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MASTER THESIS

TECHNOLOGINĖ PAŽANGA IR INOVACIJŲ TENDENCIJOS BEI JŲ ĮTAKA EBPO ŠALIŲ EKONOMIKOS AUGIMUI (ES ŠALIŲ TYRIMAS)	TECHNOLOGICAL PROGRESS, INNOVATION TRENDS AND THEIR INFLUENCE ON ECONOMIC GROWTH IN OECD COUNTRIES (EU STUDY CASE)

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(scientific, pedagogical titles of the

supervisor, supervisor‘s name, surname)

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OECD	-	The Organization for Economic Co-operation and Development
EU	-	The European Union
WB	-	The World Bank
WIPO	-	The World Intellectual Property Organization
GDP	-	The Gross domestic product
GDPcap	-	The Gross domestic product per capita
POLS	-	The Pooled ordinary least squares regression model
FE	-	The Fixed Effects regression model
WTO	-	The World Trade Organization
IoT	-	The Internet of Things
AI	-	The Artificial Intelligence
ICT	-	The Information and Communication technology

INTRODUCTION

The relevance of the topic. The technological progress and innovation development in nowadays environment is enivitable (Freeman & Soete, 1997). Reviewed literature is confirming that the new stage of industrial revolution has begun and it is called Industry 4.0 (Kinkel et al., 2020; Schwab, 2017). Academic society highlight that the future of manufacturing belongs to the machines, integrated sensors which in general will form the entity called Smart Factory (Frey & Osborne, 2017; Maresova et al., 2018, Lasi et al., 2014). Despite the transformations based on Industry 4.0 yet another wave is arround the corner which is introducing humankind collaboration opportunities with precise and intellected robots (Maddikunta et al., 2022; Muller, 2020). Different scholars note that innovations are one of the key elements ensuring long-term prosperity. According to M. M. Khyareh and N. Rostami (2022) and capital invested to the research and development (R&D) returns in favour of macroeconomic stability and international competetiveness (Kiselakova et al., 2020; Khyareh & Rostami, 2022).

Next to the innovations and economic development goes hand in hand contradictions. Researched academic papers emphasize that the big data and data analytics in general creating inequalities in finance and retail sectors (Begenau et al., 2018; Kacperczyk et al., 2016; McAfee et al., 2012), innovation development process is execessively concentrated in big cities and benefiting only those which are inside the hub or operating so called innovative hubs (Fukuda 2020). Yet another stressed topic is innovation adoption and ability to quickly integrate them in societies which is crucial for developing countries in order not to regress according global macroeconomy paces (Castelo-Branco et al., 2019; Comin et al., 2008; Khyareh & Rostami, 2022).

To sum up, the primary review of literature indicate that innovation trends and technological progress are highly discussed topics among scholars. According various scientific sources author highlight that Technological progress and Innovation phenomenons topic is not homogenous and create various discussions on economic growth tendencies in different regions.

The level of topic's exploration and research gaps. First, author have reviewed solid list of references in order to overview current statements on technological progress and innovation trends topics. The majority of authors analyse technological progress and innovation foundational therminology, trends and developments (Kline & Rosenberg 2010; Freeman & Soete, 1997; Fagerberg, 2004; Brynjolfsson & McAfee, 2011; Schwab, 2017; OECD, 2018; Lasi et al., 2014; Kinkel et al., 2020; Van Duijn, 2013; Kondratieff, 1979; Schumpeter & Backhaus, 2003; Frey & Osborne, 2017; Maresova et al., 2018; Eurofound, 2019; Maddikunta et al., 2022; Muller, 2020).

Authors emphasize that technological progress and innovation trends topics typically are analyzed in Organisation for Economic Co-operation and Development (OECD) high-income (Guloglu & Tekin, 2012) or high-development European Union (EU) countries (Kabaklarli et al., 2018). There are few academic papers which analyzed EU technological progress and innovations impact. More importantly, those scholars who did it they executed it through ICT technologies defining variables (Fernandez-Portillo et al., 2020). Based on academic literature review there is lack of topic development in relation to technological progress and innovation trends in general OECD and EU context. The chosen topic covers the latest academic research papers gap reviewing these phenomenons of OECD membering countries in EU point of view.

The main aim of the study is to estimate the impact of technological progress and innovation trends phenomenons on OECD membering states in EU economic growth. Based on correlation and regression analyses results researcher about to present findings and draw conclusions related to statistical relationships of latter phenomenons.

In executed research paper author is filling the gap of missing newest scientific analyses by reviewing and gathering the latest possible secondary data up to 2021. The chosen period for this research paper is from 1996 to 2021. Motivation to select longer period of study was argumented by 2008-2009 global Financial crisis and 2020 erupted COVID-19 pandemy, which clearly had impact to the global macroeconomic development. Besides, author is trying to answer the question whether recession and COVID-19 had the effect on dependent variable – gross domestic product. As presented earlier, researcher did find few academic research papers which analyzed technological progress topic in fragmented parts of EU countries. However, there was no latest academic researches implemented for unified OECD EU object. For this matter, scholar will be analyzing 22 OECD EU member states based on two secondary data sources: the World Bank (WB) Development indicators data and the World Intellectual Property Organization (WIPO) data. In general dataset is panel and the final list of countries is as following - Austria, Belgium, the Republic of Czechia, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, the Republic of Slovakia, Slovenia, Spain, Sweden.

This paragraph author would like to dedicate to **research paper question** which can be raised as following - *Can we create a statistically significant and reliable regression model analyzing two individual factors – technological progress and innovation trends?*

Author raised following **master thesis objectives** for the Master thesis:

1. Review academic research paperworks, analyze and systematize the common academic notion
2. Estimate the technological progress and innovation trends statistical relationship with dependent variable – gross domestic product
3. Analyze the econometrical research models, test them and prove which one suits the best to provide final conclusions
4. Review raised hypotheses according final research paper econometrical output

During the whole research paper development process author applied variety of different tools to provide statistically proven results – SPSS, Gretl, Rstudio, Eviews. In this research paper author aplied the pooled ordinary least squares (POLS), the fixed effects (FE) regression models. In order to test different econometrical data assumptions following test been aplied – Stationarity test, Normal Distribution test, Cointegration test, Heteroscedasticity test, Statistical and Equation significance etc. More importantly, the dependent variable in this study will be gross domestic product (GDP) or this secondary data transformed versions such as percentage change of GDP (pc_GDPm).

The research paper structure is devided to following chapters: introduction, literature analysis, the empirical research methodology, the graphical data analysis, the empirical results analysis, conclusions with recommendations part. The each one of five body parts presented below:

- In the first chapter called - technological progress and innovation trends and economic growth theoretical, researcher is describing the terminology, possible measurement indicators and impacts on economy and society. It consists of six subchapters.
- The second chapter called – the empirical research methodology author reviewes theoretical notion to build correlation and regression analysis and what specific tests other scholars applied and what personally should author use. Chapter consists of five subchapters.
- The third chapter called - the graphical data study and empirical research analysis. In this chapter author reviewing the primary gathered data, analyzing the object countries finding similarities and differences among object countries. Chapter consists of three subchapters.
- The fourth chapter called – the correlation and regression analysis. In this chapter it is reviewed the econometrical process in depth. Here author step by step presenting

executed correlation and regression analysis actions and executed data and final results quality defining tests. Chapter consists of seven subchapters.

- The fifth chapter called – the empirical research conclusions and recommendations.

1. TECHNOLOGICAL PROGRESS, INNOVATION TRENDS AND ECONOMIC GROWTH THEORETICAL CONCEPTIONS

In the first chapter of research study paper author in general is reviewing academic literature. The first paragraph is devoted for technological progress and innovation definitions and how various scholars are describing these interconnected phenomenons. In the second paragraph scholar is presenting the historical technological progress and innovation tendencies development, how humankind get to the Industry 4.0 point and what is next. Furthermore, in the third paragraph author is analysing literature in relation to different researchers approaches to analyze technological progress and innovation trends impact on economic growth. In the fourth chapter it is analyzed the most suitable economic growth models in relation to technological progress and innovations. The fifth paragraph is dedicated to reviewing the research papers which analysed closely related topics in the Orginasation for Economic Co-operation and Development (OECD). Last but not least, is the technological progress and innovation contradictions paragraph which is presenting the key issues which these two phenomenons are creating based on academic society point of view.

1.1 Technological progress and Innovation foundational therminology

In the introductory section, author will start with foundational knowledge on technological progress and innovation therminology. In this research technological progress and innovation terms is considered as seperate terms. In publications reviewing technological progress it is presented as follows (Kline & Rosenberg 2010):

„<...> it is a major ingridient of long-term economic growth, and it is characterized by a high degree of uncertainty.“

After reviewing various scholars research papers and publications the literature presents that technological progress therminology is interpreted differently, sometimes it is juxtaposed with synonyms as transformation, development, acceleration, change, revolution (Freeman & Soete, 1997; Fagerberg, 2004; Brynjolfsson & McAfee, 2011; Schwab, 2017).

Looking from historical perspectives environment were constantly transforming which required adaptation. The mankind were forced to change their habits and adopt foraging and later on farming and change the settlements from rural to urbanized locations (Schwab, 2017). Based on authors personal interpretation these shifts in society done in thousands years ago considering from todays perspective would also be considered as technological progress.

In order to transform existing technological environment and create so called industrial revolution scientists and developers must create and patent thousands of innovations. This way technological progress is further developing and creating spillovers – when existing technologies are applied in practice they stimulate new secondary technologies emerging. The Industrial revolution shows us that technologies have brought spillovers which trasnformed regions from poverty to better quality of life (Freeman & Soete, 1997).

The next phenomenon analyzed in this paragraph is Innovation. In order to define the phrase as precise as possible a *Table 1* with quotations were created. Reviewed literature presenting that various scholars defined the therminology differently.

More than hundred years ago important changes in defining innovation and invention were made. J. Schumpeter and U. Backhaus first published in 1912 (2003) defined innovation as an often patentable idea - a new or highly improved equipment or organizational process. According to scholar, innovation from economical point of view is accomplished only with the first commercial agreement or contract involving the invented product, process etc. Also researcher is using phrase as "creative destruction" what nowadays could be defined as spillovers in order to visually describe constant business and society changes in order to develop and adapt innovations (Freeman & Soete, 1997; Schumpeter & Backhaus, 2003). Author would like to highlight that more that hundred years ago published document is using invention and innovation definitions which is practically applied until nowadays.

Table 1. *The list of Innovation therminology*

Author/Source, year of publication	Description
Kline & Rosenberg, 2010	Innovation is complex, uncertain somewhat disorderly, and subject to changes of many sorts.
Oslo Manual 4th edition (OECD), 2018	a) Innovation is central to improvements in living standard and can affect individuals, institutions, entire economic sectors and countries in multiple ways.
	b) An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)
	c) Innovation is more than a new idea or an invention. An innovation requires implementation, either by being put into active use or by being made available for use by other parties, firms, individuals or organizations.
	d) Innovation is a dynamic and pervasive activity that occurs in all sectors of an economy;

	e) A product or process of a newly established entity is an innovation if it differs significantly from products available in the relevant market or process that are currently in use by other entities in the relevant market.
	f) A business process innovation is a new or improved business process for one or more business functions that differs significantly from the firm‘s previous business processes and that has been brought into use by the firm.
Fagerberg, 2003	g) Innovation in the first commercialization of the idea.
	h) <...> innovation is often the result of a lengthy process involving many interrelated innovations.

Source: prepared by author (based on Kline & Rosenberg, 2010; OECD, 2018; Fagerberg, 2004)

After reviewing academy published research papers author concludes that technological progress and innovations are seperate terminologies and can not be merged or defined as synonyms. Technological progress is entity of applied and researched innovations which fosters economic development. Innovation is described as a new product technology or service differing from others existing solutions in the market. It is mostly one-time process with short period of validity.

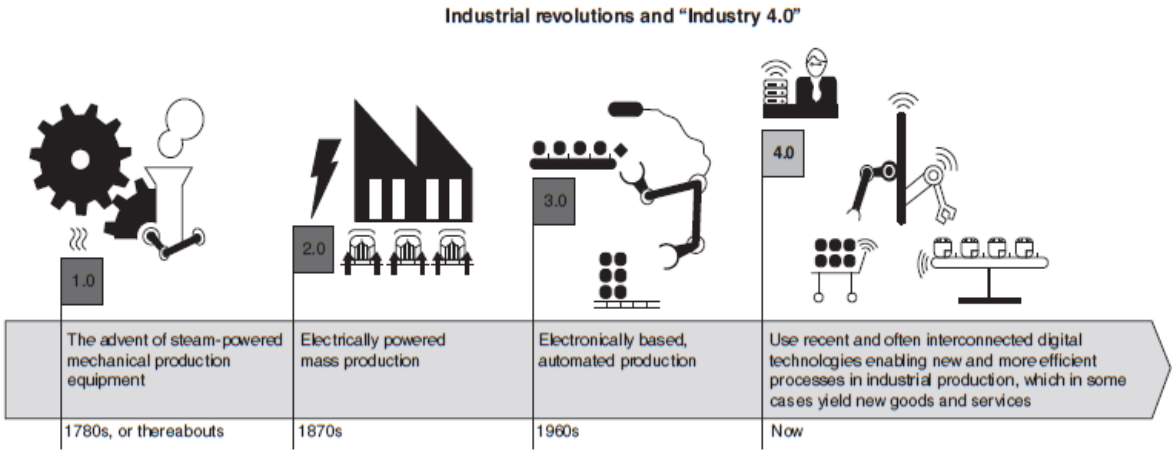
1.2 Historical development of technological progress and innovation trends

Since the first industrial revolution and steam invention technological progress encoded the demand to change. Moreover, new inventions created spillovers which benefitted societies and economic growth. Looking from today’s perspectives rapid innovations developing sectors started transforming our’s environment and classical perceptions as well encouraging scholars, businesses and governments to discuss and analyze impacts of it. Humankind development is inevitable which encourages to change outdated processes, adopt new policies and escalate impacts and risks. Further paragraph ideas are introduced according to reviewed study papers (Lasi et al., 2014; Kinkel et al., 2020; Schwab, 2017; Brynjolfsson & McAfee, 2011; Freeman & Soete, 1997; Van Duijn, 2013; Frey & Osborne, 2017; Maresova et al., 2018; Eurofound, 2019; Maddikunta et al., 2022).

To start with, humankind since the eighteenth century til twenty first century have witnessed three industrial revolutions. S. Kinkel (2020), presented simplified picture of industrial development since 1780s til nowadays showed in *Figure 1*. Schwab (2017) and Brynjolfsson & McAfee (2011) emphasizing the importance of each technology. The first mechanical engine powered by steam have helped to build innevitable infrastructure in railway sector. The second industrial revolution was based on electricity and scaled mechanical production and flourished

mass production. Furthermore, it was the third revolution which was fuelled by computers and networks and it's output was visible in society's increased digitalization (Brynjolfsson & McAfee, 2011; Schwab, 2017).

Figure 1. *Industry development based on technological progress. Visualization til nowadays*



Source: Kinkel et al., 2020.

C. Freeman and L. Soete (1997) in publication described that the innovation development is constant process and the view towards technologies have transformed from "means of human enslavement and destruction to liberating force" to "critical element in the competetive enterprises and national environment" (Freeman & Soete, 1997). The first three industrial revolution effects after implementing it been already introduced. Author would like to raise the question if the technological progress is a constant change, what is next the step?

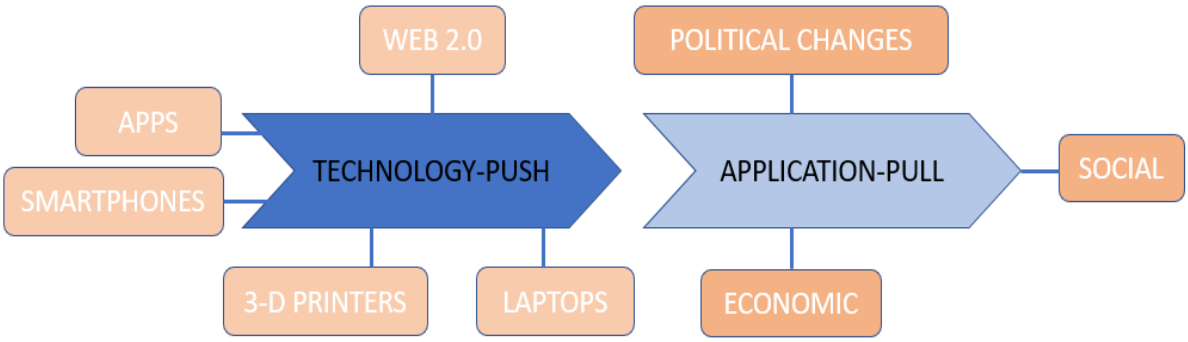
K. Schwab (2017) reported that hints of a new technological revolution began in 2011 at the Hannover Fair in Germany with the german term Industrie 4.0. S. Kinkel (2020) expressed no surprise that the fourth industrial revolution term was mentioned in Germany which had one of the most developed manufacturing facilities in the world and had one of the highest Industry 4.0 readiness index (Kinkel et al., 2020; Schwab, 2017).

Secondly, researcher K. Schwab (2017) clearly described the new chapter of industrial revolution which is called Industry 4.0. Researcher described it as interconnecting technologies which are "eliminating the boundaries between physical, digital and biological worlds". Author giving a notion that the fourth industrial revolution is considered as distint rather the prolongation of the third revolution. In reviewed study paper researcher argument it's opinion according three characteristics: velocity, breadth and depth in others words it is speed, scope and size (Schwab, 2017). Furthermore, academic scholars C. B. Frey & M. A. Osborne (2017), P. Maresova (2018), and H. Lasi (2014) introducing the manufacturing trends looking for future perspectives. Based

on their emphasized and systematized opinion it must have belong to integrated sensors and automated processes. These smart accessories broadly used in Smart Factories gathering the data which will merge the current place and data with cyber-physical systems. Scientists informs that growing numbers of robots in Smart Factories manufacturing processes will increase dexterity and non-routine manual tasks performace (Lasi et al., 2014; Frey & Osborne, 2017; Maresova et al., 2018). Yet another research paper but not academic however presenting the Eurofound (2019) governmental organizations point of view. Researchers described that automation will enable industries to transform and it might have great impacts in following activities - innovation research and development period reduction, enabling to execute individualized orders in small quantities due to customization, improve resource utilization and increase cost efficiency and decentralize decisions (Eurofound, 2019).

In addition to academic point of view H. Lasi (2014) introduced the cause (technology-push) and the consequence (application-pull) which is presenting that technology is the first which encourages society, political organizations to adapt to the changes. The scholar describing following technologies which lately acted as a catalyst for political, social and economic changes – Web 2.0, apps, smartphones, 3-D printers, laptops (Lasi et al., 2014). Based on research paper's systematized information author prepared *Figure 2*.

Figure 2. *The technological progress impact on environment development*



Source: prepared by author based on research paper's information (Lasi et al., 2014)

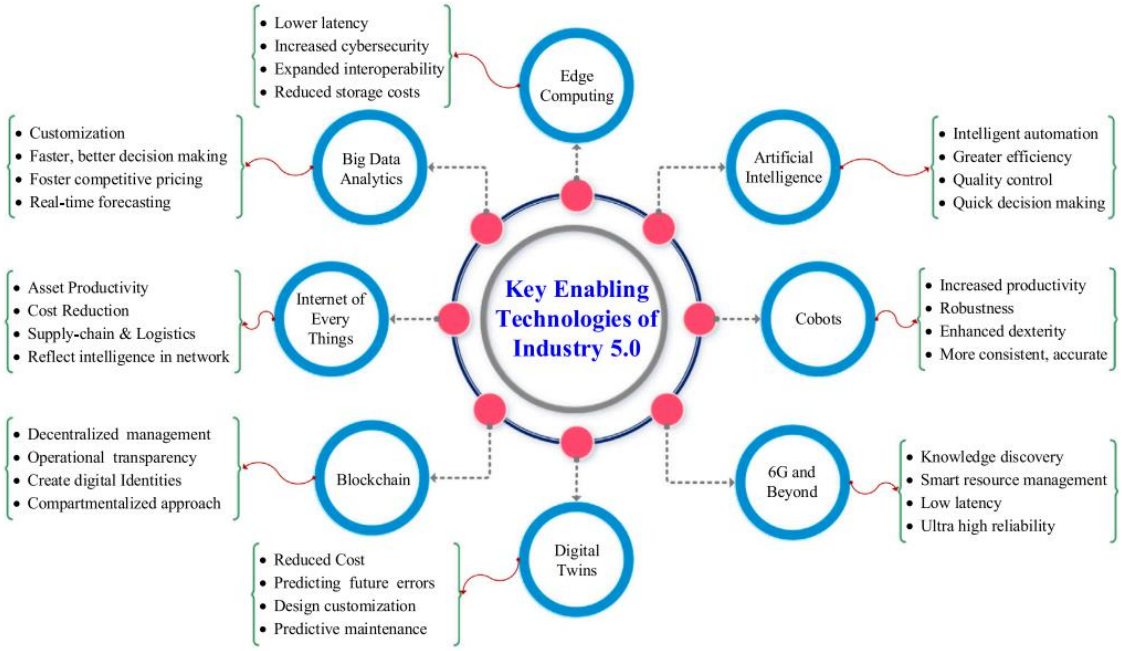
In spite of already reviewed technologies and ideas, researchers (Eurofound, 2019; Schwab, 2017; Maresova et al., 2018) presenting more systematized list of industry changing technologies which must be adopted shortly. The Eurofound (2019) agency distinguished five trending technologies and called it as game-changing technologies: advanced industrial robotics (AIR), additive manufacturing (AM), the industrial Internet of Things (IIoT), electric vehicles (EVs) and industrial biotechnology (IB) (Eurofound, 2019). The researcher K. Schwab (2017)

defined technologies as emerging which are - artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing (Schwab, 2017). Yet another scholar P. Maresova (2018) presented technologies and used synonym as promising technologies – Internet of Services (IoS) and Internet of People (IoP) (Maresova et al., 2018). Author would like to highlight the adjectives usage describing technologies in different publishings – game-changing, emerging, promising.

On the other hand, the technological progress had become demanding resources process. Academic society supporting the ideology that timeframe between different industrial revolution stages been decreasing due to faster R&D development and spillovers. J. J. Van Duijn (2013) reported that the classical economists J. Schumpeter, N. D. Kodratieff developed models predicting the length of business development periods called waves or cycles were significantly shortened since the start of model presentation in XX century (Van Duijn, 2013; Kondratieff, 1979; Schumpeter & Backhaus, 2003).

With respect to existing academic publishing, there exists contradicting oppinions (Maddikunta et al., 2022; Muller, 2020) which are supporting the fifth industrial revolution ideology and describing it as not intermediate but rather distinct. P. K. R Maddikunta state that Industry 4.0 is processes automation in manufacturing activities, while a new stage of revolution called Industry 5.0 is complete automation and humankind collaboration with powerful, smart and accurate machinery (Maddikunta et al., 2022). J. Muller's (2020) monograph describing the next stage technologies as - human-centric solutions, human-machine-interaction, bio-inspired technologies, smart materials, real time based digital twins, cyber safe data transmission, storage, analysis technologies, artificial intelligence, technologies for energy efficiency, autonomy (Muller, 2020). P. K. R Madikunta (2022) in study paper introduced technologies which can be called as prolongation of existing Industry 4.0 such as – Big data, artificial intelligence, Blockchain, Internet of Every Things). Moreover, scholars presented new technologies – Edge computing, Cobots, 6G and beyond, Digital Twins) which supposed to transform 4.0 to a distint stage of industrial development. In order to better depict Industry 5.0 *Figure 3* from analyzed research paper (Maddikunta et al., 2022) were published.

Figure 3. *The fundamental technologies defining Industry 5.0*



Source: Maddikunta et al., 2022.

Ultimately, the technological progress in described as continuous and ongoing process. The current industrial revolution stage called Industry 4.0 been applied since 2011 and from that time on became one of the most analyzed topics among academic scholars, governmental agencies etc. According to analyzed academic litterature author state that technologies often are juxtaposed with following adjectives - game-changing, emerging and promising. Also, technologies are seen as resource resources intensive process which in general is affecting environment's economy, society and politics. Spillovers and decreasing periods between technological changes are one of the aspirations which drive our society to a better living standard point.

1.3 Technological progress and innovation trends measurement methodology

In this subchapter author will review research papers on technological progress and innovation trends variable point of view and how scholars chose to measure it's impacts.

Generally speaking innovation measurement is a complex and demanding process. S. J. Kline and N. Rosenberg (2010) in their study presenting that analysis requires close coordination and technical background not forgetting excellent market judgement to meet economic, technological and other demands all simultaneously (Kline & Rosenberg, 2010). Yet another research paper which indicated innovation assessment as complex and subjective model was

published by the OECD governmental organization. Scholar highlight the importance of model suitability in order not to receive diverging results. Same study stresses the gathered data quality and suitability. Moreover, to collect reliable and quality data researcher must take into account differences in language, vocabulary used and understood while interviewing, statistical data quality and comparability (OECD, 2018).

After reviewing scholars works (Kiselakova et al., 2020; Khyareh & Rostami, 2022; Kumar Dhar et al., 2023; Maradana et al., 2019; Guloglu & Tekin, 2012; Comin et al., 2008; Kabaklarli et al., 2018; Castelo-Branco et al., 2019; Appiah-Otto & Song, 2021; Fernandez-Portillo et al., 2020) author indicate there are differences among analyzed research paper defining technological progress and innovation variables. Based on systematized information author have grouped different research paper in four categories represented in Figure 4. Each one of those groups are further described below.

First grouping of research papers which authors had selected the most popular and traditional innovation or technological progress measurement approach was based on macroeconomic data. Scholar D. Kiselakova (2020) used following variables in order to define innovations - gross domestic expenditures on research and development (GERD), European patent grants (EPG), high-tech exports (HTE), government expenditure on education (GEE), direct investment in the reporting economy (DI), gross fixed capital formation (GFC), tertiary educational attainment (TEA). Research paper overviewed 28 European Union (EU) memberstates economic development based on innovation defining variables. Assessment model for impact on economic growth were built by following indicators - high-tech exports, governmental expenditure on education, direct investment, tertiary educational attainment. Scholars highlighted that in the developed model the greatest significance on dependent variables had GERD (Kiselakova et al., 2020).

Another second analyzed study delivered by M. M. Khyareh & N. Rostami (2022) presented that the correlation between macroeconomic conditions and innovation development exists which further impacting international competetiveness process. In general this research paper as latter one chose traditional macroeconomic variables based model. The targeted analysis object is 19 Organization for Economic Co-operation and Development (OECD) memberstate countries in Europe. In order to measure the innovation in the context of macroeconomic environment authors have distinguished five macroeconomic indicators: financial development (FIND), trade openness (TR), governental spending in percentage of GDP on secondary education (EDU), Government spendings on research and development (R&D), foreign direct investments inflows (FDI) (Khyareh & Rostami, 2022).

Last research paper from first grouping was analysing Innovation impact on economic growth. B. Kumar Dhar (2023) in study paper relied on two-sided variable sets – macroeconomic and patents targeted organizations. The independent variables describing innovation phenomenon here are - research and development expenditures (RDEx), researcher number in research and development sector (RRD), number of published articles in science and technical journals (STJA), number of patents by the residents (PR), number of patents by nonresidents (PNR) and high technology trasnfer (HTR). This study chosen to assess economic growth by simply analysing gross domestic growth dependent variable changes (Kumar Dhar et al., 2023).

