36.01	36.76
C28	5.27	5.27	6.59	7.72	8.86	10.96	15.27	20.83	21.76	15.74	21.05	25.36	24.76	25.65	27.86	26.48	28.26	34.48	36.44
C30	10.02	10.02	9.64	13.01	16.37	18.80	19.52	23.07	23.87	19.49	35.59	36.32	46.94	54.10	41.44	35.96	31.90	32.77	37.36
C31	7.57	7.57	8.48	9.28	10.08	11.04	13.27	16.71	18.34	18.41	21.11	23.26	24.99	25.14	26.60	26.03	26.28	28.63	30.81
C33	6.09	6.09	6.15	8.11	10.06	12.26	14.63	15.57	21.12	20.38	17.66	23.86	26.38	25.72	27.23	27.48	27.31	24.65	28.63

Table A.16. Characteristics of labor productivity data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	15.48	54.59	34.90	14.95
C11	15.14	61.01	36.10	16.79
C13	8.42	24.84	16.34	5.80
C14	3.58	12.09	7.25	2.58
C15	8.08	14.86	10.57	1.90
C16	4.61	32.74	18.85	8.35
C17	13.81	51.32	31.11	13.00
C18	10.79	25.02	18.45	5.48
C22	16.76	59.07	38.51	14.29
C23	9.14	36.88	23.89	9.51
C24	8.89	66.67	35.11	21.33
C25	7.41	32.28	18.85	7.73
C26	13.54	41.88	27.49	8.78
C27	12.48	36.76	23.93	7.85
C28	5.27	36.44	19.40	9.84
C30	9.64	54.10	27.17	13.20
C31	7.57	30.81	18.61	7.94
C33	6.09	28.63	18.39	8.27

Table A.17. Foreign capital to total capital ratio

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	0.19	0.23	0.25	0.34	0.26	0.27	0.27	0.28	0.25	0.28	0.28	0.29	0.29	0.30	0.29	0.36	0.43	0.44	0.45
C11	0.32	0.19	0.45	0.52	0.44	0.58	0.56	0.58	0.54	0.58	0.62	0.58	0.41	0.39	0.42	0.66	0.67	0.61	0.59
C13	0.45	0.53	0.55	0.55	0.47	0.36	0.41	0.43	0.36	0.41	0.40	0.45	0.42	0.51	0.50	0.50	0.54	0.54	0.53
C14	0.19	0.19	0.21	0.19	0.21	0.20	0.21	0.20	0.32	0.22	0.23	0.23	0.23	0.23	0.20	0.24	0.17	0.18	0.15
C15	0.02	0.04	0.06	0.22	0.18	0.09	0.10	0.10	0.07	0.08	0.04	0.03	0.03	0.03	0.04	0.05	0.05	0.05	0.05
C16	0.27	0.28	0.32	0.36	0.34	0.36	0.37	0.39	0.54	0.51	0.53	0.51	0.45	0.43	0.41	0.43	0.60	0.57	0.62
C17	0.33	0.34	0.43	0.53	0.42	0.30	0.33	0.35	0.39	0.40	0.26	0.29	0.28	0.24	0.24	0.23	0.24	0.23	0.24
C18	0.10	0.11	0.10	0.13	0.12	0.13	0.15	0.10	0.16	0.18	0.18	0.26	0.26	0.28	0.28	0.24	0.27	0.27	0.28
C22	0.49	0.50	0.55	0.49	0.83	0.70	0.68	0.65	0.57	0.62	0.65	0.65	0.68	0.61	0.61	0.67	0.66	0.69	0.62
C23	0.29	0.30	0.34	0.40	0.51	0.55	0.50	0.52	0.55	0.50	0.53	0.58	0.57	0.57	0.55	0.45	0.44	0.53	0.53
C24	0.43	0.45	0.59	0.53	0.20	0.06	0.06	0.06	0.28	0.28	0.24	0.58	0.62	0.67	0.83	0.78	0.73	0.81	0.79
C25	0.04	0.04	0.07	0.07	0.15	0.12	0.14	0.20	0.17	0.19	0.19	0.19	0.16	0.20	0.21	0.22	0.23	0.25	0.28
C26	0.24	0.31	0.38	0.42	0.47	0.59	0.56	0.52	0.02	0.02	0.02	0.15	0.13	0.12	0.13	0.12	0.22	0.29	0.17
C27	0.15	0.16	0.29	0.22	0.34	0.41	0.44	0.43	0.40	0.39	0.43	0.54	0.29	0.28	0.26	0.25	0.43	0.56	0.55
C28	0.06	0.07	0.07	0.04	0.04	0.08	0.10	0.16	0.16	0.18	0.20	0.21	0.17	0.16	0.30	0.12	0.14	0.25	0.13
C30	0.74	0.49	0.49	0.88	0.83	0.84	0.85	0.85	0.82	0.88	0.89	0.89	0.91	0.90	0.21	0.21	0.56	0.55	0.15
C31	0.08	0.10	0.11	0.10	0.09	0.18	0.20	0.17	0.19	0.22	0.17	0.17	0.21	0.19	0.20	0.21	0.20	0.20	0.34
C33	0.06	0.11	0.10	0.14	0.02	0.04	0.05	0.05	0.07	0.08	0.10	0.10	0.07	0.13	0.13	0.08	0.11	0.09	0.21