Following further, author would like review research papers which chose different models of innovation assessment. The first one is based on patents variables. It is unlike the others chose slightly different approach based on gathered and analyzed data. In research conducted by R. P. Maradana (2019) innovation is defined by following variables – patents registered from residents (PAR), patents registered from non-residents (PAN), both categories submerged together (PAT) and number of researchers in R&D activities per thousand of pupulation (RRD). It was the single research paper among reviewed which selected stingy number of variables (PAN, PAR, PAT, RRD) to test the Granger causality (Maradana et al., 2019). Also, regressor PAT seems to have homogeneity isue because it is derived from variables which are already used in the research – PAN+PAR=PAT. Based on author observations on slight variables and likely issue of homogeneity this regression model analyzing innovations impact on economic development conclusions must be reviewed seriously and with critical thinking. Author is about to present second study paper which used patents data series in order to define innovations. B. Guloglu (2012) analysed relationships between R&D, innovation and economic growth in OECD high income countries. This research paper gathered granted patent data from European patent office (EPO), Japanse patent office (JPO) and American patent offices (USPTO). Based on Granger Causality researchers state that innovations have positive effect on technological progress development which have secondary effect via latter phenomenon to economic growth in 13 high income OECD countries during research period of 1991 to 2007 (Guloglu & Tekin, 2012).

Instead, researcher D. Comin (2008) reviewed another group class of scholars which chose unorthodox model of innovation characterization. The study authors have collected data from 185 countries based on 10 existing technologies lags from invention till the moment of full application. In this case variables considering innovation were used: lag in electricity, internet users, telephones, aviation cargo, aviation passengers, trucks, personal cars, tractors, telephone and computer. Those lags in regression model is applied as independent variables and tested whether it has significant effect impacting economic development. Researchers as a reference point chose

country which invented the technology and date of invention. The country which invented the technology is considered as leader and all other countries are described as countries of postponed application or laggards if they are among the slowest (Comin et al., 2008). Moreover, there are E. Kabaklarli (2018) study which was classified to the same grouping. Author made decision to group it, because scholars work is analysing not economic growth as dependent variable but medium and high-technology export (export) (Kabaklarli et al., 2018). The benefit of reviewing this study is to analyze what economic development variables other scholars used in order to analyze opposite phenomenon.

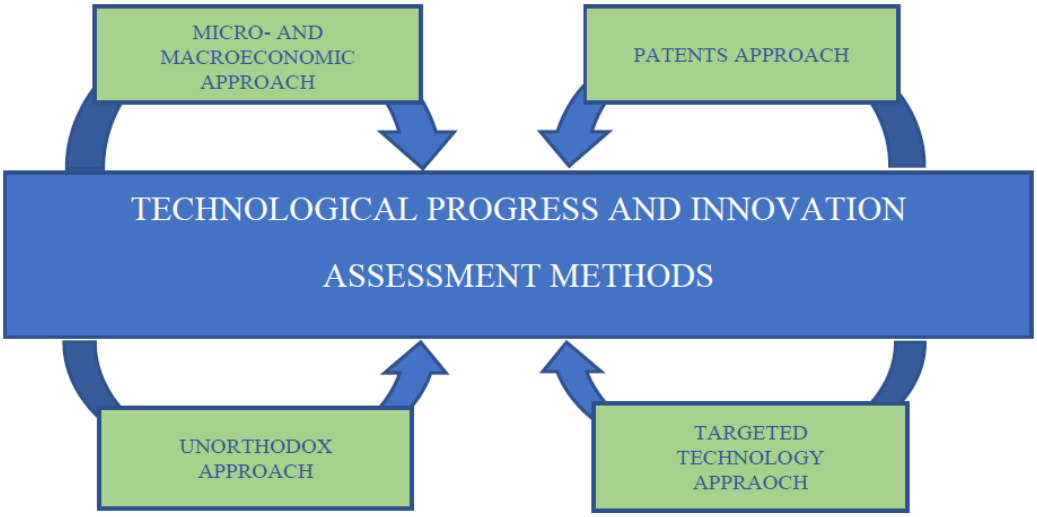
This paragraph is reviewing last assessment aproach – targeting specific technology variables. In I. Castelo-Branco research paper authors selected different objective to measure Industry 4.0 infrastructure and countries capabilities to process, transmitt Big Data. It is one of the unusual correlations which seeks to find relationship among existing technologies and infrastructure development trends. In this research authors defined innovations selecting interested technologies one by one as variables – mobile connection to the internet for business use (mobint), maximum contracted download speed of the fastest fixed internet connection (speed), enterprises who have enterprise resourcing planning software package to share information (erp), enterprises buying high cloud computing services (advcloud), enterprises analyzing big data from any kind of source (bd_anysrc), businesses analyzing their own big data gathered from smart devices or sensors (bd_sensors), enterprises analyzing big data from geolocation of portable devices (bd_geo). Looking from overall perspectives, this solid and complex list of variables helping to see the broader view of each nation preparation level to adopt Industry 4.0 technologies. Scholars based on results grouped each country into 5 different class – leaders, laggards, big data maturity, Industry 4.0 infrastructure maturity and average (Castelo-Branco et al., 2019).

Similarly, there is another research paper which can be assigned to this group. Researchers analyzed the innovation by employing specific variables targeted to ICT. In I. Appiah-Otto (2021) study researchers applied following variables – internet users (lnmob), mobile cellular subscriptions (lnint), fixed broadband subscriptions (lnfbb), gross fixed capital formations (lnk), total employment (lnl), composite index of mobile, internet and fixed broadband (lnict). The author have found a significant and analytically tested positive effect of information and communications technology impact on economic growth (Appiah-Otto & Song, 2021).

The technology and innovation assessment are often juxtaposed with ICT. For this matter, author presenting third research paper of it's category. A. Fernandez-Portillo published study paper analyzing ICT impact on economic growth. Independent variables gathered from social index (DESI) databases. Variables are divided into five sections – connectivity, human capital,

use of internet, technological integration and digital public services. Specifically author will present one variable per section full standard broadband coverage (1a1), individuals who use internet regularly (2a1), households subscribed to some form of video-on-demand (3a3), companies that have enterprise resource planning (ERP) (4a1), individuals who use the internet to deal with public authorities (5a1). Researchers stated that analysed OECD EU 23 membering countries have statistically proven ICT effect in the research period from 2014 to 2017 on economic growth, which dependent variable was gross domestic product (GDP) (Fernandez-Portillo et al., 2020). Although, each one of above mentioned ICT studies analysed the same topic however none of them taken precisely the same regressors, but all three study papers confirmed that ICT has statistically proven impact on economic development.

Figure 4. *The technological progress and Innovation trends assessment methods*



Source: author's ellaboration based on reviewed study papers (Kiselakova et al., 2020; Khyareh & Rostami, 2022; Kumar Dhar et al., 2023; Maradana et al., 2019; Guloglu & Tekin, 2012; Comin et al., 2008; Castelo-Branco et al., 2019; Appiah-Otto & Song, 2021, Fernandez-Portillo, 2020).

After analysing reviewed research papers author highlight that majority of those studies relies on complex methodology and specific econometrical approaches which makes it hard to apply. Therefore, in this study author will rely on macroeconomic variables presented in four scientific papers (Kiselakova et al., 2020; Khyareh & Rostami, 2022; Guloglu & Tekin, 2012, Kumar Dhar et al., 2023). According to the D. Kiselakova (2020) study paper researchers used following variables - European patent granted, high-tech exports (HTE), gross domestic expenditure on R&D (GERD), government expenditure on education (GEE), direct investment in the reporting economy (DI), gross fixed capital formation (GFC), tertiary educational attainment

(TEA). From the second study quoted by M. M. Khyareh and N. Rostami (2021) additional variables will be added – Foreign direct investment inflows (FDI), trade openness (TR), GDP growth (GDP). Last but not least, the innovations depicting variable was argumented according B. Guloglu & R. B. Tekin (2012) study which were using total patents granted (TPG). However in this study we will be using not EPO, JPO, USTPA but World Intelectual Property Organization (WIPO) datasets. Concentrating on innovations defining variables author highlight the final variable based on B. Kumar Dhar (2023) study – research and development expenditures, percent of GDP. Moreover, scholar's had more innovations defining variables such as high technology transfer (HTR), number of science and technical publications in journals (STJA) however due to author's solid list of variables it was decided to use only single one – research and development expenditures, percent of GDP (RDEXP).

1.4 The Economic growth, measurements and models

Here in this subchapter author built theoretical backgrond for economic growth theoretical and most practically applied models in order to further analyse technological progress and innovation empirical research (Solow, 1956; Acemoglu, 2008; Helpman, 2009; Solow, 1988; Barro & Sala-i-Martin, 2014; Jones, 2019; Thompson, 2018; Smith, 2010; Harrod, 1939; Domar, 1946; Lewis, 1954; Cobb & Douglas, 1928; Solow, 1957; Romer, 1990).

First of all, let's review the economic growth therminology. According to D. Acemoglu (2008) economic growth and development are dynamic processes, focusing on how and why output, capital, consumption and population change over time. Author E. Helpman (2009) describing economic growth research field as elusive and mysterious. In other words Robert M. Solow (1988) presented that economic development ideas did not started with his personal contributions and it will not end there. Generalizing it is dynamic research field which tend to adapt to never stopping changes. D. Acemoglu (2008) pointing the importance to know economic growth affecting parameters in order to have a positive effect on economic policies. The researcher stated that the knowledge in economic growth plays a significant role decreasing cross-country income differences.

Researcher E. Helpman published that despite humanity key interest in earnings (capital) other topics are also closely related for defining standard of living which is - political freedom, education, health, the environment and the degree of inequality. Economic growth is often juxtaposed with different variables. Posibly one of the most applied rough measures in academy, to describe people standard of living is real income per capita (GDP per capita) (E. Helpman,

2009). Moreover, scholars R. J. Barro and X. Sala-i-Martin (2004) pointing that aggregate economic growth is probably the key factor affecting individual levels of income. In order to decrease world poverty societies should focus on gross domestic product per capita annual increase (Barro & Sala-i-Martin, 2004). On the other hand, D. Acemoglu (2008) presented that economic growth is a complex field of research and despite growing GDP per capita sometimes results are negative and different. If county is in growth period different societies members can even experience standards of living decrease. As an example author is sharing sub-suharan Africa's region country South Africa. This country is rich in gold minerals and despite long-term economic growth black South Africans experienced apartheid and decreasing wages during the same period of country's growth. Thus, many authors sharing their research results but it is important to keep in mind that different countries should be compared with precaustions because of it's development level, economy cycle, population size, geopolitical situation etc. (Acemoglu, 2008). The gross domestic product per capita is a great indicator to measure country's level of development or people standard of living however it is not the only measure to analyze economic growth.

R. M. Solow published that looking from theoretical perspectives, the first succesfull academic steps analyzing economic growth in empirical methodology was made by Adam Smith with a publication "Wealth of Nations" in 1776. Afterwards many scholars analyzed this field of interest. One of the most succesfull are - Roy Harrod and Evsey Domar with dynamic theory explanation, Arthur Lewis with capitalist interest on labour development, Charles Cobb and Paul Douglas with a theory of production, Robert M. Solow with aggregated production function (Solow, 1956; Smith, 2010; Harrod, 1939; Lewis, 1954; Cobb & Douglas, 1928; Solow, 1957). The final academic researcher is Paul Romer with endogenous economic growth theory (Romer, 1990).

The profound economic growth models were introduced by R. Harrod and E. Domar (Harrod, 1939; Domar, 1946) . This model was created during the great depression and emhasized how economic growth could be dealt in terms of increasing unemployment. The Harrod-Domar economic growth model's production function is depicted in *Formula 1.*

The Harrod-Domar economic growth model equation

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

where:

Y - economic growth;

K – stock of capital

L – labour rate of input (labour hours)

Source: Solow, 1956.

Second model in the list is Cobb-Douglas Function developed by Charles Cobb and Paul Douglas. The difference here is that economic growth is condition by technological inputs and human capital changes. The Cobb-Douglas production function is depicted in *Formula 2.*

The Cobb-Douglas production function equation

$$Y(t) = F[K(t), L(t)] = AK(t)^{\alpha} L(t)^{1-\alpha}, \qquad (2)$$

$$0 < \alpha < 1$$

where:

A – technological input

K(t) – capital input at time t

L(t) – labour input at time t

α – elasticity of substitution parameters

Source: Acemoglu, 2008.

C. Cobb and P. Douglas which developed this model drew attention that education have positive affect to labour input changes. Also, technological input is part of incentives in production function. It was a different approach than the Harrod-Domar previously presented model (Acemoglu, 2008). E.Helpman stated that the Cobb-Douglas production function has a specific functional form, in which the output level equals the product of the inputs, each one raised to a fixed power These elasticity and substitution parameters add up to one. Nevertheless, the model had imperfections and other scholars doubts such as – constant share of labor ir output, it is creating mismatch in analyzed countries results which labour markets are growing at steady figures (Helpman, 2009). To sum up, this model was applied in micro- and macroeconomic levels and created background for further academic researches.

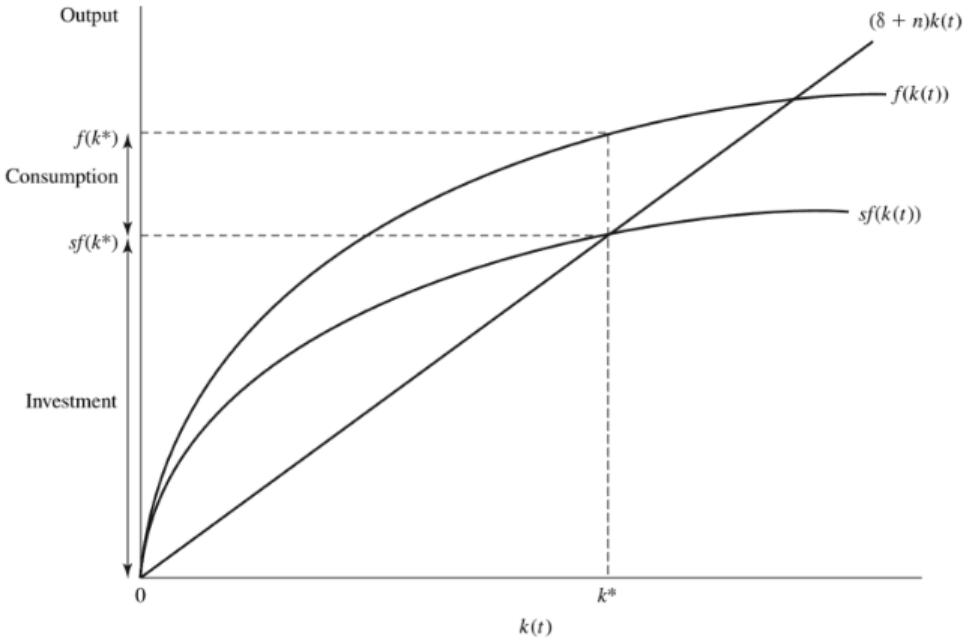
Secondary, D. Acemoglu (2008) presenting the next historically developed economic growth model which was encouraged by Cobb-Douglas and model's insights. It is created based on technological impacts and the Harrod-Domar model's following imperfections:

- The fraction of income saved by businesses and individuals lead to investments;
- Investments leads to changes in capital stock;
- Saving rate, the rate of growth of the labor force, and the capital-output ratio were given constants, facts of nature. It was considered that these parameters changing from time to time, sporadically.
- In order to double the rate of growth entities supposed to double the savings rate. It was believed that savings serves as catalyst of economic growth.

The new model was called Solow's and it was fighting to change the model assumptions (no fixed parameters), the economic growth is triggered by the technological progress rather capital formation. Authors turned to neoclassical aggregate production function. This enabled them to interact with other scholars already developed ideas in microeconomics, competetiveness, diminishing returns etc. The Solow's model explaining that capital has dereasing returns to scale in the economy. In below listed *Figure 5* student is presenting SSE – steady state equilibrium, based on R. M. Solow (1956) and D. Acemoglu (2008) research findings.

Here we have three graphs. Let's focus on depreciation and capital curve. The point k* is presenting the SSE point were additional capital input will not improve output in the same ratio as exepected. If we will look at other two graphs depreciation and output per worker curve we see that SSE point also exists but it is further point. In the second case consumption in general economy had an impact on a final production function shape.

Figure 5. *The Steady State Equilibrium graphical presentation in the Solow's model*



where:

$(\boldsymbol{\delta + n})\boldsymbol{k(t)}$ – depreciation curve

$\boldsymbol{f\big(k(t)\big)}$ – output per worker curve

$\boldsymbol{sf\big(k(t)\big)}$ – capital curve

k* - steady state equilibrium (SSE) point

Source: Acemoglu, 2008.

Based on research results D. Acemoglu (2008) and R. M. Solow (1956) gave early modern growth model findings that in general when economies are driven by technological progress after the recession it will recover and the previous output peak will be beaten. It is the evidence to support constant capital investment in technological progress or in other words research and development activities which have empirically proven positive impact on long-term economy development. The Solow's economic growth model's production function is depicted in *Formula 3*.

In practice L(t) shortening corresponds to hours of employment or number of employees. The capital stock K(t) corresponds to the quantity of "machines" used in production. The technology A(t) representing a number incorporating the effects of the organization of production and abilities on efficiency. It is considered that A(t) once technology is invented and published it is free and available to other market participants. To sum up, Solow's proposed model which was mathemically simple and abstract analyzing complex macroeconomy.

The Solow economic growth model's equation

$$Y(t) = F[K(t), L(t), A(t)] \qquad (3)$$

where:

Y(t) – total amount of production of the final good at time t

K(t) – the capital stock at time t

L(t) - the total employment at time t

A(t) – technology at time t.

Source: Acemoglu, 2008.

Last but not least, is the Endogenous growth theory and scholars developed this economic growth model - Paul Romer and Robert Lucas. Economic growth model presented by P. Romer was encouraged by the imperfections in the Solow's model. E. Helpman (2009) published a statement highlighting previous model's irrelevance:

"…exogenous rate of technological change is inadequate for explaining long-run economic trends." (p. 52)

Instead in E. Helpman's (2009) publication P. Romer's model output described in the context of labor and capital inputs, but it also affected by the economy's stock of knowledge. Model's developer focused on externalities, spillovers, subsidized education, investments in research and development. The model stressed the importance of capital investment in R&D, when business launches the new product or service after the innovation is presented to the market it is no longer a secret. It can be tested by other market players. Here private knowledge becomes public. Another pillar point is the competition between ideas. Romer pointed that new ideas are scarce, but existing ideas are not scarce and this has impact on economic development. The Romer's model key figure is knowledge accumulation (Helpman, 2009). In following equation we will see the simplified AK endogenous growth model's form expressed in *Formula 4*.

Based on the latter equation economic growth an an output is dependent on technology and capital stock at specific time. It means labour is not among parameters affecting the production.

The abbreviated endogenous growth model's equation

$$Y(t) = AK(t) \qquad (4)$$

where:

Y(t) - total amount of production of the final good at time t

A – production technology input

K(t) – the capital stock at time t

Source: Acemoglu, 2008.

Ultimately, the economic growth is a broad topic with many potential models developed and upcoming in the near future. Based on reviewed research papers and publications academic society drawing attention to different parameters building economic growth models. It is multifaceted phenomenon which can not be clearly defined by few indicators such as capital, labour, human capital, technological input. The economic growth research field is developing due to it's ever changing global environment and it is the matter of time when new findings adoptions, innovations will be presented.

1.5 The Topic examination in the context of OECD and EU countries

The fifth subchapter is dedicated to review research papers (Fernandez-Portillo et al., 2020; Guloglu & Tekin, 2012; Kabaklarli et al., 2018; Kumar Dhar et al., 2023; Maradana et al., 2019; Kiselakova et al., 2020) analyzed relationships between technological progress, innovations and economic growth in OECD and in single study EU object analysis. After reviewing these study papers author presented *Table 2* with key findings.

Table 2. *The researched study papers findings*

Study	Sample and duration	Technological progress, innovation trends proxy	Main methods	Results
Impact of ICT development on economic growth. A study of OECD European union countries. (Fernandez-Portillo, Almodovar-Gonzalez, Hernandez-Mogollon, (2020))	OECD 23 EU belonging countries 2014-2017	social index (DESI) related variables grouped in five clusters – connectivity, human capital, use of internet, technological integration, digital public services.	Partial Least Squares technique (PLS)	Researchers state that ICT defining technologies have statistically significant positive impact on OECD EU countries economic growth results. This analysis findings is favourable to advanced EU nations in development which indicate the strongest effect on economic growth.
A panel Causality Analysis of the Relationship among Research and Development, Innovation, and Economic Growth in High-Income OECD countries. (Guloglu &Tekin, 2012)	OECD 13 high income countries 1991 to 2007	Independent variables – patents, research and development expenditures. Dependent variable – gross domestic product.	Pairwise, multivariate causal relationship analysis, panel vector autoregressive (VAR) model, GMM, FE panel regression methods.	R&D investments granger cause technological change Technological change granger cause economic growth in chosen countries The study shows that capital investment in R&D activities stimulate technological progress development is is favourable phenomenon for economy growth.

Source: private elaboration based on research papers information (Fernandez-Portillo et al., 2020; Guloglu & Tekin, 2012; Kabaklarli et al., 2018; Kumar Dhar et al., 2023)

High-technology exports and economic growth: panel data analysis for selected OECD countries. (Kabaklarli et al., 2018)	14 selected OECD countries 1989 to 2015	Independent variables – GDP growth rate, FDI, application of patents by residents, and gross capital formation % of GDP. Dependent variable – high-technology exports (current US$)	Panel cointegration model	Research paper does not analyse economic growth as dependent variable. However it is advantageous to compare regressors what explanatory variables were used. Based on empirical results scholars' state that statistically significant long-run relationship between high-technology exports and economic growth exists in chosen 14 high development OECD countries. Patents application and FDI variables had positive impact on dependent variable while GDP growth rate and investments (Gross capital formation, % of GDP) had negative effect.
The causal nexus between innovation and economic growth: an OECD study. (Kumar Dhar et al., 2023)	34 OECD countries Study period 1961 to 2018	Independent variables constructing R&D index – research and development expenditures, researchers number in research and development field, number of science and technical journal articles, patent by the resident, patent by nonresident and high technology transfer. Dependent variable defining economic growth – gross domestic product (GDP).	Innovation index development based on innovation factors and principal component analysis. Causality analysis by using Granger test	The study final results does not have one-sided answer and state that researchers' found "unidirectional and bidirectional causal relationships". There are countries which has high development however they do not invest significant ratio of their national product. However R&D is advantageous factor for developing countries which based on that can expect generating positive spillovers.

Source: private elaboration based on research papers information (Fernandez-Portillo et al., 2020; Guloglu & Tekin, 2012; Kabaklarli et al., 2018; Kumar Dhar et al., 2023)

In this paragraph author will present another two study papers which intensionally was not presented in the above listed table (Maradana et al., 2019; Kiselakova et al., 2020). First of all, review the R. P. Maradana (2019) study paper which analysed the Causality relationships between innovations and economic growth in 19 OECD and European economic area countries. The chosen dependent variable – gross domestic product per capita and regressors are as following – three different types of patent grants for residents, non-residents and two groups in total (PER, PAN, PAT) and researchers number per thousand people in R&D field (RRD) (Maradana et al., 2019). The second research paper presented by D. Kiselakova (2020) analysis EU countries and not by any means related to OECD countries. Study paper research object 28 countries belonging to EU. The analysis duration from 2010 to 2018. What is interesting scholars selected two dependent variables – real GDP per capita (GDPpc) and gross net income per capita (GNIpc) to analyse innovation effects on macroeconomic EU countries development. In D. Kiselakova (2020) study innovations defining variables chosen - European patent granted (EPG), High-tech exports (HTE), Gross domestic expenditure on R&D (GERD), Government expenditure on education (GEE), Direct investment in the reporting economy (DI), Gross fixed capital formation (GFC), Tertiary educational attainment (TEA) (Kiselakova et al., 2020).

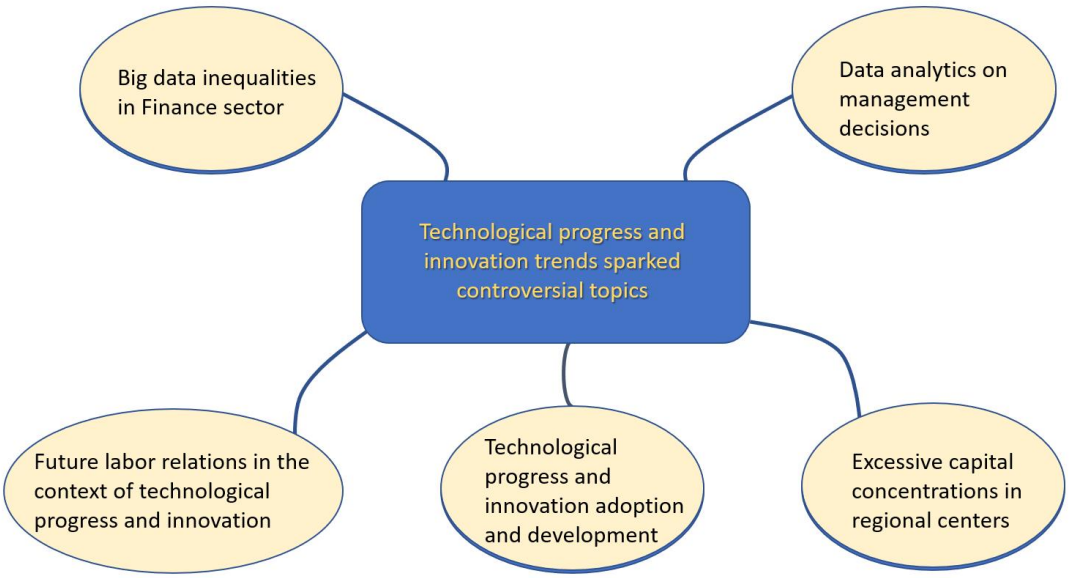
From this point, it can be concluded that typically researchers choosing to analyze high development countries as in the following research papers published by E. Kabaklarli (2018), A. Fernandez-Portillo (2020) and Guloglu & Tekin (2012). It is clear evidence that researchers are choosing to analyze regions and countries which have strict and long-term oriented political incentives to gather and share quality data with academic society. Author highlight that single research paper was analyzing as dependent variable medium and high-technology export development (Kabaklarli et al., 2018). However it is a good study example to check what methodology and independent variables other scholars used in order to solve practically closely related topic. To sum up, author state that reviewed studies confirms that analysed phenomenons have statistically proven significant and effect in general on on economic growth.

1.6 Technological progress and innovations contradictions and debates

As already reviewed in previous subchapters technological progress, innovations development are closely related to prosperity and growing standards of livings in the long-run. In spite of, rapid technological implementation, the topic in general is highly contraversial, creating contradictions and ambiguities in society and environment. Moreover, author will present few of

the debatable cases related to technological progress. All analyzed topics are presented in *Figure 6.*

Figure 6. *The technological progress and Innovation trends summarization of contradicting topics*



Source: prepared by author's ellaboration based on research papers systematized information (Begenau et al., 2018; Kacperczyk et al., 2016; McAfee et al., 2012; Fukuda 2020; Castelo-Branco et al., 2019; Comin et al., 2008; Khyareh & Rostami, 2022; Acemoglu, 2008; Brynjolfsson & McAfee, 2011; Frey & Osborne, 2017; Aghion et al., 2018; Maresova et al., 2018; Arntz et al., 2020; Eurofound, 2019).

The first topic to discuss from reviewed literature is big data technology. The reviewed research papers (Begenau et al., 2018; Kacperczyk et al., 2016) indicate that big data technology has impact in financial sector. J. Begenau and researchers highlighted that inequalities in the financial sector exists due to big data. Corporate funds which adopt big data and data analytics they receive a tool which benefit them over the smaller companies. It is disadvantageous to companies which mostly does not have capital to adopt such technology. Yet another drawback presented by scholars is that information gathered by fund managers directly effecting decisions, because it is easier to predict future of analyzed assets and portfolio investments in general (Begenau et al., 2018). M. Kacperczyk (2016) in their's research paper confirmed that the big data technology is defined as powerful tool especially during the recesions when leading financial companies is outperforming smaller companies receiving higher average earnings (Kacperczyk et al., 2016).

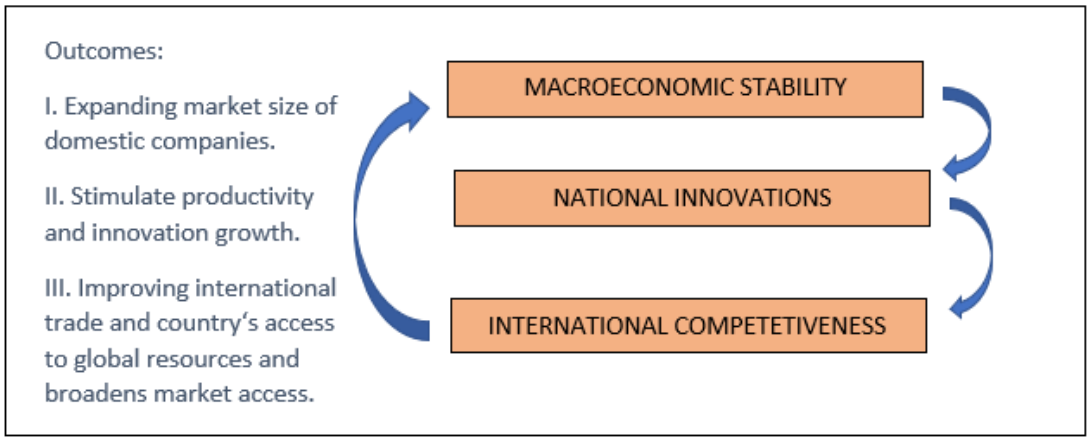
Moreover, A. McAfee (2012) in research paper representing the correlation between big data gatherings and management decisions. Researchers illustrate that due to analytical data technology, company or entity can achieve better results simply by predicting and improving decisions in more precise. Researchers acknowledge that big data technology is developing rapidly and is seen as business advantage. Based on 330 public North American companies management practices authors can state that data driven decisions are better. Looking from general perspectives to the future businesses and leaders will adapt big data technology because of inevitability - the adopters will eliminate their rivals (McAfee et al., 2012).

Although, K. Fukuda (2020) researchpaper author expressed a consern of capital sharing inequalities in Japan. Author stressing the current capital sharing policies which have created high concentration in a few regions. The scholar illustrates that the innovation scatter among geolocations is in decrease and further development is favoring citizens only in urban locations. The posibility to provide the sufficient standard of living in the reagions according to current model is highly criticized because the income gap is increasing anually. Research paper contributing to the new model creation when urban service provision network would be based on rural resources and this would increase rural efficiency (Fukuda, 2020).

More importantly, the academic society and analyzed publications (Castelo-Branco et al., 2019; Comin et al., 2008; Khyareh & Rostami, 2022; Acemoglu, 2008) are reporting technological progress and innovation development and adoption importancy. In I. Castelo-Branco (2019) publication scholars' presented the existing correlation between technological infrastructure and further technology adoption. Researchers evidence show that there is a large dispersion among European Union countries in relation to the presence of the conditions necessary for further technological Industry 4.0 development. Based on the General Directorates of the European Commission (EUROSTAT) and the European Union's statistical classification on Economic Activities (NACE) databases scholars drawing a conclusions that different countries implementing innovative technologies in different paces which is important phenomenon seeking economy development especially in developing countries. In addition, D. Comin (2008) presented that according to 185 countries data on different technology implementation durations strongly reinforced previous scholar findings that technology adoption is highly correlated mechanism to foster economic development. For example, M. M. Khyareh & N. Rostami (2022) research paper excemplifies parallel between innovations and macroeconomic stability. Scholars note that especially developing countries must guarantee stable economic environment in the long-run to foster innovations application. The scientists distinguished innovations as triggering factor increasing internation competetiveness. In order to reinforce the latter scholars findings illustration

Figure 7 were created. Likewise, D. Acemoglu (2008) have also reported that the economical progress can be blocked due to inequalities in society. For this reason, technological progress and innovation trends playing a key factor, creating benefitial conditions in economical growth which ought to be distributed equally among different society members.

Figure 7. *The correlation visualisation between Innovations, macroeconomic stability and global competetiveness*



Source: Prepared by the author based on study paper content (Khyareh & Rostami, 2022)

Secondly we have another type of technological progress relating contradictions the Future labor relations. The insights are presented based on extensive academic literature analysis (Brynjolfsson & McAfee, 2011; Frey & Osborne, 2017; Aghion et al., 2018; Maresova et al., 2018; Arntz et al., 2020) also adding governmental organization's published study point of view (Eurofound, 2019). E. Brynjolfsson and A. McAfee (2011) highlighted digitization have significant effect on employment and sudden technological progress increase. So, part of the society might be left behind. A paradox presented – the faster is the technological progress the less advantages are received by different society members. Moreover income inequalities and employment opportunities among individuals becoming more uneven. Despite the fact, that technology is seen to have a strong debates in regards of employment, authors is not critically describing this phenomenon, because they had presented recommendations:

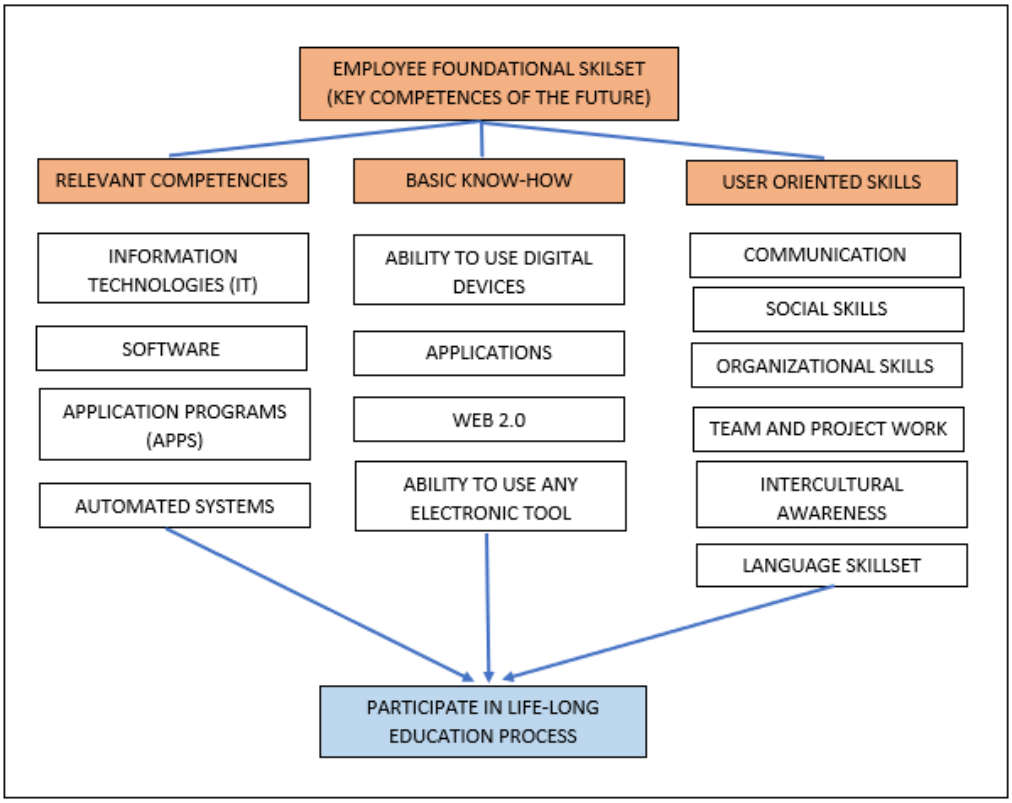
- Stop competing with computers and foster human intercommunication, networking skills. Global environment is searching for new products and professionals and it is available;
- Increase human capital which is based on learning and improving labour input. Overall in society it is creating a culture of long-term self-improvement.

Furthermore, C. B. Frey and M. A. Osborne (2017) presented that computerisation and automation processes impacting the future labor relations. Authors have developed a model based on 702 occupations and variables characterising the general work skills used at work. Models showed that most workers in transportation and logistic, bulk office and administrative, manufacturing and even service provision sectors is highly susceptible to computerisation. This means that majority of existing works based on mobility and dexterity is at risk. Scholars found that despite the short-term shocks in the long-run laborforce wage level will continue to raise. The article contributes to the ideology that technological progress and innovations are affecting classical employment perceptions. Based on empirical research findings it is believed that in the long run most of the current market jobs will be affected due to big data and automation processes (Frey & Osborne, 2017).

In additional to expressed academic ideas P. Maresova (2018) presented that in the market is growing demand for higher and advanced qualification employees which in the short-run will not not be met. Current high-skilled employees will face requirements to work longer hours and tensions to increase productivity between employers and employees might occur. The triggering factor is shortage in the market of highly-skilled manpower with advanced skills (Maresova et al., 2018). Developed study researchers highlighted the core competences of the future's employee in order to participate succesfully in the employment market which is illustrated in *Figure 8.*

Also, P. Aghion (2018) publication authors had analysed how artificials intelligence impacting the economic growth. Scientists gave their's assumptions that in the near future AI will replace creative works executed by high-skill workers. Authors is predicting that AI adopted companies will continue to rely on high-skilled laborforce. On the other hand, scholar Arntz (2020) which analyzed digitization effects on future work conditions in Germany underlining the positive trend in employment market. Authors despite the criticism and society fears embodied the findings that employment balance in the upcoming five years in between 2016 and 2021 will be positive. Which corresponds to more employed rather lost their jobs due to technological progress. By focusing on digitization in more detail, authors expressed many positive secondary outcomes brought by technological progress – technologies favor to reduce income inequality among genders, technologically advanced female employees increase their chances to attract conservative enterprises s.a. energy sector, mining, manufacturing etc (Aghion et al., 2018; Arntz et al., 2020).

Figure 8. *The key employee competences for sucessfull participation in the changing labour market*



Source: figure is created by author according following study (Maresova et al., 2018)

Lastly, the governmental organization's point of view will be presented reviewing the European Foundation for the Improvement of Living and Working conditions (EUROFOUND) publication oriented to the EU manufacturing industry and analyzing the timeframe up to 2030. The Publication contributes to the idea that due to fast developing technological progress and arising game-changing technologies many manufacturing and organizational processes will be transformed and adapted. Researchers declare that more than 50% of current manufacturing sector occupations in EU can be automated and employment is characterized as bidirectional process. It is affecting not only directly as job loss and job creation but also indirect processes such as cost reduction due to scale of economy, quality improvement, increased employee income due to increased productivity and many more. The Eurofound report highlighted that despite already mentioned contradictions, yet another exists – the health and safety level of employee. The agency informs that technological progress have impact on employee psychological and menthal health. The report pointed that technology is affecting and creating outcome that social skills in manufacturing is excessive and invaluable value, human role transformation from creator to intervener, the rising sense of insignificance based on limited liability tasks (Eurofound, 2019).

Ultimately, rapid changing technologies and evolution gives us unique opportunity to follow and become a part of global development process in real time. The above reviewed literature was systematized and presented in Table 3.

Table 3. *The list of grouped references*

Relevant topics	Authors
A. Technological progress and Innovation foundational therminology in academic society	Kline & Rosenberg 2010; Freeman & Soete, 1997; Schumpeter & Backhaus, 2003; Fagerberg, 2004; Brynjolfsson & McAfee, 2011; Schwab, 2017; OECD, 2018.
B. Technological progress and innovation phenomenons historical development and current industry development status	Lasi et al., 2014; Kinkel et al., 2020; Schwab, 2017; Brynjolfsson & McAfee, 2011; Freeman & Soete, 1997; Van Duijn, 2013; Frey & Osborne, 2017; Maresova et al., 2018; Eurofound, 2019; Maddikunta et al., 2022; Muller, 2020.
C. Technological progress and innovation trends defining variables	
1. Traditional classical macroeconomic variables grouping	Kiselakova et al., 2020; Khyareh & Rostami, 2022; Kumar Dhar et al., 2023.
2. Patents oriented innovations defining variables	Maradana et al., 2019; Guloglu & Tekin, 2012.
3. Study papers relying on unorthodox variables and methodologies defining technological progress and innovations	Comin et al., 2008; Kabaklarli et al., 2018.
4. Studies targeted ICT technologies and variables to calculate technological progress and innovations impacts	Castelo-Branco et al., 2019; Appiah-Otto & Song, 2021; Fernandez-Portillo et al., 2020.
D. The economic growth therminology and methodology defining studies	Solow, 1956; Acemoglu, 2008; Helpman, 2009; Solow, 1988; Barro & Sala-i-Martin, 2014; Jones, 2019; Thompson, 2018; Smith, 2010; Harrod, 1939; Domar, 1946; Lewis, 1954; Cobb & Douglas, 1928; Solow, 1957; Romer, 1990.

E. The technological progress and innovation trends impact on economic growth analysis of OECD, EU countries object	Fernandez-Portillo et al., 2020; Guloglu & Tekin, 2012; Kabaklarli et al., 2018; Kumar Dhar et al., 2023; Maradana et al., 2019, Kiselakova et al., 2020.
F. The innovation contradictions and debates	Begenau et al., 2018; Kacperczyk et al., 2016; McAfee et al., 2012; Fukuda 2020; Castelo-Branco et al., 2019; Comin et al., 2008; Khyareh & Rostami, 2021; Acemoglu, 2008; Brynjolfsson & McAfee, 2011; Frey & Osborne, 2017; Aghion et al., 2018; Maresova et al., 2018; Arntz et al., 2020; Eurofound, 2019.

Source: prepared by the author

Author emphasize that technological progress and innovations are broadly analysed as an impact on economic growth and development. Reviewed studies mostly relies on developed or high-income countries which can provide long-term quality data for this type of research problem solve. There is lack of literature sources which analyse technological progress and innovation trends as heterogenous factors. Usually latter phenomenons are analyzing separately or somehow mixing them all together. So the chosen topic covers the gap of latest data research of individual phenomenons analysed in OECD EU countries.

2. THE EMPIRICAL RESEARCH METHODOLOGY

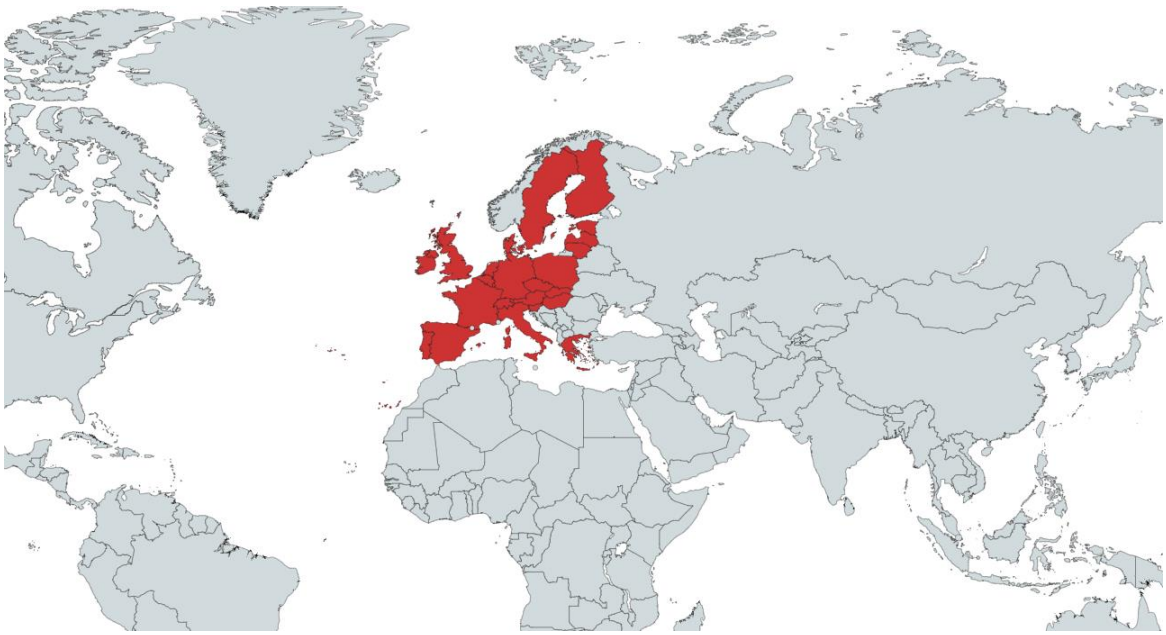
In the second chapter author will be reviewing practically applied research paper methodology. The first subchapter is dedicated to research paper object explanation and why it was finished with OECD member countries of European Union. Also, here will be presented the data collection methodology with practical visualization. Moreover, scholar will describe what is the research paper investigation period. In the second subchapter it will be closer reviewed applied models' regression equations and applied tests in methodological part. Afterwards in the next subchapter reviewers will be presented with technological progress and innovation trends defining variables and how practically pooled ordinary least square regression equation might be formed. Additionally, this paragraph will provide graphical and descriptive information about raised research paper hypothesis and how they were grouped. The last subchapter belongs to data limitations and author's executed empirical methodology adjustments in relation to object and time frame. This chapter consists of five divided paragraphs.

2.1 Practical justification for the chosen countries and period of investigation

The primary research object was all 38 countries belonging to Organisation for Economic Co-operation and Development (OECD). However based on data fragmentation or not provided data something has to be done in order not to receive biased final research results, Therefore scholar based on literature review and good secondary data quality in OECD European Union countries it was decided to focus here specifically. Analysis object 22 countries belonging to OECD and EU - Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden.

Decision to pick up the OECD countries is made up due to the fact that main research goal is to assess technological progress and innovation trends phenomenons effect on economic growth. In order to execute and receive quality results it is preferably to use similar development countries datasets. Exactly in this case the OECD countries belonging to EU were selected. The OECD EU countries in other words analysis objects geographical density can be seen in *Figure 9*.

Figure 9. *The OECD EU memberstates geography visualization*

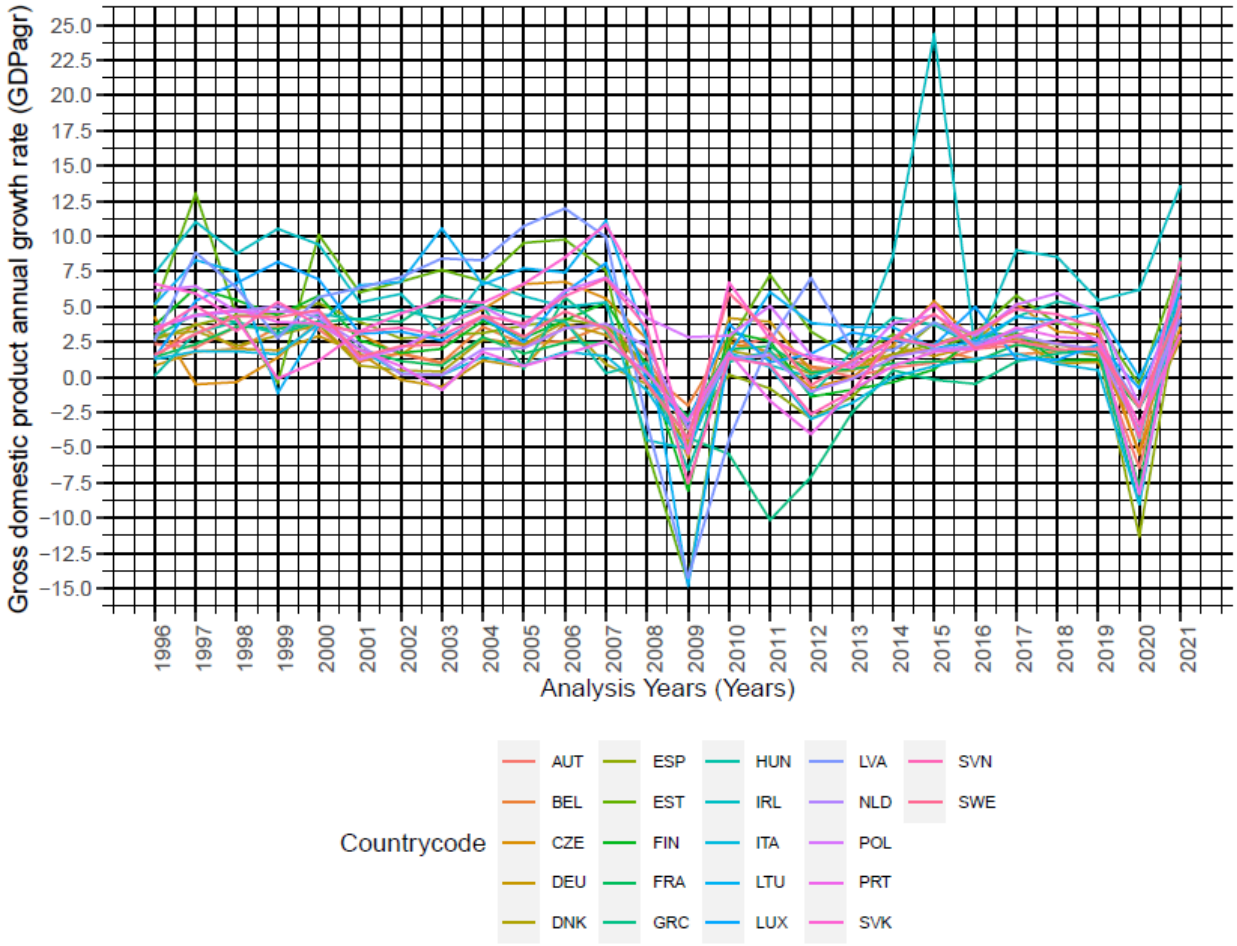


Source: prepared by the author using online sources

The researcher was motivated to choose 1996-2021 years period based on overall macroeconimic situation and recessions occurred in that time. All in all it is the duration of 26 years. It is important to highlight that gross domestic product annual growth rate visualized in *Figure 10* was negative in 1998, 1999, 2001, 2008, 2009, 2010, 2011, 2012, 2013. These latter periods can be called and described as rec which will be analyzed more thoroughly in the further research paper methodology. Yet another factor affected global economy is COVID-19 pandemy which outbreak's financial effects were visible in 2020. The latest effect will be reviewed and statistically assessed as cov factor. Author made below listed graph according to the World Bank (WB) indicator – gross domestic product annual growth rate in percent (ID: NY.GDP.MKTP.KD.ZG) (World Bank, 2023a). In data set this variable is depicted as GDPagr.

As already discussed graph shows that economic development was strongly influenced by the events in those years. In this research paperwork scholar will review recessions (rec) and COVID-19 (cov) impact on economic growth during the analysed period 1996-2021.

Figure 10. *The economic development of OECD countries during investigation period*



Source: author's contribution based on the WB GDP annual growth rate (GDPagr) variable

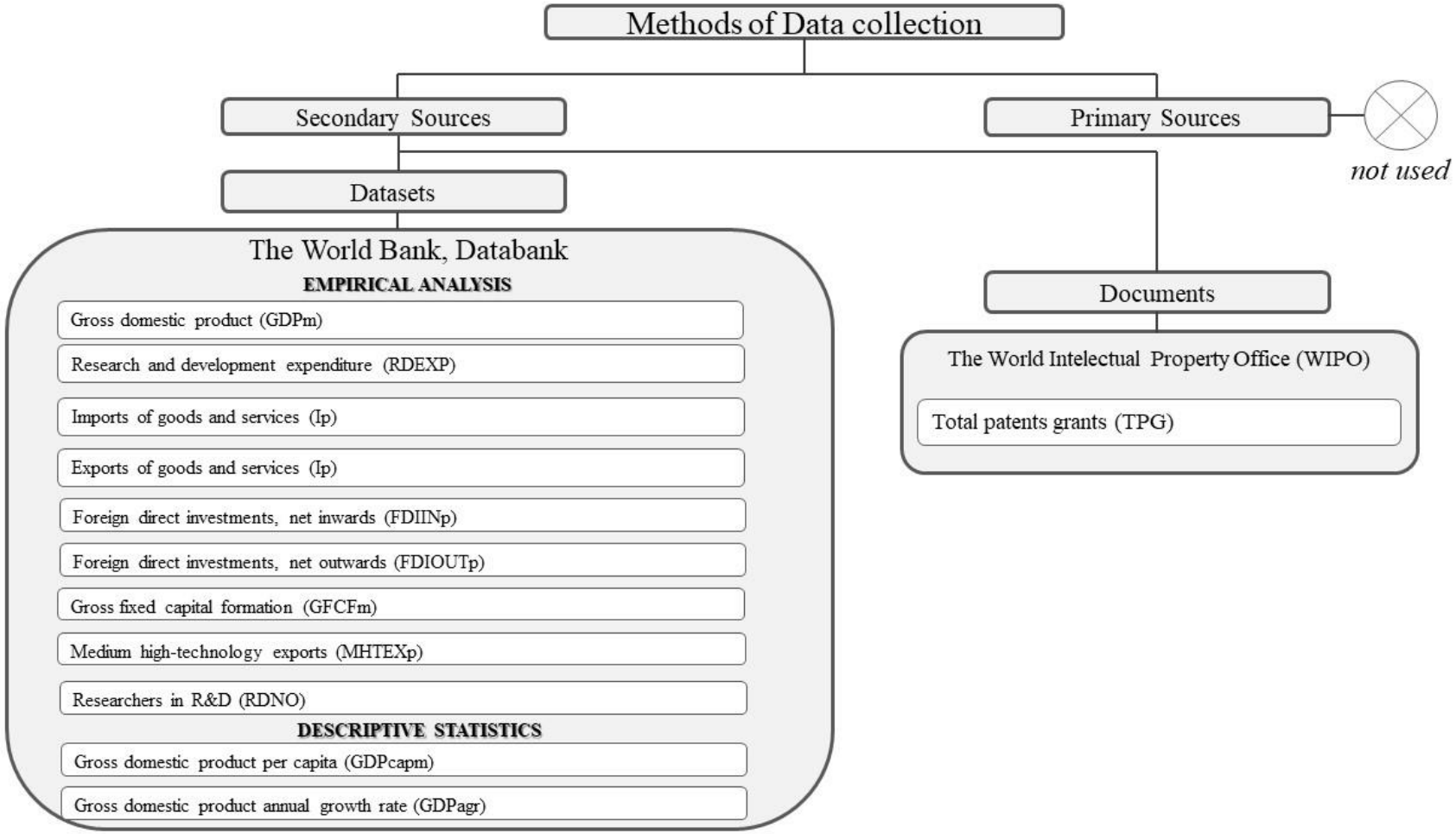
Thus, according to the main topic interests on technological progress, innovation trends and their's influence on economic growth author decided to analyze OECD countries which core memberstates are similar development level and favourable to execute comparisons among each other. Besides, author indicated the recession and covid as impact on OECD macroeconomic development therefore these factors will be among analyses topics. In this subchapter researcher disclosed which countries will participate and what is the period length of analysis.

2.2 Theoretical concept of Empirical research methodology

This research paper will rely on secondary data gathered from datasets and documents from two sources – The World Bank (WB) and The World Intelectual Property Office (WIPO). The data collection methodology is showed in *Figure 11*. The analyzed data is unbalanced panel. Unbalanced is self explaining by looking at the gathered dataset set, because there are missing values. As J. R. Gil-Garcia and G. Puron-Cid (2014) presented there are different synonyms existing to refer to panel data – pooled data, pooled time series, cross-sectional data, micropanel data, longitudinal data etc. Additionally, C. Hsiao (2022) claim that panel allowing to construct and test more complex behavioral models than purely cross-sectional or time-series data. J. R. Gil-Garcia & G. Puron-Cid (2014) emphasize that panel data models are more robust, because they consider full information from all observation between countries and different timing. Moreover, J. M. Wooldridge (2010) highlighted that in panel model observations are gathered for each variable in case by case followed in time. (Hsiao, 2022; Gil-Garcia & Puron-Cid, 2014; Wooldridge, 2010). The research paper object is cross-country and the focus is on finding out the macroeconomic development tendencies. Selected twenty six years time frame from 1996 to 2021 witnessing that researcher is focused on long-run analysis.