Table A.18. Characteristics of foreign capital to total capital ratio data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	0.19	0.45	0.30	0.07
C11	0.19	0.67	0.51	0.12
C13	0.36	0.55	0.47	0.06
C14	0.15	0.32	0.21	0.03
C15	0.02	0.22	0.07	0.05
C16	0.27	0.62	0.44	0.11
C17	0.23	0.53	0.32	0.09
C18	0.10	0.28	0.19	0.07
C22	0.49	0.83	0.63	0.08
C23	0.29	0.58	0.48	0.09
C24	0.06	0.83	0.47	0.27
C25	0.04	0.28	0.17	0.07
C26	0.02	0.59	0.26	0.19
C27	0.15	0.56	0.36	0.12
C28	0.04	0.30	0.14	0.07
C30	0.15	0.91	0.68	0.26
C31	0.08	0.34	0.18	0.06
C33	0.02	0.21	0.09	0.04

Table A.19. Inflation adjusted net profit, thousands of euros

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
C10	-219.19	210.44	95.52	386.74	633.50	704.79	481.86	975.62	138.92	635.49	624.39	761.30	863.00	919.49	953.97	912.81	1 364	1 130	1 071
C11	207.19	240.56	288.98	303.95	284.58	461.02	526.13	954.65	492.87	322.07	-49.25	135.63	209.59	219.49	345.18	252.04	952.40	130.99	103.19
C13	-338.95	-305.16	-278.53	-60.71	-2.01	57.75	21.07	-108.61	-116.49	-41.45	-6.20	201.55	181.59	126.23	143.09	169.85	231.07	172.97	175.87
C14	-72.21	20.96	62.14	219.88	170.81	175.18	135.28	54.73	-14.11	-2.60	81.77	171.55	129.52	120.19	188.35	156.77	146.73	154.43	106.96
C15	-409.34	-57.54	-6.50	-76.08	-129.57	-40.58	45.52	-18.03	4.61	12.68	-4.28	5.42	-2.44	1.44	2.33	-1.77	-2.93	-3.38	-9.51
C16	-187.75	51.71	7.78	159.73	121.43	164.52	121.74	-51.97	-555.55	-308.67	46.73	72.85	144.41	206.93	292.36	181.90	213.78	288.12	458.94
C17	-17.92	9.70	-18.67	-339.66	35.00	75.78	90.71	87.71	45.26	96.95	160.91	137.90	185.55	247.99	256.44	271.35	291.49	321.45	443.49
C18	-2.91	-3.34	-50.37	49.67	8.64	69.81	91.78	42.00	-4.68	-100.43	7.79	56.93	113.27	124.20	172.58	180.38	99.11	90.98	71.39
C22	80.77	146.72	157.98	165.46	134.76	242.48	333.96	392.55	78.48	-13.66	112.54	168.59	332.15	296.02	352.24	423.44	511.45	509.66	572.19
C23	-280.83	-99.92	-196.03	85.28	108.06	260.20	626.02	905.68	186.66	-388.77	-106.51	420.69	69.89	127.73	184.85	87.61	275.40	136.94	79.20
C24	-17.50	-9.12	-46.99	-55.86	3.83	-8.61	18.89	-1.87	15.03	-72.14	-38.35	-6.88	-16.47	8.24	-7.94	0.03	1.57	5.62	0.24
C25	-66.51	-45.24	-8.27	95.15	152.87	191.97	301.83	319.01	154.71	-62.47	119.90	273.78	295.30	312.67	407.56	447.73	525.14	387.44	348.13
C26	112.32	251.20	52.82	237.28	118.57	-332.59	-230.24	162.99	96.66	12.32	166.53	147.65	205.58	150.47	138.90	291.68	311.42	413.59	372.44
C27	-132.83	37.87	41.14	62.12	151.76	71.15	100.62	51.06	-8.28	-257.16	55.36	121.46	162.19	116.45	188.77	177.24	290.13	82.03	160.09
C28	-251.44	-728.74	-82.59	25.30	30.55	113.45	189.14	188.70	138.14	-7.40	130.79	160.85	227.43	283.29	263.74	251.89	217.95	352.94	317.95
C30	-46.46	49.96	54.17	23.65	40.51	74.51	37.85	82.63	39.34	56.91	84.95	32.75	-166.08	-62.20	-17.13	54.17	29.03	56.75	116.44
C31	-35.76	5.76	97.15	190.89	205.53	97.64	94.04	265.34	-13.60	47.34	302.19	355.71	443.12	346.84	539.87	643.14	603.51	761.18	906.31
C33	-104.74	-37.47	-150.39	-75.46	30.45	47.38	311.29	236.03	335.06	-63.57	54.71	129.12	197.08	115.20	71.27	64.60	247.35	291.05	335.63

Table A.20. Characteristics of inflation adjusted net profit data

	MIN	MAX	AVERAGE	STD. DEVIATION
C10	-219.19	1364.20	665.54	403.55
C11	-49.25	954.65	335.86	257.37
C13	-338.95	231.07	11.73	178.05
C14	-72.21	219.88	105.60	78.73
C15	-409.34	45.52	-36.31	97.99
C16	-555.55	458.94	75.21	229.53
C17	-339.66	443.49	125.34	169.51
C18	-100.43	180.38	53.52	71.85
C22	-13.66	572.19	263.04	167.64
C23	-388.77	905.68	130.64	301.85
C24	-72.14	18.89	-12.02	24.50
C25	-66.51	525.14	218.46	179.15
C26	-332.59	413.59	141.03	182.00
C27	-257.16	290.13	77.43	119.96
C28	-728.74	352.94	95.89	248.61
C30	-166.08	116.44	28.51	63.91
C31	-35.76	906.31	308.22	276.91
C33	-150.39	335.63	107.08	155.36

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