The data used in empirical part have different units (monetary, percentage) for this reason author is drawing early assumption of incoherency and the need of transformations. Based on the list of countries and investigated duration number observations are identified – 22*26=572, in this research paper significance level will be used 5% which in other terms is p=0,05. During the whole master thesis execution process following econometric program software packages were used – IBM Statistics (SPSS), Eviews, Gretl, Rstudio. Different tools were applied in order to receive the most reliable results and most visual graphs. Also, above mentioned software allowed to test and verify assumptions when there were any concerns.

Figure 11. *The visualization of data collection methodology*



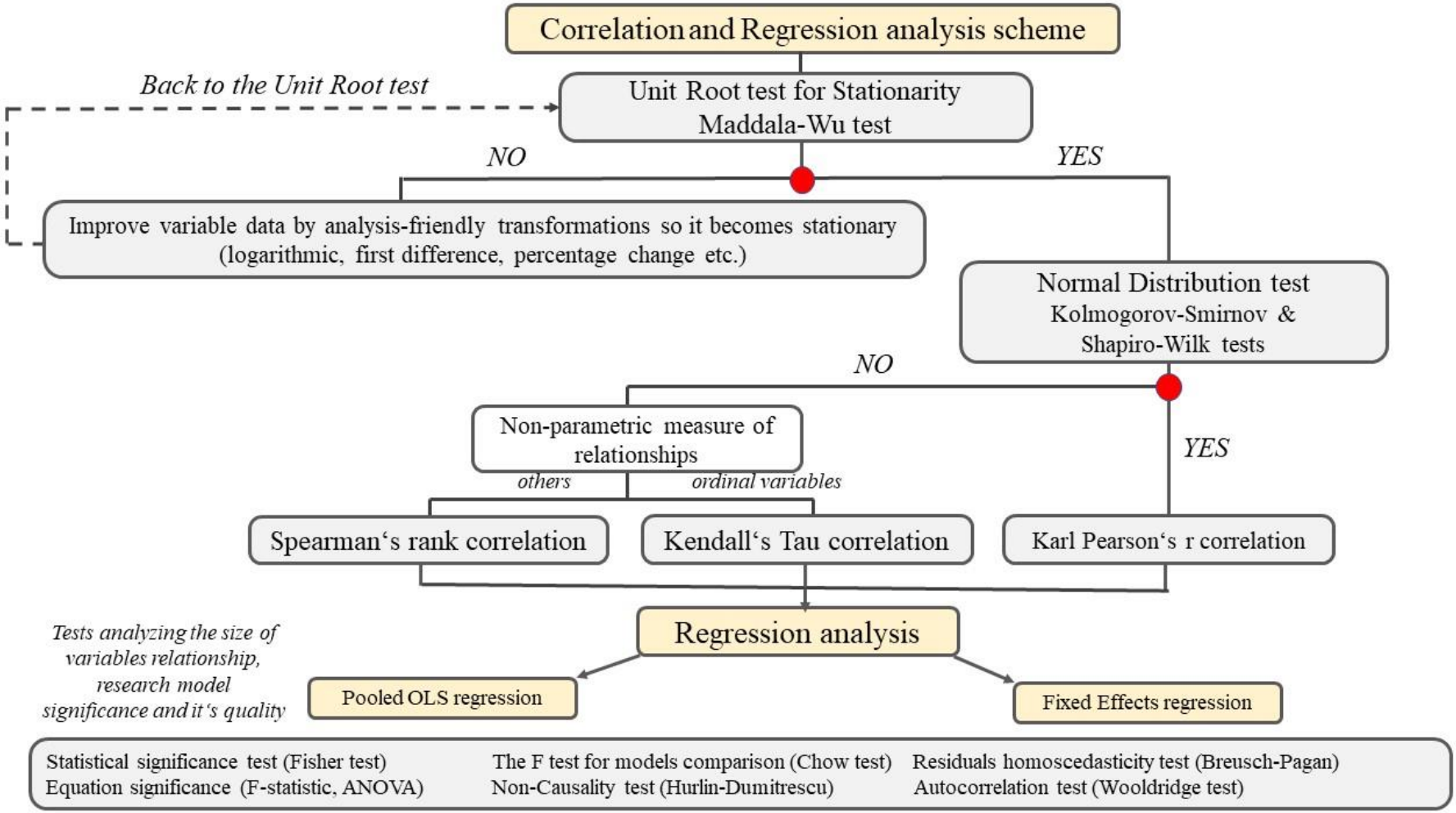
Source: prepared by author

The empirical research is divided into three categories – primary analysis (stationarity, normal distribution), correlation analysis, regression analysis. Stationarity and Normal distribution is data quality defining parameters and is considered as the first stage of empirical research methodology. Secondly, Correlation analysis answers to the question is there any relationship between analysed independent and dependent variables. Correlation analysis is divided to two general fields of interest – distribution test and correlation significance test. To make this research analysis explanation process more easy author have prepared *Figure 12* which is visually depicting the sequence and steps of empirical research methodology.

First of all, start with stationarity. The data can be stationary or non-stationary. Requirement for the model is to use stationary data which has statistical parameters that do not vary in time. In typical and standard panel model it is possible to apply Unit root test by Augmented Dickey Fuller (ADF) test (Baltagi & Baltagi, 2008). However here researcher have imbalanced panel data which requires other type of tests. For this reason, Maddala-Wu test were applied (Maddala & Wu, 1999). Generaly speaking, if data is not stationary author should apply analysis friendly methods (logarithmic, percentage change, normalization, indexing, new variables creation with lags transformation etc.) to change variables stationarity. In current case original secondary variables from WB and WIPO were not stationary until author executed transformations. Variables dataset been transformed based on econometrical software Gretl functions – first difference (d_A*) and percentage change (pc_A*). Variables A* displayed in the brackets are fictional, only to describe how these variables after transformations would be named.

Afterwards, stationarity tests were repeated and test results are displayed in *Annex 1*. On the left hand side you can see the primary approach with not transformed variables and on the right hand side with transformed ones. Two approaches findings are different, because five of those not transformed variables (GDPm; RDEXPp; TEp; GFCFm; RDNO) were not stationary. And the second test results confirms that all transformed single dependent and nine independent variables become stationary. As a result of executed test author state that variables transformation have helped to improve data quality so it become stationary.

Figure 12. *The Correlation and Regression analyses methodology visualization*



Source: prepared by author

The second test analysed in the primary stage is Normal Distribution test to find out whether data is normally distributed. In general author executed two test cases. The first one when variables are standard secondary data (not transformed) as it is gathered from WB and WIPO databases. The second case is when variable series were transformed. Both results are merged and visualized in signle table called *Annex 2*. To fulfill this test, researcher applied Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) distribution tests (Massey Jr., 1951; Razali & Wah, 2011). The logic behind using two different tests came after finding out that not in all analyzed variables cases K-S approach will be valid. Therefore S-W test also was included. Based on null hypothesis and significance values which in all cases are lower than statistical significance level ($p<0,05$) author can state that non of these variables are normally distributed.

As a result of cointegration and stationarity test results provided in *Annex 1* and *Annex 2* author conclude that research paper regression analysis will be empirically executed based on non-parametric measures of relationships – Spearman's rank or Kendall's Tau correlations (Croux & Dehon, 2010; Croissant & Millo, 2019). Pearson rank correlation approach was rejected based on received data quality limitations. Author is making early statement that research paper will rely on Spearman's coefficient of correlation (rank correlation) technique showed in *Formula 5*.

Spearman's coefficient of correlation (or r_s)

$$r_s = 1 - \left[\frac{6\sum d_i^2}{n(n^2-1)}\right] \qquad (5)$$

where: d_i = difference between ranks of ith pair of the two variables,

n = number of pair of observations;

Source: Kothari, 2004.

On the other hand, executed tests is only the beginning and gives us the background what relationships measure to choose executing the next step – Correlation analysis. As already introduced in this step author chose to apply Spearman's rank correlation in order to find out two-way relationships between dependent and independent variables. During the second empirical research paper development stage author will provide the Correlation Heatmaps and Correlation matrixes which is thoroughly explained in visual and descriptive information in chapter four.

Last but least, there are the third and at the same time most important empirical research part – Regression analysis. During which various tests will be applied and implemented in order to find out the most appropriate model which would allow the scholar to conclude on analysed topic aim, goals, hypotheses etc. From this point it can be highlighted that during empirical

methodology part following test will be executed – Statistical significance, Equation significance, Non-Causality, Autocorrelation, Residuals homoscedasticity etc (Baltagi & Baltagi, 2008).

Different regression models exist and many are developed at the same time. Hence, in this research author concentrate on two panel models depicted in Figure 12 – pooled ordinary least squares (POLS), fixed effects regression (FE) models. Before making any conclusions about one or another model following statistical parameters must be reviewed - Adjusted R squared, Coefficient correlation significance, Wooldridge test figures, Variance of Infliation (VIF) values. Kothari in published research paper highlight that in regression analysis certain numbers of samples are considered. And for each sample researcher should calculate various statistical measures such as Mean, standard deviation, F-probability distribution, Chi-square, Student‘s t distribution etc. proving regression analysis validity (Kothari, 2004; Wooldridge, 2010).

It follows that pooled ordinary least squares regression model is less complex and must be the first to analyze. J. R. Gil-Garcia and G. Puron-Cid (2014) stated that pooled OLS is a simple linear regression with panel data arrangement. This model stack observations on top of the other and disregards the effects over individuals and time. Reviewed published research authors warns that despite POLS model positive findings – statistical significant coefficients, positive sign slope coefficients, R^2 value reasonbaly high, but estimation might have auto-correlation in the data which can be checked based on Durbin-Watson VIF values. Yet another potential risk while using this model is heteroscedasticity or auto-correlation in the estimations which might lead to biased estimates of variances and as conclusion statistical tests and confidence intervals would be false (Gil-Garcia & Puron-Cid, 2014). Equations are visualized in *Formula 6* and *Formula 7*.

Pooled ordinary least squares (POLS) regression model equation in regards of time

$$Y_t = \alpha + \beta_1 X_{1t} \dots \beta_n X_{nt} + e_t \quad (6)$$

where: t=1…t

Source: Gil-Garcia & Puron-Cid, 2014.

Pooled ordinary least squares (POLS) regression model equation in regards of studying cases

$$Y_i = \alpha + \beta_1 X_{1i} \dots \beta_n X_{ni} + e_i \quad (7)$$

where: t=1…t

Source: Gil-Garcia & Puron-Cid, 2014.

The second in the list is Fixed Effects (FE) or Least-Squares Dummy Variable Regression model (LSVD). Moreover, J. R. Gil-Garcia and G. Puron-Cid (2014) presented that above

mentioned model is traditional OLS model using dummy variables for each category, characteristic of cases or time expressions (Gil-Garcia & Puron-Cid, 2014). The empirical model equation is provided in *Formula 8*.

Fixed effect regression model's classical equation

$$Y_{it} = \alpha + \alpha_1 D_{1it} + \ldots + \alpha_n D_{nit} + \beta_1 X_{1it} \ldots \beta_m X_{mit} + \mu_{it} \quad (8)$$

where: t = 1…t

n = 1… number of dummy variables

i = 1…i

m =1… number of independent variables

Source: Gil-Garcia & Puron-Cid, 2014.

Nowadays when statistical software become more powerfull modern FE techniques not really consider dummy variables in their models. Preferably they use probabilistic estimations based on covariance matrix. The modern panel data model for fixed effects are visualized in *Formula 9*.

Fixed effect regression model's modernized equation

$$Y_{it} = \alpha_{1i} + \beta 1 X_{1it} \ldots \beta_n X_{nit} + \mu_{it} \quad (9)$$

where: t = 1…t

i = 1…i

Source: Garcia & Puron-Cid, 2014.

Regression models can be divided according their's complexity. If analysed data are autocorrelated and homoscedastic simple linear regression method could not be employed and this requires to test other more advanced regression models - Pooled Ordinary Least Squares (POLS), Fixed Effects (FE) etc. The autocorrelation in regression models will be checked based on Wooldridge test results. Autocorrelation hypothesis can be reject if Chi-square probability is higher than significance level (5%) and significance value p is greater than 0,05 (p > 0,05). While executing Heteroscedasticity test F-probability and Chi-square results will be analysed. In order to reject the heteroscedasticity hypothesis of unequal residuals dispersity these two coeficients should be higher than significance level F > 0,05 and χ^2 > 0,05 (Croissant & Millo, 2019). F and Chi-square coefficients calculation method is defined by *Formula 10* and *Formula 11*.

Testing the equality of variances of two normal populations.

F-test or F-distribution equation

$$F = \frac{\sigma_{s1}^2}{\sigma_{s2}^2} = \frac{\sum \frac{(X_{1i} - \bar{X}_1)^2}{n} - 1}{\frac{\sum (X_{2i} - \bar{X}_2)^2}{n} - 1} \quad (10)$$

Source: Kothari, 2004.

Hypothesis testing for comparing a variance to some hypothesised population variance.

The chi-square value to test the null hypothesis

$$\chi^2 = \frac{\sigma_s^2}{\sigma_p^2}(n-1) \qquad where\ \sigma_{s1}^2\ is\ treated\ > \sigma_{s2}^2 \quad (11)$$

where: $\overline{X}_1$ – mean of sample one,

$\overline{X}_2$ – mean of sample two,
$\overline{X}$ – mean statistical parameter of the sample,
n = No. of items in a sample,
σ_p - standard deviation of population
σ_s - standard deviation of sample

Source: Kothari, 2004.

Ultimately to fulfill the correlation and regression analysis requirements indeed many statistical tests, assumptions must be employd and fulfilled. It requires complex econometrical skills. It is an unambigous path to test which independent variables describing technological progress and innovation trends have an statistically significant impact on economical growth phenomenon. In order to draw conclusions author must execute these steps and anylize the outcome critically and with the level of seriousness, due to topic importance.

2.3 Technological progress and Innovations trends defining variables, regression modeling and hypotheses

In this subchapter scholar will define variables based on two analyzed phenomenon's classification. Those groups are technological progress and innovation trends. Both effects are considered as heterogenous and presented in *Figure 13*.

As already presented in previous chapter this research paper will be modelling according two different regression models - pooled OLS and fixed effects. Each one of those can be

empirically written according equation simplified formulas as presented in POLS regression case in *Formula 12*.

Multiple linear regression model with standard secondary variables would look like this:

$$GDP_m = \alpha + \beta_1 RDEXP_p + \beta_2 TI_\rho + \beta_3 TE_p + \beta_4 FDIIN_p + \beta_5 FDIOUT_p + \beta_6 GFCF_m + \beta_7 RDNO + \beta_8 MHTEX_p + \beta_9 TPG + e(GDP_m) \quad (12)$$

Where: $\boldsymbol{\alpha}$ – intercept

$\boldsymbol{\beta_1}$ ... $\boldsymbol{\beta_9}$ – regression coefficients

$\boldsymbol{e(GDP_m)}$ – residual regression model's standard deviation

Source: prepared by author based on reviewed research papers

Based on final the most suitable regression model's results below listed nine hypotheses will be checked. In order to better understand the concept visual graph was made to present it in *Figure 14*.

Hypothesis no. 1a: Imports of goods and services variable (TIp) representing technological progress have statistically significant effect on any form of dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis no. 1b: Exports of goods and services variable (TEp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis no. 1c: Foreign direct investment, net inflow variable (FDIINp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis no. 1d: Foreign direct investment, net outflow variable (FDIOUTp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis 1e: Medium and high-tech exports variable (MHTEXp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

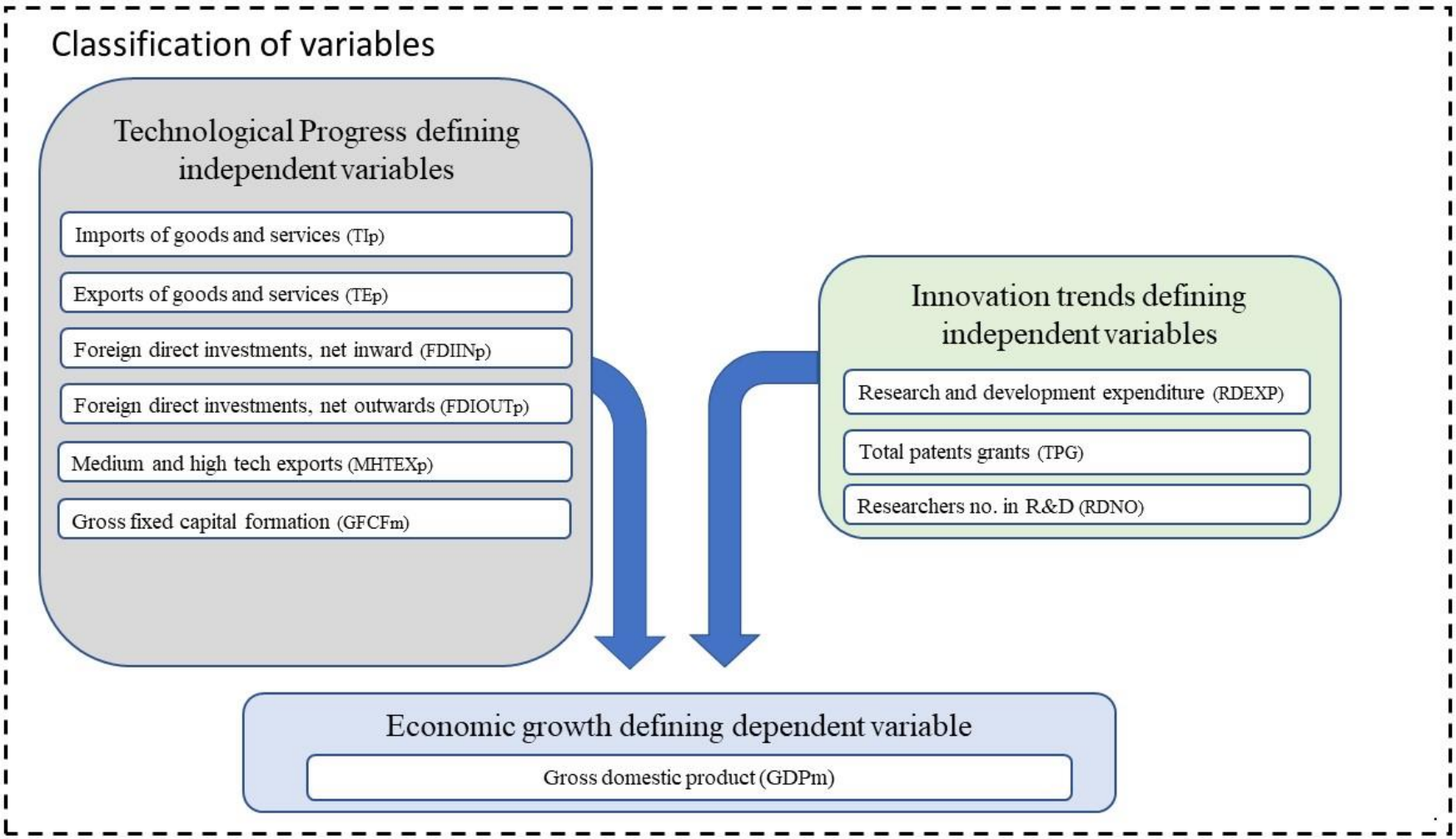
Hypothesis 1f: Gross fixed capital formation variable (GFCFm) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis no. 2a: Research and development expenditure variable (RDEXPp) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

Hypothesis no. 2b: Total patents granted variable (TPG) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries;

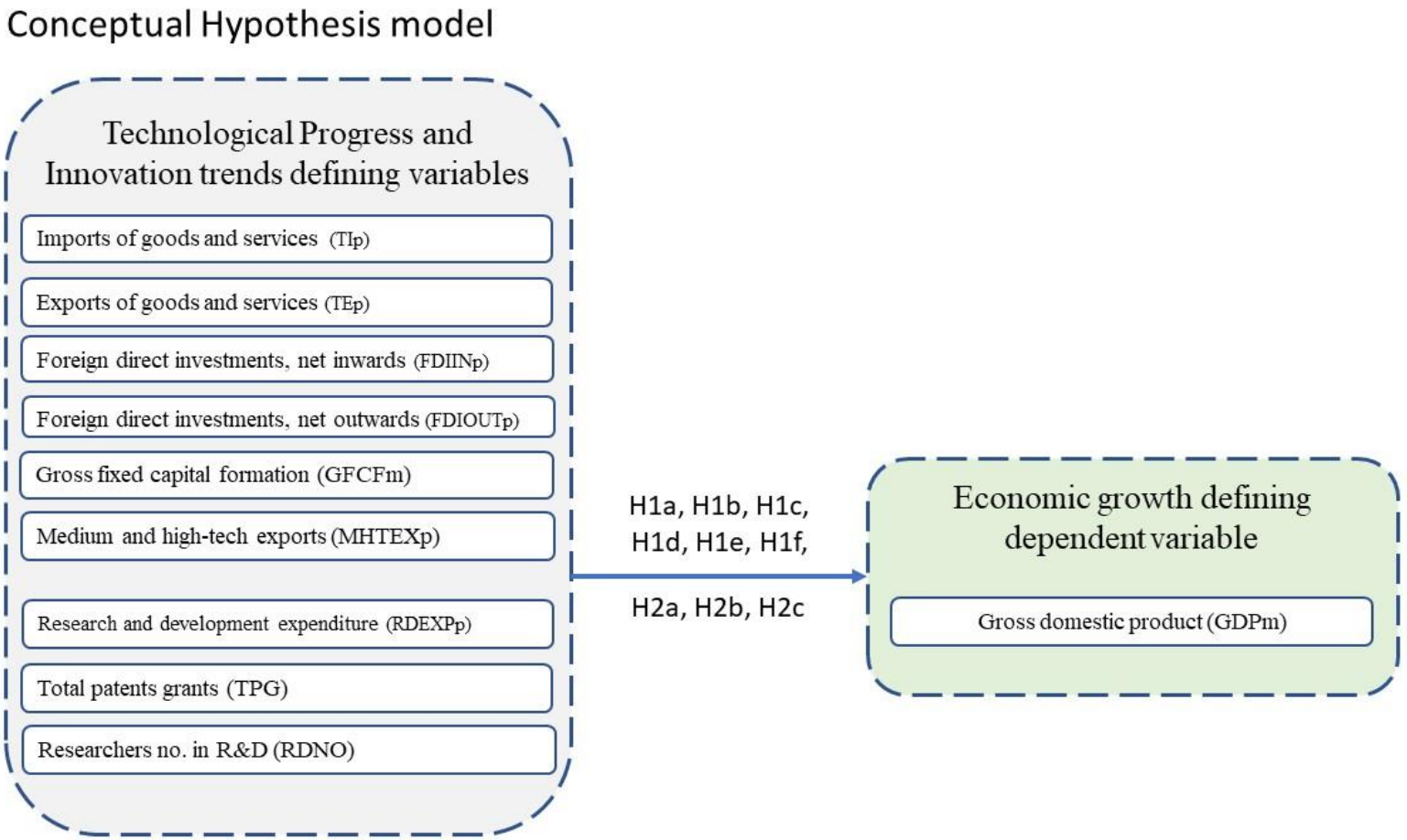
Hypothesis no. 2c: Researchers numbers in R&D variable (RDNO) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD EU membering countries.

Figure 13. *The Technological progress and Innovation trends defining variables impact on economic growth visualization*



Source: prepared by the author

Figure 14. *The simplified visualization of raised research paper's hypotheses*



Source: created by the author

To sum up, in this research paper author will adopt two different regression analysis methods and based on the most suitable model's econometric results raised nine hypotheses will be checked and rejected or not rejected.

2.4 The Research study variables

In order to build well functioning empirical research model it is crucial to critically select the variables. This chapter is devoted to review the variables. In this research paper author based on reviewed literature analysis will rely on following indicators: gross domestic product, gross domestic product per capita, gross domestic product annual growth rate, research and development expenditures, imports of goods and services, exports of goods and services, foreign direct investment net inflows, foreign direct investment net outflows, gross fixed capital formation, total patent grants, medium and high tech exports and researchers numbers in R&D sector (World bank, 2023b). These variables are encoded with abbreviations and illustrated in *Table 4*.

Since, in this dataset we have different variables scholar decided to assign different letter next to each variable. As a consequence, variables which are monetary (U.S. dollars, units) these variables received letter m for example GDPm. The next additional abbreviation were received by those variables which are ratio (percent of GDP) or proportional aspect, next to these letter p was added for example RDEXPp.

To be more precise in this research paper only single dependent variable exists which is gross domestic product – GDPm. Additional variables gross domestic product per capita (GDPcapm) and gross domestic product annual growth rate (GDPagr) are gathered and listed in the dataset for the purposes of graphical and descriptive statistics. The latter variables will not be used in correlation analysis neither regression analysis.

Final variables abbreviations are - GDPm, GDPcapm, GDPagr, RDEXPp, TIp, TEp, FDIINp, FDIOUTp, GFCFm, TPG, MHTEXp, RDNO. GDPm in further research development will be used as dependent variable and other nine variables will be used as independent variables – RDEXPp, TIp, TEp, FDIINp, FDIOUTp, GFCFm, TPG, MHTEXp, RDNO. Further, each variable will be presented individually.

Table 4. *The list of variables applied in empirical research part*

Variable description	Type of variable	Short variable identification	Units	Data source	Comments
GDP	Dependent	GDPm	current US$	WB Databank Development indicators	no fragmentation
GDP per capita	Explanatory variable	GDPcapm	current USD$	WB Databank Development indicators	no fragmentation
GDP annual growth rate	Explanatory variable	GDPagr	% of GDP	WB Databank Development indicators	no fragmentation
Imports of good and services	Independent	TIp	% of GDP	WB Databank Development indicators	no fragmentation
Exports of goods and services	Independent	TEp	% of GDP	WB Databank Development indicators	no fragmentation
Foreign direct investment, net inflows	Independent	FDIINp	% of GDP	WB Databank Development indicators	Missing values LUX N/A 1996-2001
Foreign direct investment, net outflows	Independent	FDIOUTp	% of GDP	WB Databank Development indicators	Missing values LUX N/A 1996-2001
Gross fixed capital formation	Independent	GFCFm	current US$	WB Databank Development indicators	no fragmentation
Total patent grants	Independent	TPG	direct and PCT national numbers	WIPO	Missing values LUX N/A 2004, 2013 SVN N/A 2012-2017, 2019-2021
Medium and high-tech exports	Independent	MHTEXp	% of manufactured exports	WB Databank Development indicators	Missing values Data series started collected since 2007. In all countries missing data between 1996-2007. Only LUX had this historical data which was presented. IRL N/A 2021 LUX N/A 2021

Continuation of **Table 4**

Research and development expenditure	Independent	RDEXPp	% of GDP	WB Databank Development indicators	Missing values AUT N/A 2021 BEL N/A 2021 CZE N/A 2021 DNK N/A 2021 FIN N/A 2021 FRA N/A 2021 DEU N/A 2021 GRC N/A 1996, 1998, 2000, 2002, 2021 HUN N/A 2021 IRL N/A 2021 ITA N/A 2021 LUX N/A 1996-1999, 2000, 2001, 2021 NLD N/A 2021 POL N/A 2021 PRT N/A 2021 SVK N/A 2021 ESP N/A 2021 SWE N/A 1996, 1998, 2000, 2002, 2021 EST N/A 1996, 1997, 2021 SVN N/A 2021 LVA N/A 2021 LTU N/A 2021
Researchers number in R&D sector	Independent	RDNO	Ratio per million people	WB Databank Development indicators	Missing values AUT N/A 1996, 1997, 1999, 2000, 2001, 2003, 2021 BEL N/A 2021 CZE N/A 2021 DNK N/A 1998, 2000, 2021 FIN N/A 1996-2003, 2021 FRA N/A 2021 DEU N/A 2021 GRC N/A 1996, 1998, 2000, 2002, 2004, 2008-2010, 2021 HUN N/A 2021 IRL N/A 2021 ITA N/A 2021 LUX N/A 1996-1999, 2001-2002, 2021 NLD N/A 2021 POL N/A 2021 PRT N/A 2021 SVK N/A 2021 ESP N/A 2021 SWE N/A 1996, 1998, 2000, 2002, 2021 EST N/A 1996, 1997, 2021 SVN N/A 2021 LVA N/A 2021 LTU N/A 2021

Source: prepared by the author

Author highlight that below listed variables' definitions are based on the main World Bank Indicators source.

Gross domestic product (GDPm) is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies no included in the value of the products. Variable units are measured in current U.S. dollars. Current variable was collected from the World Bank Development indicators dataset and is considered as secondary. Letter m in the variable's abreviation is showing that the variable is monetary showing it's type for the author.

Gross domestic product per capita (GDPcapm) is domestic product divided by midyear population. GDP in general the variable defines the total value added and the sum of gross created by all residents in the economy. Variable units are measured in current U.S. dollars. Author disclose that this variable is collected from the World Bank Development indicators dataset and is considered as secondary. It is descriptive and graphical analysis data series which will not be used in regression modelling.

Gross domestic product annual growth rate (GDPagr) is annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. Variable units are ratio of annual growth rate in these terms it is percentage. Data series gathered from the World Bank Development indicators dataset and is considered as secondary. It is the second one and the last descriptive variable used in this research.

Research and development expenditure (RDEXPp) is gross domestic expenditures on research and development (R&D), expressed as a percent of GDP. This variable dataset includes capital and current expenditures in the four sectors: business enterprise, government, higher education and private non-profit. Measurement units are percent of GDP for this matter letter p is indicated in the abbreviation which is showing percentage indication.

The next variable is representing the value of all goods and other market services received from the rest of the world which includes the value of merchandise, freight, insurance, transport, travel, royalties etc. Series units are percent of GDP. Since it is a ratio or percent of GDP the variable abbreviation received letter p in the end. This variable is collected from WB Development indicators dataset and considered as secondary.

Furthermore, we will review variable defining exports of goods and services phenomenon (TEp.) Variable units for this dataset is ratio, percentage of GDP, for this matter letter p is attached in the abbreviation. Variable was collected in WB Development indicators dataset and is considered as secondary.

Afterwards, we present next variable - foreign direct investments, net inflows (FDIINp). It is the variable which indicating the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital. Variable units net inflows divided by GDP which states that this variable is ratio or percentage. For this matter letter p was added in the abbreviation. This series refering to net inflows in the reporting economy from foreign investors and is divided by GDP . The data and descriptions collected from WB Development indicators dataset and considered as secondary data (World Bank, 2023b).

The next variable – foreign direct investments, net outflows (FDIOUTp). This variable units are ratio or percentage of net outflows percent of GDP (FDIOUTp). In general, it is the sum of equity capital, reinvestment of earnings, and other capital. It shows net outflows of investment from the reporting economy to the rest of the world, and is divided by GDP. The overall measurement units are percetage for this case the letter p were added to the abbrevation. This series data was gathered from WB Development indicators and considered as secondary.

The gross fixed capital formation (GFCFm) is representing investments such as land improvements, machinery, equipment purchases, constructions of roads, railways and hospitals. Data units are in current U.S. dollars for this matter the letter m was attached indicating monetary variable shortening among others. This series gathered from WB Development indicators and considered as secondary data.

The total patent grants (TPG) is measuring the total number of anually granted patents for the analyzed country. It is the secondary data which was collected from the World Intellectual Property Organization (WIPO). Units are number of cases. This makes this dataset exclusive due to the fact that all other variables are collected from WB Databank.

The next analysed indicator - medium and high-tech exports (MHTEXp) which represents the share of medium and high-tech exports in total manufactured exports. This is the percentage expression for this matter the letter p is added in the series abbreviation. The dataset gathered from WB Development indicators and considered as secondary.

Last but not least, researchers in R&D sector (per million people) (RDNO). This indicator is ratio, because the exact number of individuals working in research and development sector in the end is divided by million. The series are gathered from WB Development indicators which state that researchers are considered as professionals engaged in the conception or creation of new knowledge, products, processes, methods or systems. Besides already mentioned fields R&D project management and postgraduate PhD students engaged in R&D activities are included in stats. The dataset is considered as secondary.

To sup up, the gathered list of variables consists of 12 variables were justified based on reviewed and analyzed academic literature. Two of presented variables GDPcapm and GDPagr will be used as descriptive variables. Despite the long list, most likely any of 9 presented independent variables will fell off and the final stage of regression model will be formed based on statistically significant varibales according correlation analysis results.

2.5 The Data limitations, research object and duration corrections

During the first data processing stage scholar found out that:

1. There are lacking research papers analysing both phenomenons at once. Usually scholars assessing single factor impact on economic growth or development. Despite the fact, author have dealt with grey zones (unclear independent variables for each factor analysis) which was solved in creative way. Author based on academic studies splitted variables in order to analyse two independent phenomenons – technological progress and innovations trends.

2. To develop this research author selected three core studypapers (Kiselakova et al., 2020; Khyareh & Rostami, 2022; Kumar Dhar et al., 2023) according which independent variables were gathered. However some of thee variables was missing and couldn't been gathered – government expenditure on education (GEE), direct investment in the reporting economy (DI), tertiary educational atainment (TEA), trade openess (TR). Based on missing parameters author decided instead of trade openess gather import and export figures and see whether it has any effect on dependent variable.

3. Gathered data is fragmented and requires either methodological approval on how to deal with missing cells or eject missing countries and review/reduce timeframe. Executing first approach author tried using all 38 variables however data poor quality and fragmentation have done it's negative work. Evidently, researcher had to decide how to receive non biased final research paper results. And it was decided to eject all countries apart EU. The decision as already presented in previous chapter was made based on limited technological progress and innovation trends both phenomenons development in the latest academic society researchpapers in OECD EU countries.

4. Variable MHTEXp was started collecting since 2007 which indicate that values from 1996-2006 will be missing. Only single country – Luxembourg (LUX) had provided historical data which was presented in data series. This variable throughout the whole empirical research process should be analyzed with procesciousness due to partially missing cell values.

5. The next variable which must be described is RDEXPp. It is historical variable which is collected for a while, however different countries had their own data gathering legislations. In the early stage of OECD data processing author found out that countries provided the data every second year - Australia (AUS), New Zealand (NZL) and Switzerland (CHE). Since, non of three mentioned countries belongs to the EU and research object it must be rejected. Likewise, researcher had similar issues with EU countries which are far more fragmented than other analysed variable data series. Countries which might potentially have issues with missing cell values - Greece (GRC), Luxembourg (LUX), Sweden (SWE), Estonia (EST). For further research paper development this variable will be analysed with serious cautiousness.

6. Last variable from the list is researchers number in R&D sector (RDNO). Scholar admits that RDNO variable is contraversial due it's data quality. In particular, data series are also fragmented. Following country's missing cell values might create an issues of further independent variable applicability – Austria (AUS), Denmark (DNK), Finland (FIN), Greece (GRC), Luxembourg (LUX), Sweden (SWE), Estonia (EST). For the further empirical research development variable RDNO must be critically assessed and applied.

Outcome. Despite missing values in different variables author decided to proceed with current panel dataset and execute correlation and regression research analyses. In order to deal with missing values author will be using Rstudio integrated development environment for R programming language. This econometrical software will allow to test imbalanced panel data's statistical computings and find out graphics (Croissant & Dehon, 2010). Final dataset's extract you can see in the *Annex 3*.

3. THE GRAPHICAL DATA STUDY AND EMPIRICAL RESEARCH ANALYSIS

The third chapter is dedicated to graphical and descriptive statistics in order to analyze and better understand research object, duration and variables. In the first subchapter scholar will present what type of transformation were executed for standard secondary data variables. Next, author will the help of statistical software Rstudio and SPSS Boxplot and Scatter plot visualization will be presented which will be reviewed not only graphically but in descriptive analysis way. Analyzed graphical relationships between regressor and dependent variables will create a solid background for further correlation and regression analyses development.

3.1 The Original relational variables transformations, data stationarity and distribution tests

Transformations in this research paper were executed in two different levels.

The first variables is positive numeric figures, greater than zero. It is gross domestic product (GDPm) which is value in current US$, gross fixed capital formation (GFCFm) and total patent grants (TPG) case number in thousand. For these variables were implemented percentage change function. In the previous research paper development stage these variables were transformed based on logarithmic change function. However in the final stage author will be analysing percentage change function in order not to loose each variable's value negativities (Box & Cox, 1964). Calculations executing in software package Gretl according *Formula 13a*, *Formula 13b* and *Formula 13c* listed below. Here are the following list of variables – GDPm, GFCFm, TPG. After the transformation these variables received following variable shortenings – pc_GDPm, pc_GFCFm, pc_TPG.

Statistical friendly function (percentage change) equations for selected variables

$$100*(GDPm/GDPm\ (1)-1) \quad (13a)$$

$$100*(GFCFm/GFCFm\ (1)-1) \quad (13b)$$

$$100*(TPG/TPG\ (1)-1) \quad (13c)$$

Source: prepared by an author

In the second case variables which are in percentage expression such as import, % of GDP (TIp) or foreign direct investment, net inward, % of GDP (FDIINp) were applied first difference function. In total we have six variables which are – RDEXPp, TIp, TEp, FDIINp, FDIOUTp,

MHTEXp. After the transformation these values received following variables shortenings – d_RDEXPp, d_TIp, d_TEp, d_FDIINp, d_FDIOUTp, d_MHTEXp.

All original and transformed variables are represented in the *Table 5* listed below.

Table 5. *The list of abbreviations of original and transformed variables*

Original Relational Variables	Transformed Growth rate variables
GDPm	pc_GDPm
RDEXPp	d_RDEXPp
TIp	d_TIp
TEp	d_TEp
FDIINp	d_FDIINp
FDIOUTp	d_FDIOUTp
GFCFm	pc_GFCFm
TPG	pc_TPG
MHTEXp	d_MHTEXp
RDNO	pc_RDNO

Source: created by author

Since this research paper rely on unbalanced panel data author adopted Unit Root test by Maddala-Wu in Rstudios. This test will allow to analyze the whole entity of 22 OECD EU countries and provide generalized results for data stationarity. If statistical significance probability value is lower than α ($p<0,05$) it can be stated that data are stationary. If probability value is greater than signifinace level α ($p>0,05$) it is vice versa which means data is non-stationary. Overall analyzed model results can be found in *Annex 1*. Based on provided test results scholar can state that five out of ten variables were non-stationary (GDPm, RDEXPp, TEp, GFCFm, RDNO), other five variable data sets were stationary (TIp, FDIINp, FDIOUTp, TPG, MHTEXp). After transformations author repeated the same test and foundout that applied transformation helped to increase data quality. All ten variables become stationary (pc_GDPm, d_RDEXPp, d_TIp, d_TEp, d_FDIINp, d_FDIOUTp, pc_GFCFm, pc_TPG, d_MHTEXp, pc_RDNO).

Generally speaking author had tested absolute and growth rate variables and found out that not all absolute variables are stationary. In order to further develop variables in further research it was necessary to transform them. Absolute variables which are original secondary data from WB databases were converted to **growth rate** variables. Afterwards stationarity was tested once again. In the end transformations had helped to meet the stationarity assumptions of all tested variables.

Afterwards, when the data were transformed and stationarity achieved it is time for data normality test. In order to test it researcher had implemented Non-parametric One-Sample

Kolmogorov-Smirnov test. This test is suitable for sample size greater than n>=50. This test is more descrete and suitable than checking different variables graphical data as histograms. In this research paper it was implemented twice. First was checked relative variables and in the second case the growth rate variables which were transformed. Important to highlight that despite Kolmogorov-Smirnov additional test had to be implemented, because of data fragmentation and impossible to test the normality assumptions. The second test implemented is Shapiro-Wilk it was decided when in variables RDEXPp, FDIINp, FDIOUTp, TPG, MHTEXp and RDNO was not possible to find out test results. Frankly, it was done to prove it in alternative way that data are not normally distributed.

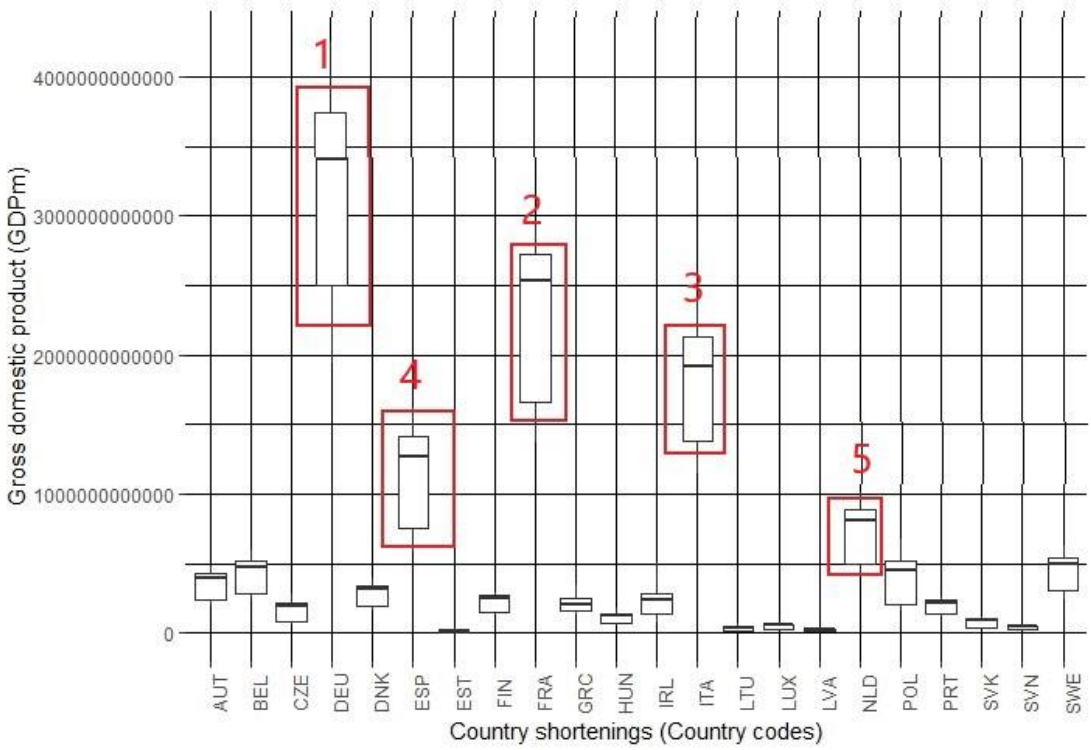
Based on received results researcher found out that all gathered (original secondary data) variables are not normally distributed. However, while analysing transformed dataset author received that single variable from final dataframe is normally distributed – percentage change of GDP (pc_GDPm). Other nine tested regressors have not normaly distributed data characteristic. Outcome is based on results provided in *Annex 2*. In this table provided significance values which are all lower (except pc_GDPm) than significance level p=0,05. In this case we can reject the null hypothesis which states that variables are normally distributed.

The received results indicate that data set is stationary however not normally distributed. For this matter author must implement Non-parametric measures of relationships – Spearman's rank or Kendall's Tau correlations. Since this research paper rely on numeric data and focus on quantitative research methodology researcher reject the Kendall's Tau correlation method as mostly applied for ordinal data.

3.2 The Boxplots

The variable gross domestic product (GDPm) boxplot is presented in *Figure 15*. Graphical data has confirmed the already obvious fact that gross domestic product in OECD EU countries perspective is seriously uneven. The first marked country in the graph is the Germany (GER) which has the leading GDP in current US$ units (3141718415378,77). It is the Mean figure values provided in the brackets. It is the leading economy among analysed 22 OECD EU countries. The second pointed country in this graph is France which based on this graph and variable mean GDPm values in current US$ (2290724878389,00) is also very contrasting in comparison with other OECD EU memberstates. The third, fourth and fifth countries are – Italy (1818733813026,56), Spain (1139539714330,13) and the Netherlands (726780259192,12).

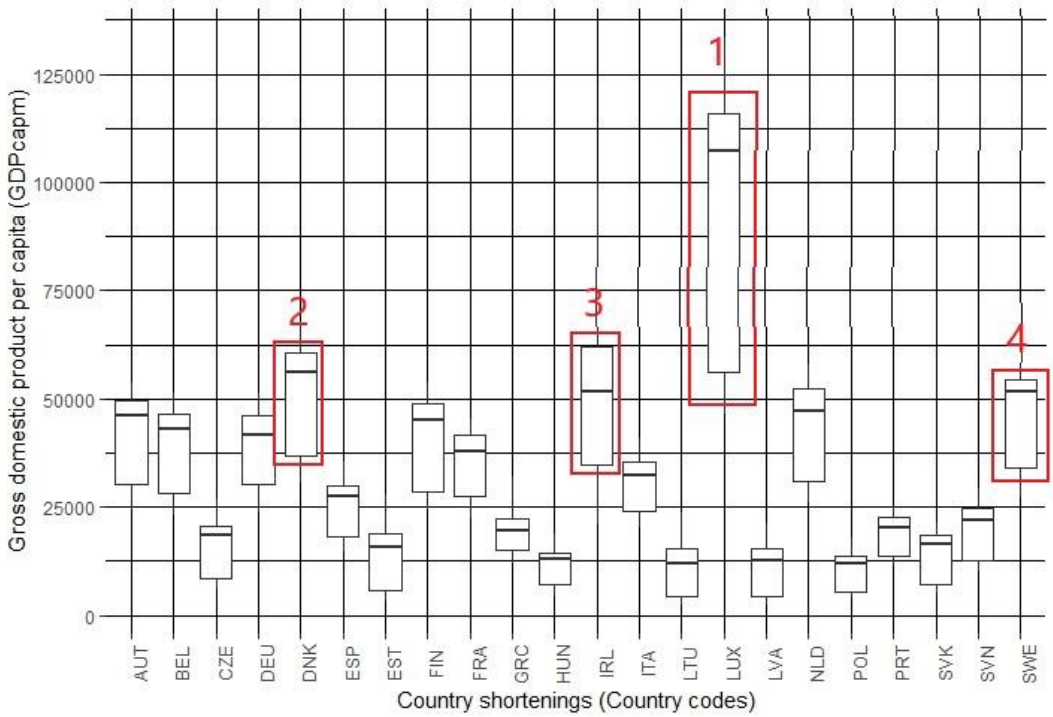
Figure 15. *The gross domestic product (GDPm) variable simple Boxplot visualization*



Source: created by the author in software Rstudio

Another variable analyzed was gross domestic product per capita (GDPcapm). This variable is used for descriptive and graphical analyses purposes. Based on Boxplot graphical data in *Figure 16* we can see that variable data are more uniform than GDPm with only signle exception. Original graph prepared with Rstudio enriched with red colour brackets to review the leaders reviewed series data. The exception among all analyzed is Luxembourg (LUX). Based on the graphical information and Boxplot rectangle size it is indicated that during the analyzed 1996-2021 timeframe this variable has changed a from minimum of 46641,64 US$ to the maximum of 133590,15 US$. This tendency of GDP per capita growth was visible among all analysed OECD EU countries. The greatest increase was visible in Denmark (DNK), Ireland (IRL), Sweden (SWE), Finland (FIN), Netherlands (NLD). However the process was not as steep as in Luxembourg. The second third and fourth place according mean values in current US$ in the brackets belongs to – Denmark (50633,42), Ireland (51854,86), Sweden (46503,92). The least developed countries among analyzed ones can be called – Lithuania (11259,60), Latvia (10861,83), Poland (10342,74) and Hungary (11399,44).

Figure 16. *The gross domestic product per capita (GDPcapm) variable simple Boxplot visualization*



Source: created by the author in software Rstudio

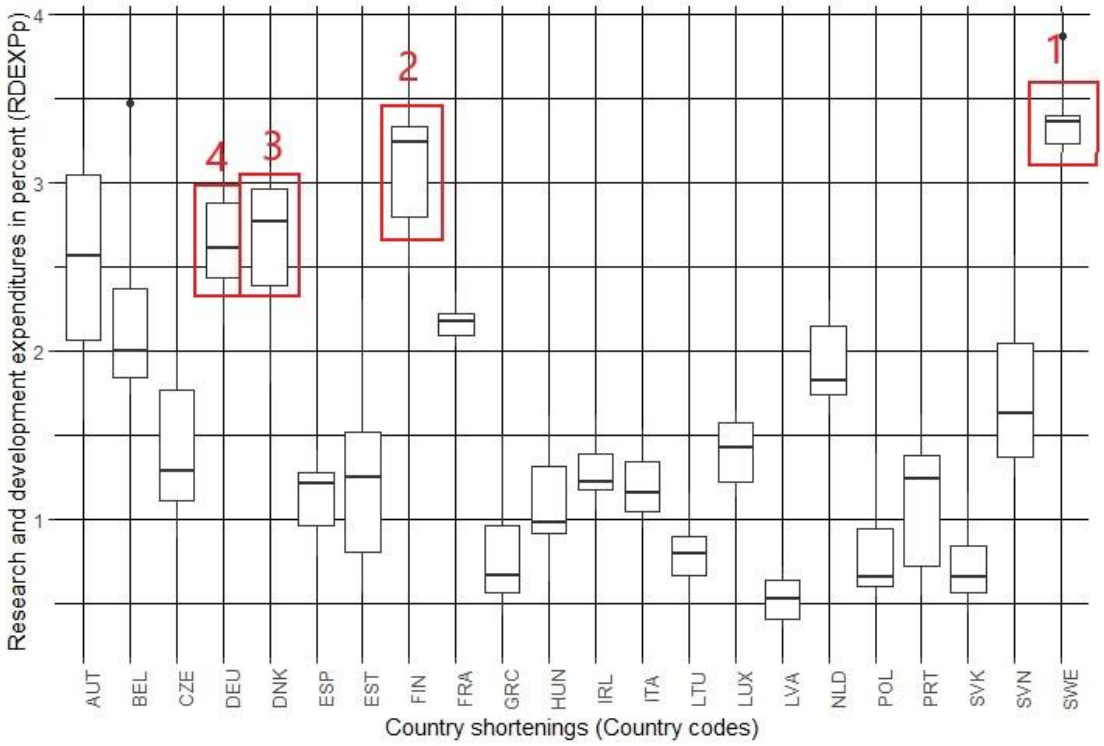
The third and fourth variables which were selected to analyze is research and development expenditure percent from gross domestic product (RDEXPp) and first difference of latter variable (d_RDEXPp). Despite that RDEXPp variable is non-stationary author is giving a comment regarding different country investment capabilities to increase R&D sector activities.

In the primary empirical analysis stage the latter variable is considered as one of the core independent variables explaining innovation trends encouraging environment for further economy and technology progress development. The following comments will be made based on *Figure 17a*. All in all this figure has marked four countries which in general shows the even data figures distribution. The leading country among analysed are Sweden which investing 3,35% of GDP to R&D activities. Boxplot graph is showing that Sweden had very stable and not fluctuating investment in R&D approach between period of 1996-2021. The second place belongs to Finland which on average was investing 3,14% of GDP to R&D activities. Based on boxplot rectangle width it is clear that Finland at some point has changed their politics and started to invest more from minumum 2,45% to maximum of 3,73% of GDP. Third and fourth places belongs to well developed countries – Denmark and Germany. Denmark on average invested 2,62% of GDP which is statistically greater than Germany 2,65%. However Germany was more consistant and it's levels fluctuated much less. Also, Germany's mean GDP are eleven times greater than Denmark's GDP

mean value. So this variable does not show exact investment amount figures rather the country's approach to constant R&D field development. In spite of leading countries, there are also countries which have opposing politics and tend to invest less in R&D sector progress those countries are – Latvia (0,52%), Poland (0,78%), Lithuania (0,79%), Greece (0,78%), Slovakia (0,71%). All mentioned countries are located in Eastern and Central Europe except one – Greece, however figures mimic the regional politics and each country socio-economic environment. These countries invest less than <1,0% of ratio to gross domestic product.

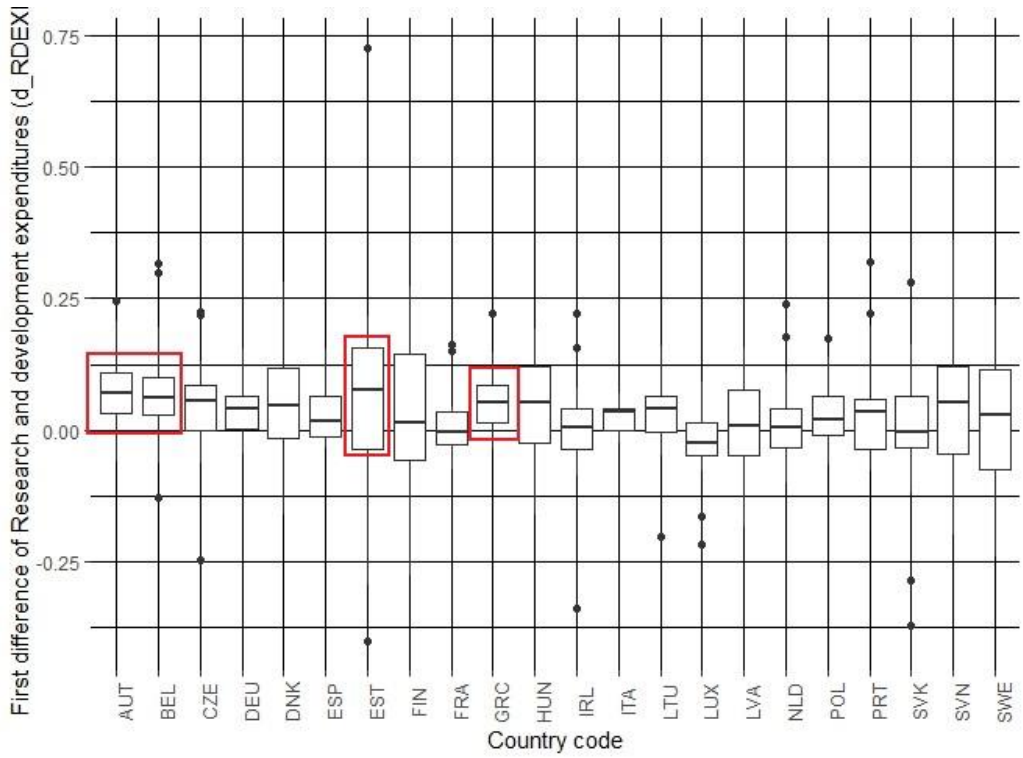
Yet another one graph analysing R&D sector development is simple Boxplot of transformed variable d_RDEXPp. It is first difference data results which needs to be interpreted separately and differently than RDEXPp. In this case Boxplot visual data is showing how countries increased or decreased their investment in R&D based on change from percentage of GDP. Leading countries based on below shared *Figure 17b* are marked in red colour – Estonia (0,06%), Greece (0,06%), Austria (0,07%), Belgium (0,07%) which during research period 1996-2021 increased annually their spendings on R&D the most. By looking at the visual data we can see the country in the first position Estonia which changed the overall comprehension and started increasingly invest share of capital year by year from minimum -0,40% to maximum of 0,73%. The least capital development change seen in following countries – Luxembourg (-0,03%), Sweden (0,00%), Slovakia (0,00%), Ireland (0,00%) and France (0,00%). Following countries can be presented as least capital increase in R&D activities built over the years. It is crucial to highlight that this variable is not showing the overall level of investments in R&D, but the tempo during researched period between 1996 and 2021.

Figure 17. *The research and development expenditures, percent of GDP (RDEXPp) variable simple Boxplot visualization*



Source: created by the author in software Rstudio

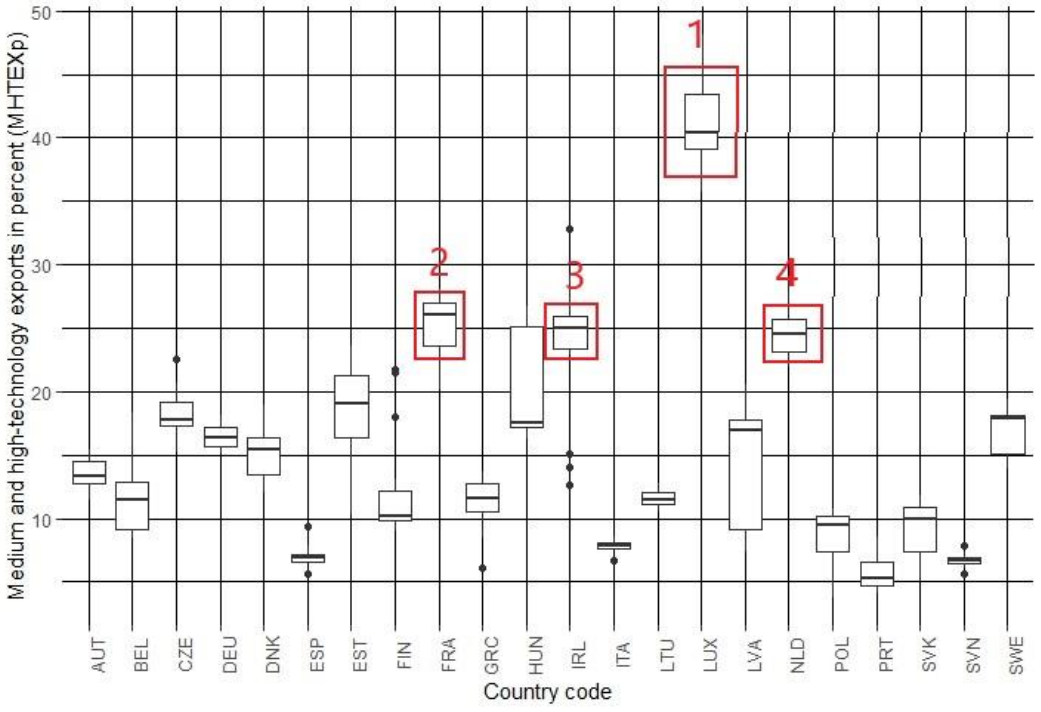
Figure 18. *The first difference of Research and development expenditures (d_RDEXPp) variable simple Boxplot visualization*



Source: created by the author in software Rstudio

The next variable medium and high-technology exports in percent (MHTEXp) which is one of variables representing technological progress phenomenon. It is interesting to analyse variable, because it is presenting how much medium and high-technology products or services consists in all export phenomenon. Analyzed graph is presented in *Figure 18*. According data results the leading country in analysed period between 1996 and 2021 is Luxembourg (LUX). Luxembourg's medium and high-tech products and services export consists 41,39% of export in general. This result might be caused due high-development services provision related with European Union parliament. Boxplot graph shows that drastic fluctuation in 26 years was not encountered. The second in the list is France (FRA) which exported 25,22% of medium and high-tech products and services over analysed period of time. The results did not vary in time, it was stable and prominent result among other OECD countries. The third on the list is Ireland (IRL) with 23,70% result. And the fourth is Netherlands (NLD) with 24,82% result of high added value products and services export. The laggards in exporting medium and high-technoly products and services are following countries, here mean values provided for comparison – Portugal (PRT) with 5,76%, Spain (ESP) with 6,96%, Slovenia (SVN) with 6,69%, Italy (ITA) with 7,77%. The characteristic for all these mentioned countries they are located in Southern part of Europe where agriculture and tourism sectors are highly developed.

Figure 19. *The medium and high-technology exports, in percent of export (MHTEXp) variable simple Boxplot visualization*



Source: created by the author in software Rstudio

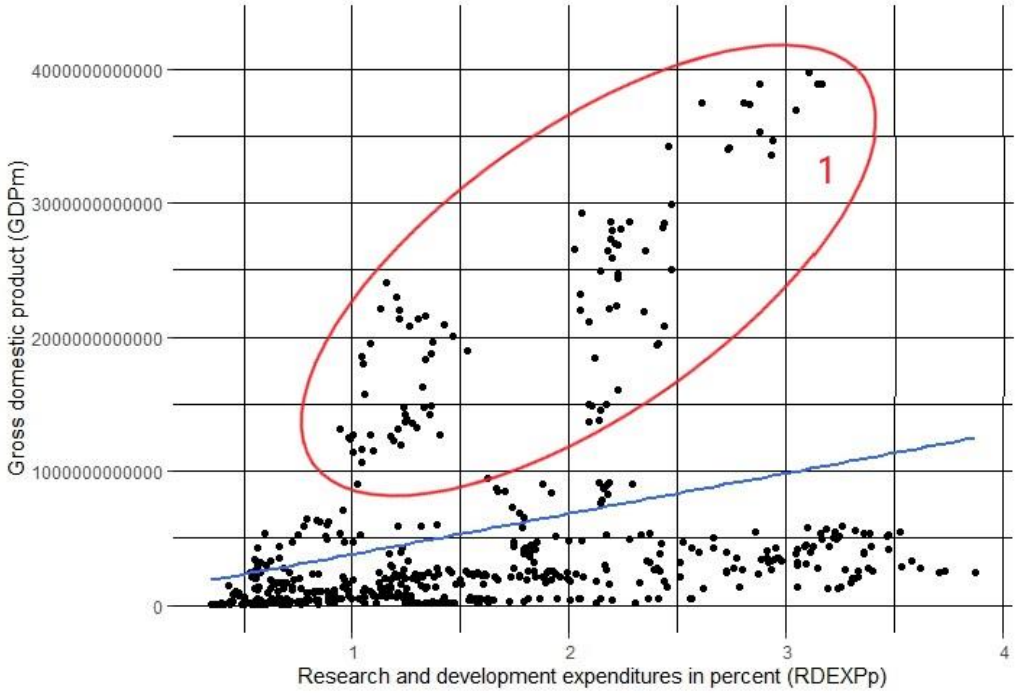
Presented Boxplots and descriptive statistics are presenting OECD memberstates in EU similarities and differences. Selected variables of analysis (GDPm, GDPcapm, RDEXPp, d_RDEXPp, MHTEXp) are only partial information of possible to analyse data. Provided cases have Outliers which are kept and not rejected from further study development.

3.3 The Scatterplots

In order to find out whether dependent variable has correlation with potential independent variables let's have a look at the Scatter plots. In this graphical data analysis task four cases were modelled. In all of those cases dependent variable is standard gross domestic product (GDPm) or transformed percentage change of gross domestic product (pc_GDPm) variables. Selected independent variables - research and development expenditure percent of GDP (RDEXPp), first difference of research and development expenditure (d_RDEXPp), medium and high-technology products and services export (MHTEXp), first difference of medium and high-technology products and services export (d_MHTEXp), foreign direct investment, net outward (FDIOUTp) and first difference of FDI, net outward (d_FDIOUTp), gross fixed capital formation (GFCFm) and percentage change of gross fixed capital formation (pc_GFCFm), trade imports of goods and services percent of GDP (TIp) and lastly first difference of trade imports of goods and services of GDP (d_TIp). To be more precise, scholar will be analysing dependent variable and five independent variable possible relationships.

In the *Figure 19a* is presented graph showing that there is no positive nor negative correlation between GDPm and RDEXPp variables. The graph shows that there exists different segmentation countries which based on their statistical data is hardly comparable. The marked areal arround number one identifies countries data which GDP level is extremely high in comparison to other OECD countries it might be one of few (GER, FRA, ITA, ESP, NLD). Displayed graph does not show any correlation between GDPm and RDEXPp for all object countries.

Figure 20a. *The gross domestic product (GDPm) and R&D expenditures, in percent of GDP (RDEXPp). Scatter plot visualisation*



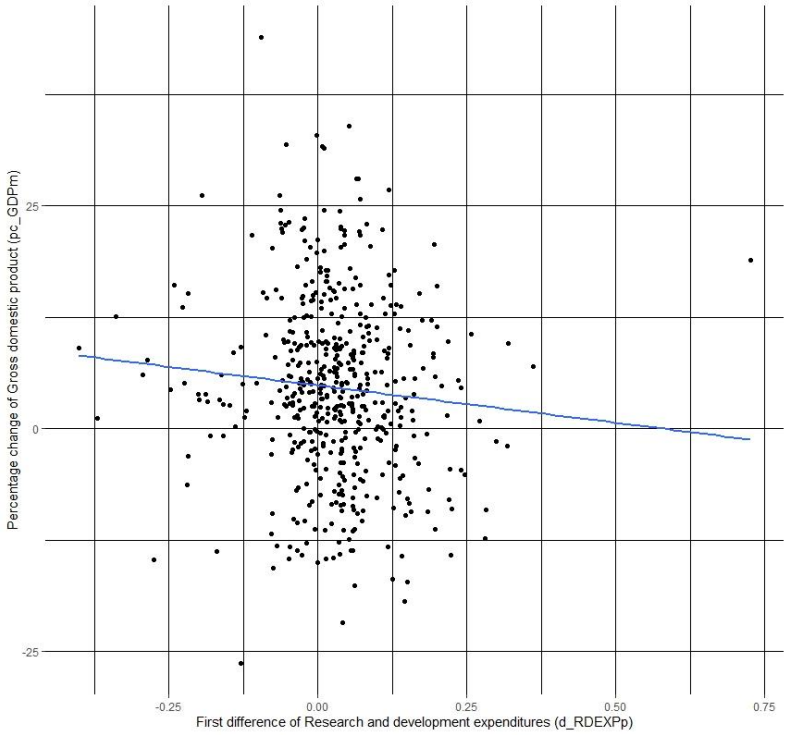
Source: created by the author in software Rstudio

The second scatter plot presented in *Figure 19b* is between transformed GDPm (pc_GDPm) and first difference of RDEXPp (d_RDEXPp) variable. In general it is showing no linear correlation among analysed dependent and independent variables.

Secondly, let's move forward and analyze yet another one phenomenon medium and high-technology products and services export, percent of exports (MHTEXp). It is one of six variables representing technological progress phenomenon. The scatter plot between GDPm and MHTEXp is visualised in *Figure 20a.* As graph shows there is no linear correlation between analysed variables. Author marked two possible clusters/grouping which can be identified easily, because of great figures of GDPm values.

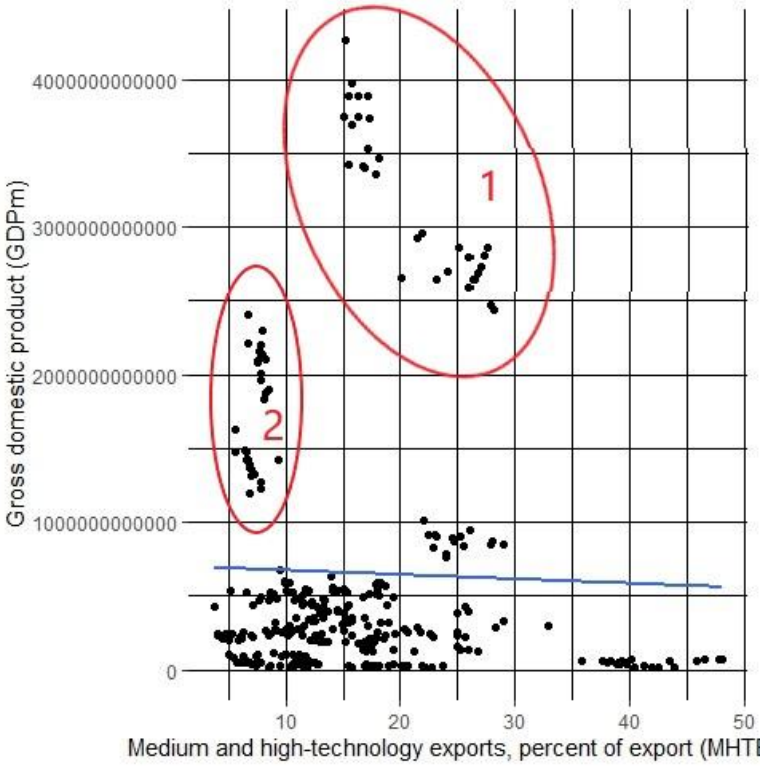
What is more interesting to review graphical relations between transformed dependent and independent variables. The scatter plot between percentage change of GDP (pc_GDPm) and first difference of medium and high-technology products and services export (d_MHTEXp) is presented in *Figure 20b*. As graph shows there is no linear correlation between a set of variables.

Figure 21. *The percentage change of GDP (pc_GDPm) and the first difference of R&D expenditures, in percent of GDP (d_RDEXPp). Scatter plot visualisation*



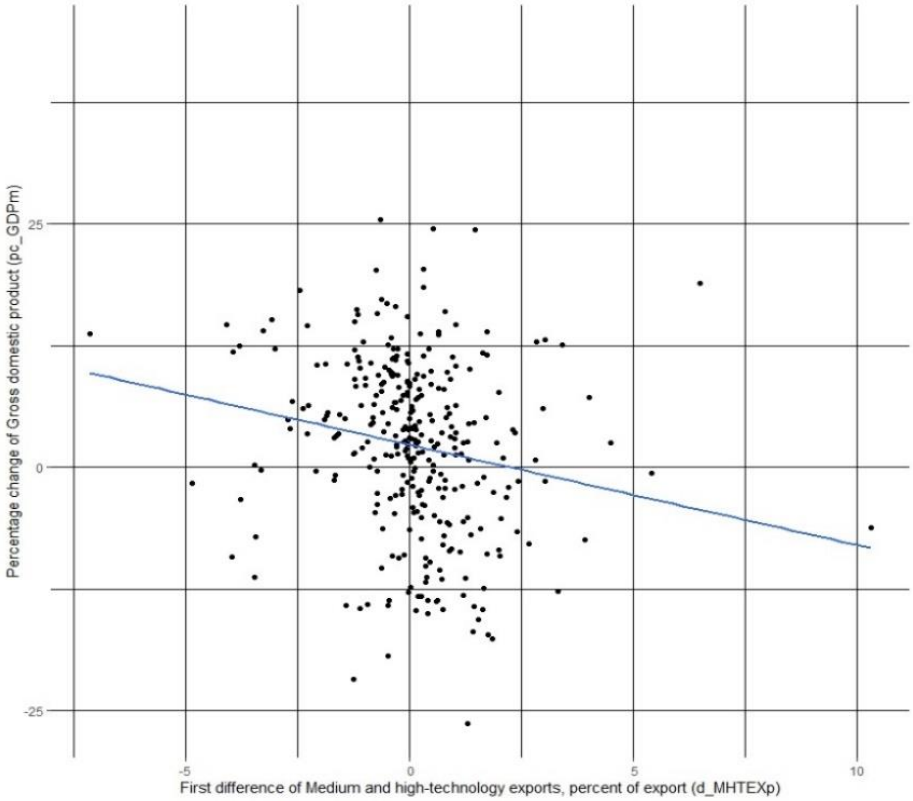
Source: created by the author in software Rstudio

Figure 22. *The gross domestic product (GDPm) and the medium and high-technology exports, percent of overall export (MHTEXp). Scatter plot visualisation*



Source: created by the author in software Rstudio

Figure 23. *The percentage change of GDP (pc_GDPm) and the first difference of medium and high-technology exports, percent of overall export (d_MHTEXp). Scatter plot visualisation*

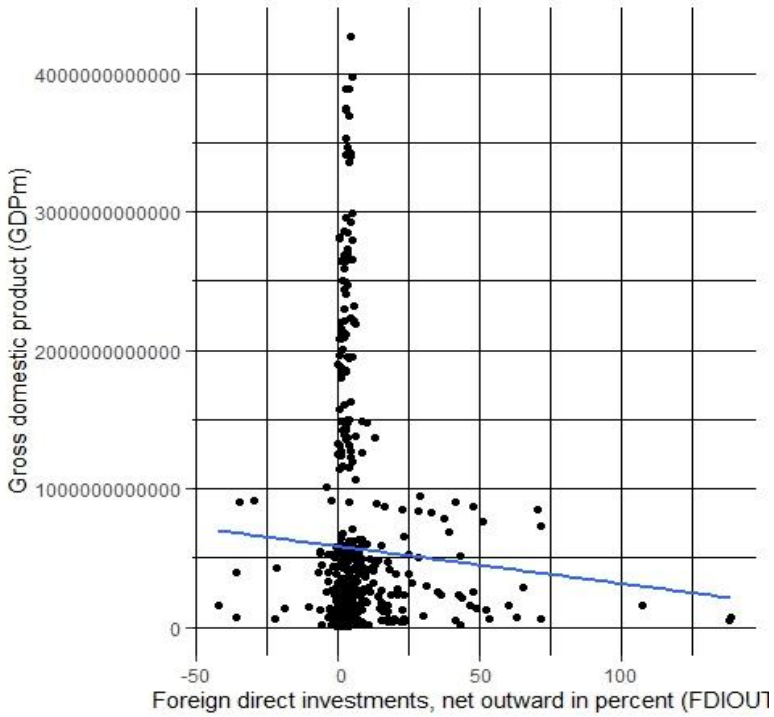


Source: created by the author in software Rstudio

To further understand the role of variable relationships, the next analysed independent variable is presented – foreign direct investments, net outward (FDIOUTp). The scatter plot of dependent and independent variable relations presented in *Figure 21a*. According below listed graphical information author state that there are no linear correlation.

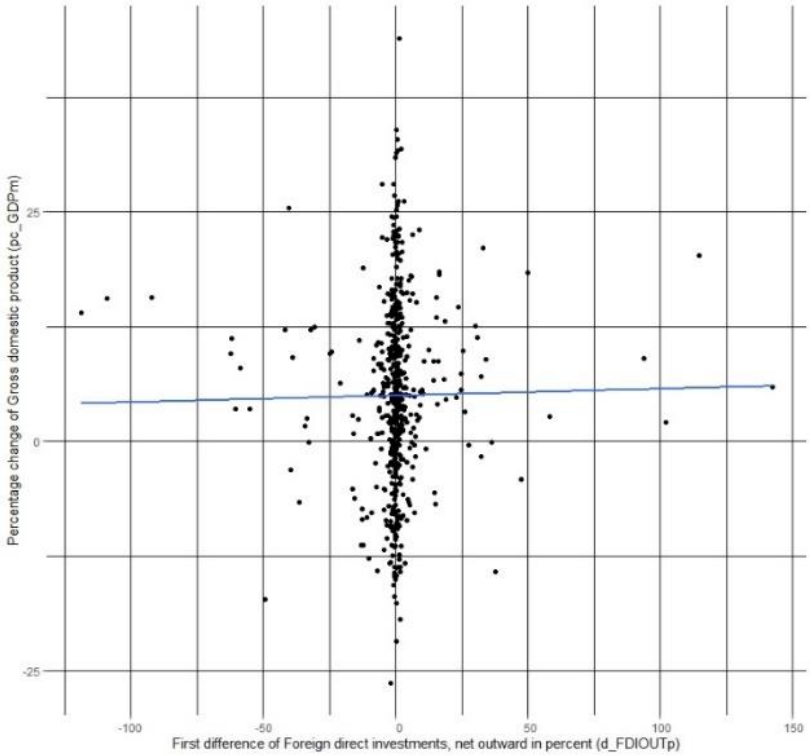
Similarly to what's been already presented author continue to analyse the same phenomenon however with transformed variables – percentage change of GDP (pc_GDPm) and first difference of foreign direct investment, net outwards (d_FDIOUTp). The relationship analysis executed with Scatter plot tool and visualized in *Figure 21b.* Based on graph information researcher state that there are no correlation or linear relationship between these variables.

Figure 24. *The gross domestic product (GDPm) and foreign direct investments, net outward (FDIOUTp) Scatter plot visualization*



Source: created by the author in software Rstudio

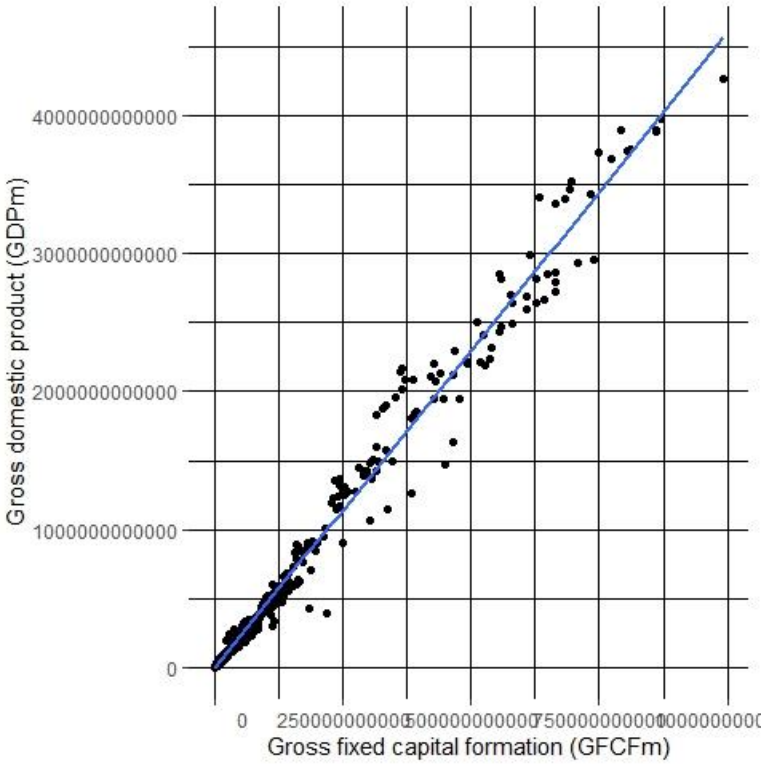
Figure 25. *The percentage change of GDP (pc_GDPm) and first difference of FDI, net outward (d_FDIOUTp) Scatter plot visualization*



Source: created by the author in software Rstudio

Another variable of thought on dependent and independent variables relations are gross fixed capital formation (GFCFm). The scatter plot between not transformed dependent and independent variables visualized in *Figure 22a.* This case is different than previous ones, because it is clearly defined two way relationship between chosen variables. According to presented graph author state that strong positive correlation exist between chosen GDPm and GFCFm variables.

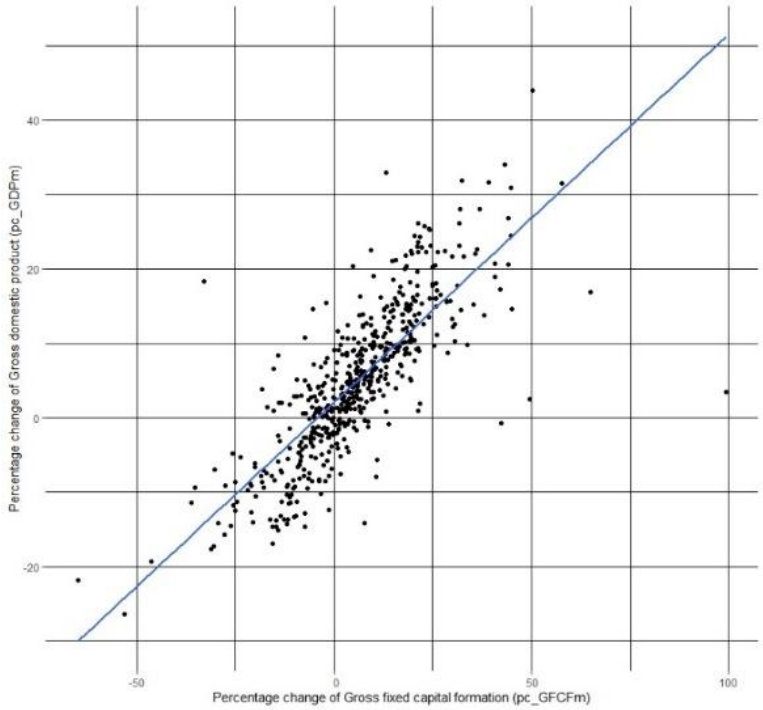
Figure 26. *The gross domestic product (GDPm) and gross fixed capital formation (GFCFm). Scatter plot visualization*



Source: created by the author in software Rstudio

In addition to executed previous graphical analysis author continues to analyse the same phenomenon however with transformed variables. The scatter plot between percentage change of gross domestic product (pc_GDPm) and percentage change of gross fixed capital formation (pc_GFCFm) are visualized in *Figure 22b.* Relying on graphical findings author state that there are linear relationship between analysed variables, however it is not that strong as in primary case when variables were not transformed.

Figure 27. *The percentage change of gross domestic product (pc_GDPm) and percentage change of gross fixed capital formation (pc_GFCFm). Scatter plot visualization*

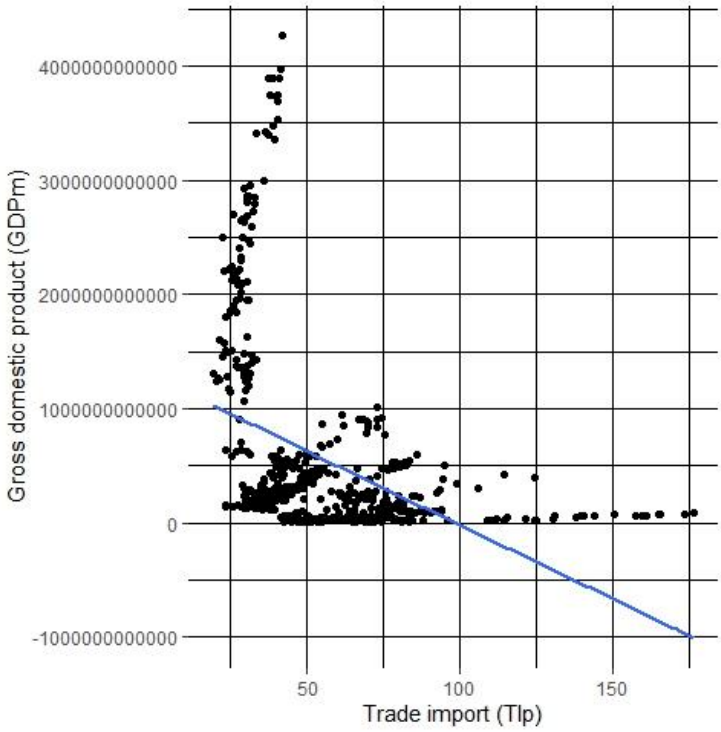


Source: created by the author in software Rstudio

Last but not least, the final analysed phenomenon is trade imports of goods and services (TIp). The relationship between dependent (GDPm) and independent variable (TIp) is visualized in Figure 23a. According to displayed graphical findings author state that there is no statistically significant linear relationship between two analysed data series.

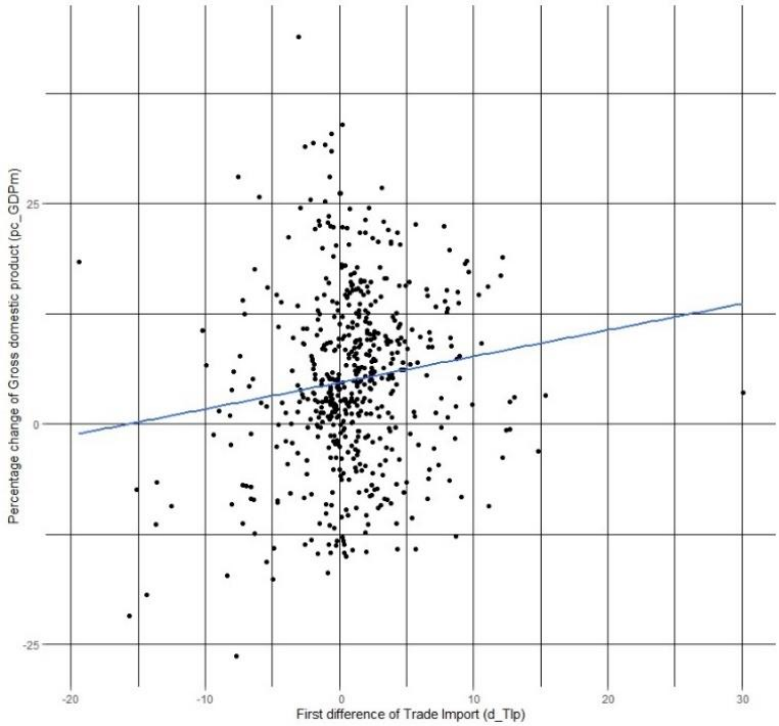
To further understand the graphical relationship between dependent variable and analyzed phenomenon author reviewing the transformed variables approach. As in the previous plot it was used standard secondary data, here scholar is using the transformed ones - pc_GDPm and d_TIp. The scatter plot visualized in Figure 23b. Based on received graphical findings author state that there are no clearly visible linear relationship between analysed data series.

Figure 28. *The gross domestic product (GDPm) and trade imports of goods and services (TIp) Scatter plot visualization*



Source: created by the author in software Rstudio

Figure 29. *The percentage change of GDP (pc_GDPm) and first difference of trade imports of goods and services (d_TIp). Scatter plot visualization*



Source: created by the author in software Rstudio

Ultimately, from this point author can state that in this chapter analysed significant amount of graphical information in order to better understand independent variables data tendencies in terms of analysed countries. Also, based on received Scatter plot data was significantly important to grasp the dependent variable relationships with potential independent variables in further empirical research analysis stages.

4. THE CORRELATION AND REGRESSION ANALYSIS

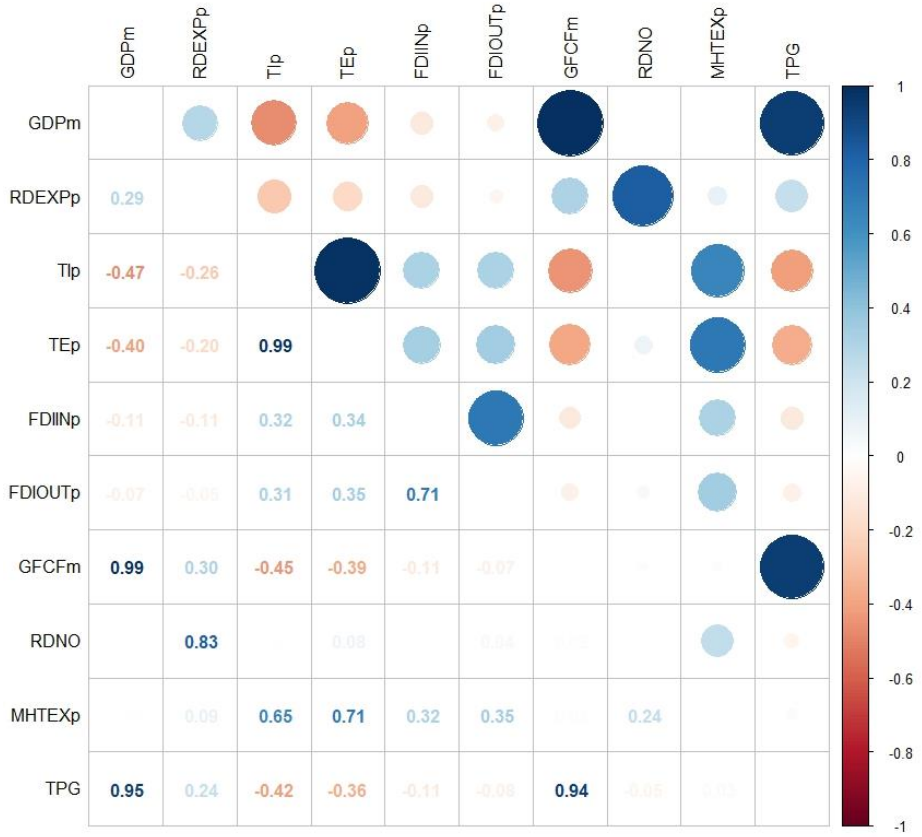
In this paragraph author will execute two most important emprical methodology parts – Correlation and Regression analyses. In the first subchapter author will present the correlation analysis results based on matrixes and heatmap visualizations. Furthermore, researcher will check and present findings whether correlation between regressors and dependent variable is causal. Next, author will introduce recession and COVID-19 potential impacts on economic growth and how these two phenomenons were integrated in research model. Lastly, this paragraph will be analysing two panel regression models the pooled ordinary least squares (POLS) and the fixed effects (FE) which are analyzed independently and afterwards checked which is the most suitable.

4.1 The Correlation analysis

In this stage let‘s analyze relationships between dependent and indendent variables based on correlation matrix results. In this chapter we will discuss two matrixes results. The first one is between dependent variable (GDPm) and not transformed variables such as RDEXPp, FDIINp, TPG, MHTEXp etc. The second one between transformed dependent and independent variables - percentage change of GDP (pc_GDPm) and first difference of R&D expenditures (d_RDEXPp) and others such as d_MHTEXp, pc_RDNO etc. It is executed and discussed with the reason to show that before selecting the right independent variable set it was done multiple times to find out which variables have the correlation between each other. Also, scholar had used Spearman’s rank correlation based on the fact that analyzed data is not normally distributed. In order to save research paper’s content author will present only correlation Heatmaps and links to the full correlation matrixes presented in annexes.

The first correlation matrix results is visualized based on Heatmap graph prepared with Rstudio software package applied for R programming language. And it is presented in *Figure 24.* All variables here are original ones – not transformed, how they are gathered from WB. Based on presented colours, intensity and positive/negative numbers we can identify what relationships each variable has within each other. Correlation coefficient values varies from negative -1 to positive +1.

Figure 30. *The Correlation matrix Heatmap #1.0 - GDPm and not transformed independent variables*

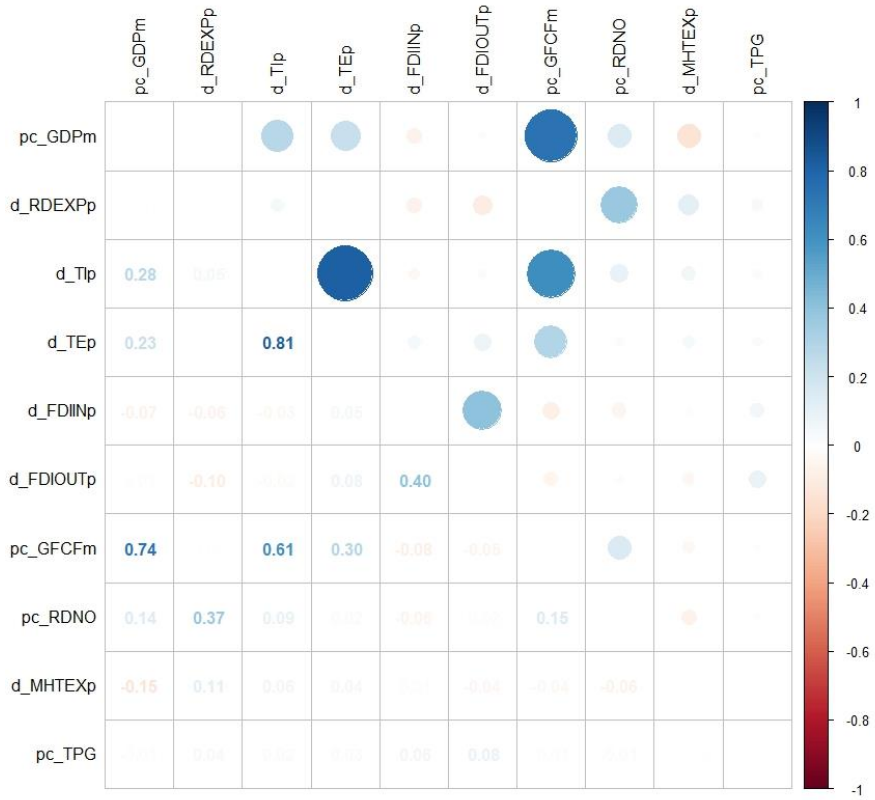


Source: created by the author in software Rstudio

From provided information we can identify multicollinearity possible cases between GDPm and GFCFm also TEp and TIp. These relationships must be checked in order not to cast any doubts. This analysis case correlation matrix provided in *Annex 4*. If significance probability is greater than α (p>0,05) then null hypothesis must be rejected state that there are no significant statistical relationship between variables. In this case all selected variables have lower significance value which indicates that they are statistically significant.

The second correlation analysis executed between transformed dependent variable (pc_GDPm) and transformed independent variables (d_RDEXP, d_TIp, d_TEp, d_FDIINp, d_FDIOUTp, pc_GFCFm, pc_RDNO, d_MHTEXp, pc_TPG). It was done on purpose to have variables which expresses growth or in other words change. The second correlation case Heatmap presented in *Figure 25a.* Corelation matrix is provided in *Annex 5.* Provided significance coefficients table informs that variables d_TEp (p=0,1626), d_FDIINp (p=0,7549), d_FDIOUTp (p=0,1869), pc_TPG (p=0,5142) are statistically insignificant.

Figure 31a. *The Correlation matrix Heatmap #2.1 - pc_GDPm and transformed independent variables*

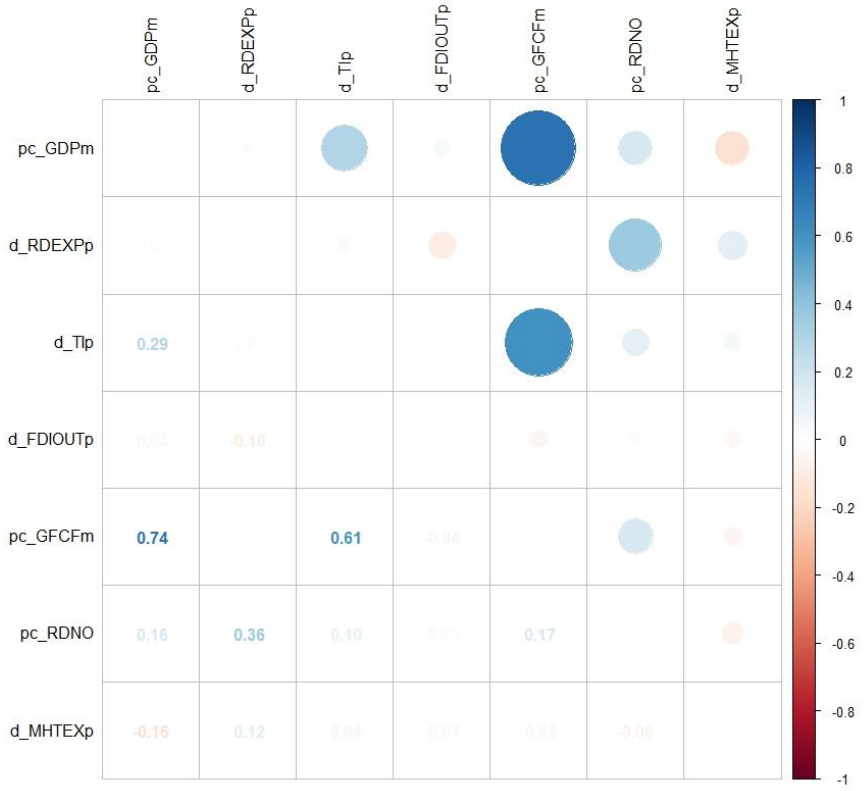


Source: created by the author in software Rstudio

Yet another approach is presented after primary results were received. Author continue assessing the tranformed variables case and excluded insignificant variables from the correlation analysis. The graphical information is presented in *Figure 25b.* The correlation matrix with complex information provided in Annex 6. Based on econometrical software prepared data results it is possible to state that key variable here is pc_GFCFm which has very strong positive association with dependent variable. Second effect according relationship strength is d_MHTEXp which has weak association with dependent variable. Furthermore, correlation matrix significance coefficients table presented that variable d_FDIOUTp is statistically insignificant (p=0,1869) due to rejected null hypothesis.

Finally we have the last correlation matrix Heatmap and final correlation matrix results. The visual information provided in *Figure 25c* and statistical information – Correlation matrix presented in *Annex 7.*

Figure 32. *The Correlation matrix Heatmap #2.2 - pc_GDPm and decreased scope of transformed independent variables*



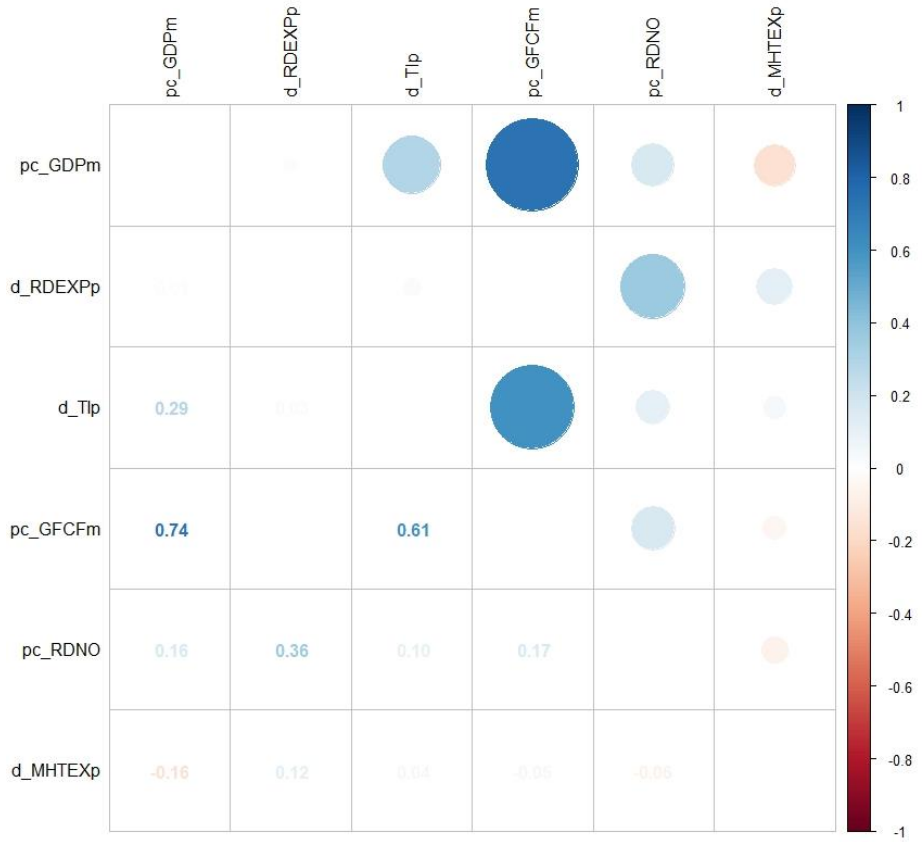
Source: created by the author in software Rstudio

Based on correlation matrix output third case (#2.3) results scholar state that all analysed variables are statistically significant based on significance probability values which are lower than our significance level set to 5%. If p is lower than 0,05 we can not reject the null hypothesis stating that our variable have statistically proven relationship.

We see that independent variable pc_GDPm had n=550 observations, however other independent variables had much less observations d_RDEXPp (n=505), pc_RDNO (n=479), d_MHTEXp (n=317) and serious data fragmentation issues. It is clear that author required to apply different unbalanced data approaches to further develop this research paper.

Although, we can review and analyse the strength of associations between analysed variables. These findings are presented in *Table 6* according *Annex 7* results.

Figure 33. *The Correlation Heatmap #2.3 - pc_GDPm and final scope of regressors*



Source: created by the author in software Rstudio

Table 6. *The analyzed variables final correlation analysis association's results*

Variable shortening	Variable type	Spearman Correlation rho Coefficient ($\boldsymbol{\rho}$)	Comment
pc_GDPm	Dependent variable	-	It is the core variable to compare with
d_RDEXPp	Independent variable	-0,12	Very weak negative or no association
d_TIp	Independent variable	0,13	Very weak positive or no association
pc_GFCFm	Independent variable	0,83	Very strong positive association
pc_RDNO	Independent variable	0,11	Very weak positive or no association
d_MHTEXp	Independent variable	-0,27	Weak negative or no association

Source: created by the author

To sum up, further regression analysis will be carrier according received results from correlation analysis part. One of the most important parts are execution of correlation matrix using Spearman‘s rank correlation coefficient values. As a result of correlation coefficient value, here comes the argumentation why d_RDEXPp, d_TIp and pc_RDNO shouldn’t be used in following regression analysis part. Simply, because correlation coefficient values are not greater than minimum association/effect range $\pm$ 0,15. With regard to statistical and econometrical

requirements author is planning to continue and implement statistically significant set of variables despite their's very weak or no association.

According to given modelation this research final variables set is as follows: pc_GDPm (DV), d_RDEXPp (IV), d_TIp (IV), pc_GFCFm (IV), pc_RDNO (IV), d_MHTEXp (IV).

where: DV – dependent variable, IV – independent variable.

4.2 The Causality test

For this part of the research causality was checked using Rstudio software. It is complex software which has opportunity to test unbalanced missing variables datasets and various tests. The Granger Non-causality test executed according Hurlin-Dumitrescu modelling (Croissant & Millo, 2019; Dumitrescu & Hurlin, 2012). Tests were applied for following variables – pc_GDPm, d_RDEXPp, d_TIp, pc_GFCFm, pc_RDNO, d_MHTEXp. The results are provided in *Table 7*.

Table 7. *The Granger Non-Causality panel test results (acc. Hurlin-Dumitrescu)*

Panel Granger (Non-) Causality test Lags: 2			
Variable shortening	The null hypothesis	Zbar-Stat. value	Prob.
pc_GDPm	d_ RDEXPp does not Granger cause pc_GDPm for all individuals. Null hypothesis not rejected.	-1,2461	0,2127
d_RDEXPp	pc_GDPm does not Granger cause d_RDEXPp for all individuals. Null hypothesis not rejected.	-1,6896	0,0911
pc_GDPm	d_TIp does not Granger cause pc_GDPm for all individuals. Null hypothesis not rejected.	-1,5787	0,1144
d_TIp	pc_GDPm does not Granger cause d_TIp for all individuals. Null hypothesis must be rejected.	-2,4313	0,0150
pc_GDPm	pc_GFCFm does not Granger cause pc_GDPm for all individuals. Null hypothesis not rejected.	1,6754	0,0939
pc_GFCFm	pc_GDPm does not Granger cause pc_GFCFm for all individuals. Null hypothesis must be rejected.	2,4353	0,0149
pc_GDPm	pc_RDNO does not Granger cause pc_GDPm for all individuals. Null hypothesis not rejected.	-1,2815	0,2000
pc_RDNO	pc_GDPm does not Granger cause pc_RDNO for all individuals. Null hypothesis not rejected.	0,4359	0,6629
pc_GDPm	d_MHTEXp does not Granger cause pc_GDPm for all individuals. Null hypothesis not rejected.	-0,4476	0,6545
d_MHTEXp	pc_GDPm does not Granger cause d_MHTEXp for all individuals. Null hypothesis not rejected.	0,9978	0,3184
d_TIp	pc_GFCFm does not Granger cause d_TIp for all individuals. Null hypothesis not rejected.	0,4387	0,6609
pc_GFCFm	d_TIp does not Granger cause pc_GFCFm for all individuals. Null hypothesis not rejected.	1,8525	0,0640
d_TIp	d_MHTEXp does not Granger cause d_TIp for all individuals. Null hypothesis not rejected.	0,2371	0,8126
d_MHTEXp	d_TIp does not Granger cause d_MHTEXp for all individuals. Null hypothesis not rejected.	-0,1858	0,8526
Alternative hypotheses: Granger causality for at least one individual			

Source: prepared by the author according Rstudio output data

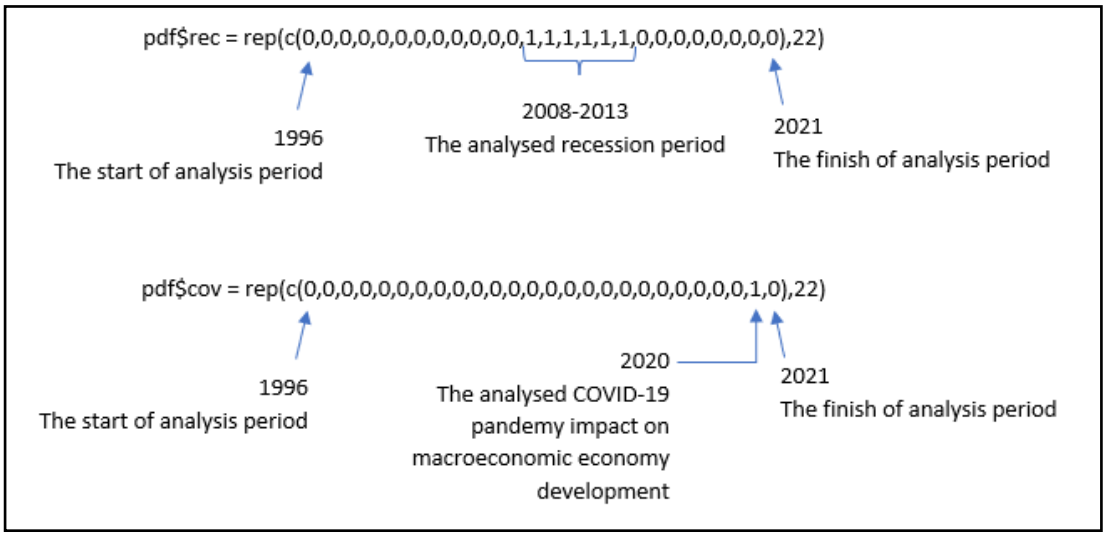
Evidently, based on test results author state that in cases: pc_GDPm and d_TIp, pc_GDPm and pc_GFCFm relationships are causal which means that researcher must reject the null hypothesis and stay with alternative one, which is clearly indicating homegeneity. In order to change the situation student tried using logarithmic difference function instead of first difference however no changes this made. The cases where causality has been indicated are marked in yellow. To finalize, these findings might indicate that relations between regressors (x's) and dependent variable (y) are slow causality. Which means that causing factors are coming in to force not in two years, but for example after five or eight years as example.

4.3 The Recession and COVID-19 pandemics impacts on OECD countries economic development

In this research paper scholar is focusing on long-term economic development and threfore analysis duration selected from 1996 to 2021. More importantly, during this period of time there were significant macroeconomic durbulences which had impacts on economic growth development. Besides, the main research paper goals and topics author will be reviewing also recession (rec) and COVID-19 pandemic impacts (cov) on economic growth.

In order to test the assumptions that recession and covid two individual phenomenons had a statistically significant impact on dependent variable dummy variables were created. The visual information is present in *Figure 26*. The top part is dedicated to recession phenomenon. Based on WB indicators development author juxtaposed recession with Global Financial crisis period. In other words period duration is from 2008 to 2013. The bottom section is showing COVID-19 (cov) dummy variable creation. In general pandemics outbreach started on January in 2020 and due to timely the European Central Bank (ECB) and the United States Federal Bank monetary policies applications OECD countries economic growth also in EU membering states from falling suddenly picked the growth curves again. For this matter the decision was made to analyze only a year of 2020.

Figure 34. *The dummy variables creation process. Excerpt from programming script to present durations*



Source: created by an author based on individually written Rstudio software programming script output

This subchapter provided the important fundamental information about the variables rec and cov creation. Author will be testing these factors effect on dependent variable development.

4.4 The Pooled Ordinary Least Squares (POLS) panel regression model analysis

The first model which is presented below is POLS which is more complex and stable compared with the previous one. Analysed model is executed with Rstudio software and the primary output presented in *Annex 8*. Researcher would like to highlight that in the primary POLS model approach programming software have adjusted the analyses timeframe to T=9-17 which is most likely due to missing d_MHTEXp values The key factor why the analysis timeframe was shortened is fragmented or missing variable values such as d_MHTEXp and others d_RDEXPp, pc_RDNO. In order to find out the best suitable dataset author also developed another cases presented in *Annex 9, Annex 10*. After the adjustments been made (removal of insignificant variables) model analysis duration improved to T=13-24. Which practically means that statistical modeling software made calculations based on existing observations from 13 to 24 years. The final model without insignificant variables are presented in *Figure 27*.

Figure 35. *The pooled ordinary least squares (POLS) regression model's final results*

```
Pooling Model

Call:
plm(formula = pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec, data = pdf,
model = "pooling", index = c("Countrycode", "Years"))

Unbalanced Panel: n = 22, T = 13-24, N = 317

Residuals:
Min.    1st Qu.     Median    3rd Qu.       Max.
-32.793495  -2.686428   0.090779   3.007689  17.397513

Coefficients:
Estimate Std. Error t-value  Pr(>|t|)
(Intercept)  0.595323   0.418574  1.4223  0.155948
d_TIp       -0.392464   0.078493 -5.0000 9.582e-07 ***
pc_GFCFm     0.483778   0.024322 19.8904 < 2.2e-16 ***
d_MHTEXp    -0.475094   0.193484 -2.4555  0.014615 *
rec1         1.997064   0.649621  3.0742  0.002297 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares:    25036
Residual Sum of Squares: 9419.9
R-Squared:      0.62375
Adj. R-Squared: 0.61893
F-statistic: 129.309 on 4 and 312 DF, p-value: < 2.22e-16
> vif(pool.mod2.3)
d_TIp pc_GFCFm d_MHTEXp      rec
1.622571 1.732258 1.024447 1.076755
```

Source: created by an author based on Rstudio software output

Model Summary. The POLS model results are indicating that model is statistically significant. It is argumented according F-statistic significance value (p=2,22x10^-16) which are lower than statistical significance value and for this matter researcher can not reject the null hypothesis stating that POLS model is statistically significant. Adjusted R square value – 0,6189, says that POLS model have the accuracy of 61,89% predicting dependent variable value changes. According coefficient table probability values scholar found out that there are three statistically significant variables – d_TIp, pc_GFCFm, d_MHTEXp and rec. Each one of those regressors have lower probability value than 0,05 which indicate that null hypotheses must not be rejected. It is important to highlight that variable rec is dummy variable. The autocorrelation in POLS model is checked by Wooldridge test. It is suitable test for unbalanced panel data. The POLS autocorrelation control results after author's implemented Wooldridge test are presented below in open text:

```
Breusch-Godfrey/Wooldridge test results for serial correlation:

      data:  pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec
      chisq = 51.77, df = 13, p-value = 1.477e-06
      alternative hypothesis: serial correlation in idiosyncratic errors
```

As a consequence of received results we can argument that according significance value which is lower than 0,05 we state that null hypothesis must be rejected therefore author state that model has serious autocorrelation issues.

Coefficients. According table's significance (Pr(>|t|)) values author have already mentioned that there are only four variables which are statistically significant. Let's review each individually. Two independent variables have negative beta coefficient (d_TIp and d_MHTEXp) and the other two has positive beta coefficient (pc_GFCFm and rec). Which tells us that when percentage change of GDP (pc_GDPm) changes one percent d_TIp (-0,39%) and d_MHTEXp (-0,48%) reacts negatively. The completely opposite situation with pc_GFCFm variable when percentage change of GDP (pc_GDPm) changes one percent pc_GFCFm variable reacts positively (+0,48%) the same with dummy variable rec (+2,0%). Here author would like to react and inform that recession defining variable rec does not have economical justification. In theoretical notion this variable must have negative relation however it is opposite.

Moreover, multicollinearity issue is not proved in this POLS model which is argumented by looking at the VIF coefficient values. All values float from 1,02 to 1,73 which indicate that it is moderate and acceptable correlation. Thus, argumenting already discussed and reviewed findings it is presented pooled OLS (POLS) regression model's equation in Formula 13. Researcher would like to add a comment that Intercept (constant) was not added to the general model's equation because of it's insignificance.

The pooled ordinary least squares (POLS) panel regression model's equation according researchers findings

$$y = -0{,}3925 \cdot d\_TIp + 0{,}4838 \cdot pc\_GFCFm - 0{,}4751 \cdot d\_MHTEXp + 1{,}9971 \cdot rec \quad (13)$$

Source: prepared by author according Rstudio POLS model lmOECD2.5 findings

Homoscedasticity. To find out whether model has homoscedastic or heteroscedastic residuals scholar executed Breusch-Pagan test in Rstudio. Test results are presented in open text format below. According presented significance value author report that it is sufficient evidence to report that heteroscedasticity is present in POLS model. Because null hypothesis is not rejected.

The POLS model homoscedasticity control results after implemented Breusch-Pagan test:

```
Breusch-Pagan test

        data:  pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec
        BP = 146.31, df = 4, p-value < 2.2e-16
```

To sum up, POLS model is statistically significant with three independent variables and signle dummy variable. As already presented the model has autocorrelation issues which was

found out after executing Wooldridge test. Moreover executed multicollinearity test based on variance inflation factor (VIF) coefficients indicate no issues. Lastly, above mentioned homoscedasticity control methods showed that current model of POLS regression have heteroscedastic residuals.

4.5 The Fixed Effects (FE) panel regression model analysis

The second analysed panel model in this research paper is the Fixed Effect (FE) regression. As all the previous one this model is executed with Rstudio software. First let's put all independent variables and see the output which is presented in *Annex 11*. Author highlight that in this stage no further comments are made. The idea behind this is to have a reference data in order to compare it with the final FE model. Afterwards another model was created however without insignificant variables which are presented in *Annex 12*.

Lastly, author presenting the final FE regression model visualised in *Figure 28.*

Figure 36. *The Fixed Effects (FE) regression model's final case results*

```
Oneway (individual) effect Within Model

Call:
plm(formula = pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec, data = pdf
,
    effect = "individual", model = "within", index = c("Countrycode",
        "Years"))

Unbalanced Panel: n = 22, T = 13-24, N = 317

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-30.65491  -2.65764   0.23635   3.02541  16.79475

Coefficients:
          Estimate Std. Error t-value  Pr(>|t|)
d_TIp    -0.425814   0.080172 -5.3113 2.166e-07 ***
pc_GFCFm  0.486217   0.024865 19.5546 < 2.2e-16 ***
d_MHTEXp -0.583391   0.201087 -2.9012  0.004001 **
rec1      2.234457   0.655668  3.4079  0.000747 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares:    23998
Residual Sum of Squares: 8819.4
R-Squared:      0.6325
Adj. R-Squared: 0.60092
F-statistic: 125.207 on 4 and 291 DF, p-value: < 2.22e-16
```

Source: created by an author based on Rstudio software output

Model Summary. The FE regression model's results are indicating that model is statistically significant. It is argumented according F-statistic significance value (p=2,22x10^-16) which are lower than statistical significance value and for this matter we can not reject the null hypothesis stating that FE model is statistically significant. Adjusted R square value – 0,6009, says that FE is pridicting 60,09% of dependent variable numeric value changes. In general it is less accurate model considering with POLS – 61,89% models. According coefficient table probability values scholar found out that there are four statistically significant variables – d_TIp, pc_GFCFm, d_MHTEXp and rec.

The autocorrelation in FE regression model is checked also by Wooldridge test. The results are presented in open text format below. Based on reported econometrical test output significance value is lower than 0,05 which is approval to reject null hypothesis and state that model has serious autocorrelation issues.

The FE regression model's autocorrelation control after implemented Wooldridge test:

```
Breusch-Godfrey/Wooldridge test for serial correlation in panel models

data:  pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec
chisq = 80.595, df = 13, p-value = 8.524e-12
alternative hypothesis: serial correlation in idiosyncratic errors
```

Homoscedasticity. To check FE regression model's homoscedastic residuals assumption author applied in POLS model already applied Breusch-Pagan test in Rstudio. Test results are presented in open text below. According presented significance value author report that it is sufficient evidence to report that heteroscedasticity is present in FE model. Because null hypothesis must be rejected. For this reason, FE model should not be implementing homoscedastic robust residual errors.

The FE model's homoscedasticity control results after implementing Breusch-Pagan test:

```
Breusch-Pagan test

data:  pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec
BP = 146.31, df = 4, p-value < 2.2e-16
```

To sum up, FE model is statistically significant with three independent variables and single dummy variable. As already presented the model has autocorrelation issues which was found out after executing Wooldridge test. Lastly, above mentioned homoscedasticity control methods showed that current model of FE regression have heteroscedastic residuals.

4.6 The regression analysis executed methods comparison

This subchapter is dedicated to clarify which of the researched panel regression analysis methods are the most suitable to answer raised questions. Also based on executed test results it will be answered which method is considered as core evaluating raised hypotheses.

To test the two panel models suitability author implemented F test of stability or in other words the Chow test. Toyoda in research paper presented that Chow test aims to check equality of sets of coefficients in two regressions. Simply it is checking whether parameters of one group (model) are equal to those of other group (model) (T. Toyoda, 1974). Researcher applied in this study pooled OLS (POLS) and Fixed Effects (FE) regression models which both are considered as panel and suitable for model comparison using the Chow test. The executed model output is presented in open text below.

The F test of stability (the Chow test). Analysis of two panel data suitability POLS vs. FE:

```
> pooltest(pool.mod2.3, fe.mod2.3)

  F statistic

data:  pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec
F = 0.94348, df1 = 21, df2 = 291, p-value = 0.5349
alternative hypothesis: unstability
```

Finally, according received test results we can conclude that probability value p=0,5349 indicating that null hypothesis can not be rejected, argumenting that POLS model is statistically sufficient comparing it with FE regression model. Author conclude, that for further research paper's conclusions core model will be used the pooled ordinary least squares (POLS) regression model.

4.7 The research hypotheses overview

The seventh subchapter is dedicated for reviewing raised research paper's hypotheses. These statements will rely on correlation and POLS regression model's results. The hypotheses will be analyzed one by one in open text format.

First of all, based on the findings author state that POLS regression model does have autocorrelation issues, but homoscedasticity is not present. And based on these assumptions author made hypotheses overview presented in *Table 8*.

Table 8. *The hypotheses summary according findings*

Hypothesis no.	Statement	Arguments	Result
Hypothesis no. 1a:	Imports of goods and services variable (TIp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	transformed variable has association with dependent variable, beta coefficient in regression model significant	Not reject
Hypothesis no. 1b:	Exports of goods and services variable (TEp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	no secondary and transformed variable association with dependent variable	Reject
Hypothesis no. 1c:	Foreign direct investment, net inflow variable (FDIINp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	no secondary and transformed variable association with dependent variable	Reject
Hypothesis no. 1d:	Foreign direct investment, net outflow variable (FDIOUTp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	secondary original and transformed variables beta coefficients in regression model is not statistically significant	Reject
Hypothesis no. 1e:	Medium and high-tech exports variable (MHTEXp) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	transformed variable beta coefficients in regression model is statistically significant. Varaible has significant effect	Not reject
Hypothesis no. 1f:	Gross fixed capital formation variable (GFCFm) representing technological progress have statistically significant effect on dependent variable – gross domestic product in OECD countries	transformed variable beta coefficients in regression model is statistically significant. Varaible has significant effect	Not reject
Hypothesis no. 2a:	Research and development expenditure variable (RDEXPp) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD countries	no secondary and transformed variable association with dependent variable	Reject
Hypothesis no. 2b:	Total patents granted variable (TPG) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD countries	no secondary and transformed variable association with dependent variable	Reject
Hypothesis no. 2c:	Researchers numbers in R&D variable (RDNO) representing Innovation trends have statistically significant effect on dependent variable – gross domestic product in OECD countries	no secondary and transformed variable association with dependent variable	Reject

Source: prepared by the author

It is clear that out of nine raised hypotheses six were rejected (1b, 1c, 1d, 2a, 2b, 2c) and three not rejected (1a, 1e, 1f). Based on received findings scholar would like to state that in this research paper technological progress representing factors have three variables (d_TIp, d_MHTEXp and pc_GFCFm) which were statistically tested and proved effect on transformed economic growth (pc_GDPm). Unfortunately, there is no statistically significant variables which would represent innovation trends phenomenon.

CONCLUSIONS

In this chapter will be presented key findings which are structurized and numbered according research paper goals.

1. Author reviewed solid list of academic studies which confirms that technological progress and innovation trends impact topics are very much debated. Above mentioned phenomenons are not homogenous however in various research papers analyzed with different variables. This obstacle to choose wisely the secondary data variables defining technological progress and innovation trends made it more interesting. Despite, already mentioned findings author state that technological progress is continuous factor which craving changes in society, politics and economics. Analyzed studies most of the times analyzed OECD developed countries or targeted EU countries. It is due to the fact that scientists are looking for quality and reliable datasets which can provide only these countries which have long-run data gathering policies and commitments. For this matter, such academic research papers are highly favourable for them in order to track newest assumptions and countries development interpretations based on academic findings. Reviewed academic paperworks were analyzed and systematized based on topics and different groupings. In some of the cases author presented figures in order to more visually present different clusters.

2. The second research paper aim was executed relying on four different research papers which were presented in the first chapter. It was presented in the text that technological progress and innovation trends is hard to interpret individually due to lacking research papers which had analysed their's impact on economic growth. Despite, received obstacles in this research paper these factors were separated and analyzed as heterogenous phenomenons. Different scholars in their studies chose alike dependent variables – gross domestic product, gross domestic product per capita, gross domestic income index per capita etc. In this study author chose to juxtapose economic growth factor with gross domestic product which is called dependent variable. Independent variables (regressors) is an output of unprecedented work with research papers. Here author present technological progress defining variables – gross fixed capital formation (GFCFm), trade import (TIp), trade export (TEp), foreign direct investment, net outward (FDIOUTp), foreign direct investment, net inward (FDIINp), medium and high-technology products and services export (MHTEXp). Secondary, innovation trends defining independent variables are presented – Research and development expenditures (RDEXPp), total patents granted (TPG), researchers

number in R&D sector (RDNO). All in all, in this researchpaper author gathered 12 variables out of which two (GDPagr, GDPcapm) were used for graphical and desciptive statistics purposes.

3. To start with, variables transformation takes significant role in this study. Author secondary goal was to create statistically stable background for further modelling. Therefore after finding out that data is not stationary data were transformed based on first difference (d_A*) and percentage change (pc_A*) functions. Mind that, after transformations applied data become stationary however data is still not normally distributed. For this matter, Spearman's rank correlation analysis method were used after rejecting Pearson's. Besides, as the dependent variable author used percentage change of gross domestic product (pc_GDPm). All regressors were also transformed. Therefore, two cross-cultural panel regression models were tested – pooled ordinary least squares (POLS) and fixed effects (FE). Both models are statistically significant. However based on the Chow test two different models were compared. The test results showed that POLS are sufficient dealing with this typology regressions. Moreover, POLS model was also more accurate, in terms of predicting dependent variable figure changes in relation to independent variables (R square adjusted – 61,89%). Secondary, this model presented already clear truth that most likely not all variables will be used as regressors. Therefore, scholar presented final list of statistically significant regressors in equation – first difference of trade import (d_TIp), percentage change of gross fixed capital formation (pc_GFCFm), first difference of medium and high-technology produts and services export (d_MHTEXp) and last one dummy variable defining recession's period from 2008 to 2013 (rec).

4. To sum up author raised nine hypotheses and based on correlation and POLS regression model analysis results author presented the findings in one of the subchapters. In general we have six hypotheses related and representing technological progress factor. And three hypotheses directly connected with innovations trends defining variables. Author highlight that based on executed empirical research calculations and tests it should be concluded that only three (1a, 1e, 1f) hypotheses are valid and must not be rejected. Furthermore, here are six hypotheses list which is not valid and must be rejected (1b, 1c, 1d, 2a, 2b, 2c). Researcher emphasize that innovation trend as heterogenous phenomenon could not been confirmed and it is not directly effecting economic growth dependent variable.

RECOMMENDATIONS

This chapter belongs to author's recommendation for further topic development.

1. One aspect which illustrates the whole research paper quality can be identified as **data quality** (proper variables and duration selection). As already confirmed in current research paper there were issues with unbalanced and fragmented data series which might had issues in executing practical empirical research part. Author would recommend testing better matching analysis periods without many fragmented variable series. Proposal is to find the best matching set of countries for specific timeframe. Also, in order to identify more clearly technological progress and innovation trends defining variables it is advised to review solid list of academic research papers.

2. Secondly, author in this research paper reviewed research papers according which variables were selected. Recommendation for other researchers would be target more attention to **innovation defining variables**. Generally speaking there is a critical point finding the right methodology to define two individual factors and it's impact on economic growth. Based on current literature review selected innovation trends defining variables were insignificant and all hypotheses must be rejected stating that research paper did not find any statistically proven relationship on economic growth.

3. Moreover, developing empirical research part there were data limitations which was not visible before executing these steps. Each one of the recommendations are numbered in bullets:

- Different variables requirs transformations in order to meet the model assumptions. Mind that different transformations such as logarithmic is changing figure symbol and ejecting it's primary negative value. Therefore data transformation is undeservedly dismissed as primary data quality assessment part.
- Primary developed regression model had assumptions that there were structural fractures which most likely are effecting the overall model quality. The control dummy variables for this matter were created simulating recession (rec) and COVID-19 pandemics phenomenons impact on OECD EU countries economic growth. Mind that these dummy variables created for specific period of time which is from 2008 to 2013 and 2020 respectively. However recession defining regressor rec does not have economically proven argumentation. Let's assume that when 1% increase of pc_GDPm rec variable reacts positively +2,0%. Which does not have any logical argumentation behind this. This might be caused by the fact that author selected too long recession duration which might be false

2008-2013. Additionally, COVID-19 pandemics impact on economic development defining variable rec was insignificant in both regression models.

4. Last but not least, author already concluded that this study paper did not find any direct innovation trends effect on economic growth it is advisable to further develop idea to **test indirect independent variable effects** on dependent variable. Here in this study author tested two variables representing innovations indirect effect on economic growth. Unfortunately percentage change of researchers number in R&D field (pc_RDNO) and first difference of research and development expenditures (d_RDEXPp) after transformed variables multiplication and division newly created variable did not have statistical significance. Researcher advise future scientists to test innovation trends indirect effect on technological progress (acting through mediator) and only afterwards assess final impact on economic growth.

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TECHNOLOGICAL PROGRESS, INNOVATIONS TRENDS AND THEIR INFLUENCE ON ECONOMIC GROWTH IN OECD COUNTRIES (EU STUDY CASE)

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Master Thesis

Global Business and Economics Master Programme

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SUMMARY

97 pages, 8 tables, 36 figures, 62 references

The main aim of this scientific study is to analyze the technological progress, innovations trends as an closely interconnected phenomenons in one regression model. Model will be testing latter phenomenons impact as independent effects impact on economic growth. Here dependent variable – gross domestic product.

The Master thesis consists of introduction and the four chapters in the body part. Body part consisting of literature analysis provided in the first chapter, empirical research methodology provided in the second chapter, the graphical and desciptive data analysis presented in the third, the empirical research correlation and regression analyses written in the fourth. Last but study paper are finished with conclusions and recommendations.

In this scientific study author gathered and analyzed studies based on the latest academic sources. Analyzed scientific literature stress the fact that both phenomenons are significant factors in macroeconomic country development.

In the research methodology part scholar presented the key panel models and theoretical concepts which allowed to build the pooled ordinary least squares and fixed effects regression models for empirical methodology part.

This research paper highlight the fact that three out of six techological progress defining variables has statistically significant effect and no out of three innovation trends defining variables have effect on gross domestic product development. Study contributes to the scientific and academic community by analyzing the technological progress and innovation trends effects on economic growth in the OECD EU countries which consists of 22 nations. The research period 1996-2021.

TECHNOLOGINĖ PAŽANGA IR INOVACIJŲ TENDENCIJOS BEI JŲ ĮTAKA EBPO ŠALIŲ EKONOMIKOS AUGIMUI (ES ŠALIŲ TYRIMAS)

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SANTRAUKA

97 puslapiai, 8 lentelės, 36 iliustracijos, 62 šaltiniai

Tiriamojo darbo pagrindinis tikslas yra išanalizuoti dviejų glaudžiai susijusių fenomenų - technologinės pažangos ir inovacijų tendencijų įtaką bendriniam regresijos modeliui. Abiems išvardintiems faktoriams priskirti skirtingi kintamieji ir analizuojamas poveikis atskirai. Pasirinktas tiesioginis kintamasis – bendras vidaus produktas (BVP).

Magistro baigiamasis darbas susideda iš keturių dėstymo skyrių. Pirmasis prasideda literatūros apžvalga. Antrajame skyriuje pristatomi metodologiniai reikalavimai tyrimui. Sekančiame skyriuje yra pateikiama analizuotų kintamųjų grafinė ir aprašomoji statistika. Ketvirtas skyrius yra skirtas koreliacijos ir regresijos analizėms. Darbas užbaigiamas išvadomis ir rekomendacijomis.

Šiame moksliniame darbe tyrėjas peržvelgia aktualiausius mokslinius straipsnius technologinės pažangos ir inovacijų tendencijų temomis ir pristato pagrindines autorių išvadas. Tiriami faktoriai pristatoma kaip turintys įtaką tolesniam ekonomikos vystymuisi.

Metodologijos dalyje autorius peržvelgia šiame tyrimo darbe taikytus modelius ir teorinius reikalavimus, kurių pagrindu buvo suformuoti paneliniai regresijos modeliai – jungtinis mažiausių kvadratų (JMKM) ir fiksuotų efektų (FE) metodai.

Rezultatai leidžia teigti, kad trys iš šešių technologinės pažangos nepriklausomi kintamieji nėra statiškai reikšmingi. Taip pat nei vienas iš trijų inovacijų tendencijas aprašantys kintamieji nebuvo reikšmingi. Šis tyrimas prisidės prie mokslo bendruomenės analizuojant technologinės pažangos ir inovacijų tendencijų įtaką ekonomikos augimui remiantis naujausiais metiniais duomenimis ir pateiks duomenis ir išvadas EBPO ES šalių kontekste. Šio tyrimo objektas 22 EBPO ES priklausančios šalys. Tyrimo trukmė 1996-2021m.

ANNEXES

Annex 1. *The Data stationarity analysis – The Maddala-Wu Unit Root test results*

UNIT ROOT TEST FOR STATIONARITY					
MADDALA-WU UNIT-ROOT TEST (ex. var.: Individual Intercepts) Ist test			MADDALA-WU UNIT-ROOT TEST (ex. var.: Individual Intercepts) IInd test		
Variables	Significance (p value)	Results	Variables	Significance (p value)	Results
GDPm	**p=1,000**	**non-stationary**	pc_GDPm	p=0,000 (2,2x10^-16)	stationary (reject H_o)
RDEXPp	**p=0,975**	**non-stationary**	d_RDEXPp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
TIp	p=0,046	stationary (reject H_o)	d_TIp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
TEp	**p=0,434**	**non-stationary**	d_TEp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
FDIINp	p=0,000 (2,2x10^-16)	stationary (reject H_o)	d_FDIINp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
FDIOUTp	p=0,000 (2,2x10^-16)	stationary (reject H_o)	d_FDIOUTp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
GFCFm	**p=0,9964**	**non-stationary**	pc_GFCFm	p=0,000 (2,2x10^-16)	stationary (reject H_o)
TPG	p=0,000 (2,2x10^-16)	stationary (reject H_o)	pc_TPG	p=0,000 (2,2x10^-16)	stationary (reject H_o)
MHTEXp	p=0,000 (2,6x10^-11)	stationary (reject H_o)	d_MHTEXp	p=0,000 (2,2x10^-16)	stationary (reject H_o)
RDNO	**p=0,971**	**non-stationary**	pc_RDNO	p=0,000 (2,2x10^-16)	stationary (reject H_o)
Original dataset variables not in all cases are stationary			Transformations improved data quality and it is stationary		

Source: prepared by an author according Rstudio results

Annex 2. *The Normal distribution analyses executed by Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) tests*

NORMAL DISTRIBUTION TEST							
KOLMOGOROV-SMIRNOV (K-S) & SHAPIRO-WILK (S-W) TESTS FIRST CASE				KOLMOGOROV-SMIRNOV (K-S) & SHAPIRO-WILK (S-W)TESTS SECOND CASE			
Variable	K-S Significance	S-W Significance	Results	Variable	K-S Significance	S-W Significance	Results
GDPm	p=0,000 (2,2x10^-16)	p=0,000 (2,2x10^-16)	NO	pc_GDPm	no results	p=0,121	YES
RDEXPp	**no results**	p=0,000 (3,2x10^-14)	NO	d_RDEXPp	no results	p=0,000 (3,3x10^-14)	NO
TIp	p=0,000 (2,3x10^-5)	p=0,000 (2,2x10^-16)	NO	d_TIp	no results	p=0,000 (1,5x10^-15)	NO
TEp	p=0,000 (3,0x10^-7)	p=0,000 (2,2x10^-16)	NO	d_TEp	no results	p=0,000 (1,8x10^-11)	NO
FDIINp	**no results**	p=0,000 (2,2x10^-16)	NO	d_FDIINp	no results	p=0,000 (2,2x10^-16)	NO
FDIOUTp	**no results**	p=0,000 (2,2x10^-16)	NO	d_FDIOUTp	no results	p=0,000 (2,2x10^-16)	NO
GFCFm	p=0,000 (2,2x10^-16)	p=0,000 (2,2x10^-16)	NO	pc_GFCFm	no results	p=0,000 (7,1x10^-9)	NO
TPG	**no results**	p=0,000 (2,2x10^-16)	NO	pc_TPG	no results	p=0,000 (2,2x10^-16)	NO
MHTEXp	**no results**	p=0,000 (5,2x10^-16)	NO	d_MHTEXp	no results	p=0,000 (8,5x10^-13)	NO
RDNO	**no results**	p=0,000 (1,9x10^-15)	NO	pc_RDNO	no results	p=0,000 (2,2x10^-16)	NO
All first case variables NOT normally distributed				K-S method insufficient due to errors, S-W showed NOT normal distribution except single dependent variable pc_GDPm			

Source: prepared by an author according Rstudio results

Annex 3. *The fragment of pilot study data file*

ID	Countryname	Countrycode	Years	GDPm	GDPcapm	GDPagr	RDEXPp	TIp	TEp	FDIINp	FDIOUTp	GFCFm	RDNO	MHTEXp	TPG
2	Austria	AUT	1996	237250948791.266	29809.0767730821	2.34953385169727	1.58077001571655	35.8343950133252	34.2492761073574	1.8223375348554	0.796236973621259	62486378996.6207	NA	NA	1481
2	Austria	AUT	1997	212790348404.555	26705.4785993891	2.09359938952392	1.65490996837616	37.8396074770871	37.0280827384957	1.2542743768135	0.939127487397037	55780133047.6942	NA	NA	1287
2	Austria	AUT	1998	218259904401.956	27361.8751106437	3.58142581460447	1.73154997825623	38.5761282051164	38.351021186462	2.09468418822409	1.26823304186135	56978190306.803	2327.40747070313	NA	1355
2	Austria	AUT	1999	217259147049.954	27183.4759263956	3.55633124664169	1.845370054245	38.9031024586734	39.3570378852981	1.36910230387565	1.51934310179015	56742769390.5716	NA	NA	1328
2	Austria	AUT	2000	197289625479.906	24625.6007227434	3.37572214708479	1.88601994514465	42.0142216659345	43.3462739519887	4.30890039482994	2.79258961320941	51151223869.9138	NA	NA	1217
2	Austria	AUT	2001	197508773215.323	24558.7636778868	1.26716818922992	1.99210000038147	42.9191092459869	44.6175555179483	2.88059839258097	1.53000641266844	49694720840.2363	NA	NA	1385
2	Austria	AUT	2002	214394866675.24	26527.5930910347	1.65155392186669	2.06597995758057	41.6287818010806	45.31938619858	0.0645287981478418	2.69616243689825	50688642610.5844	2965.6845703125	NA	1564
2	Austria	AUT	2003	262273631180.054	32294.0488606559	0.941470920725337	2.17456007003784	41.8169676971425	44.57041471914	2.36204525540375	2.6155057501082	64017705669.2077	NA	NA	1360
2	Austria	AUT	2004	301457562038.541	36889.2335135194	2.73512022241023	2.16612005233765	43.9251307189084	46.8672149740213	1.05608551598741	2.66369151009772	72533785056.5098	3158.79467773438	NA	961
2	Austria	AUT	2005	316092273276.015	38417.4577857677	2.24406532463878	2.37323999404907	45.4140534786122	48.6197522046932	25.6558278307872	25.7169931494487	75309760547.8599	3449.33447265625	NA	938
2	Austria	AUT	2006	336280064332.411	40669.3269586152	3.45404183614122	2.35923004150391	47.2466423435202	50.8416688618235	3.1225333500469	4.78406240220846	79396824794.7881	3524.13891601563	NA	1564
2	Austria	AUT	2007	389185571506.052	46915.3374004507	3.72741530093519	2.41843008995056	48.172384639555	52.560869422371	17.6948460131618	20.3090536202671	95678567534.5846	3810.03149414063	12.9838404038471	1237
2	Austria	AUT	2008	432051935642.945	51919.9835754226	1.4604236757386	2.56944990158081	48.8248221152974	53.2488606164087	1.45842274091571	6.45825690041785	105712137732.312	4136.92578125	12.6603774714095	1301
2	Austria	AUT	2009	401758735822.211	48153.3240199631	-3.76457817791677	2.59674000740051	41.8548144134358	45.2074165608437	3.55936613543504	3.87251675390701	91501841483.1445	4140.1044921875	13.4374537141208	1102
2	Austria	AUT	2010	392275107258.667	46903.7615854343	1.83709367680054	2.72609996795654	47.757635096203	51.2621603273359	-5.61017631479876	-3.65244304138458	88684956533.0002	4349.71728515625	13.7052797272585	1130
2	Austria	AUT	2011	431685217367.511	51442.2762464407	2.92279728368581	2.66867995262146	51.154117778086	53.9486708516394	5.32423673714992	8.83636576331772	104210859701.265	4390.3466796875	13.2553273422959	1198
2	Austria	AUT	2012	409401816050.531	48564.9173350875	0.680445576816723	2.91472005844116	51.1785012313079	53.9736761965302	1.27469393348716	4.5051822282906	98162711032.4297	4669.447265625	14.5446442890991	1439
2	Austria	AUT	2013	430190979705.962	50731.1272541847	0.025504712197218	2.95492005348206	50.625120789651	53.4412932967224	0.104862185985247	2.56421001969791	102055883866.071	4724.72021484375	15.369008411283	1256
2	Austria	AUT	2014	442584815286.034	51786.3771747905	0.661272848852605	3.08429002761841	50.1169562048263	53.3865790462424	0.386858115054066	-0.197784974132609	104147035170.811	4947.875	15.4904308797159	962
2	Austria	AUT	2015	381971148530.543	44195.8175947748	1.01450158590511	3.04969000816345	49.3382548303838	53.0890605587958	-2.08805653898309	-0.560119576025427	90930239902.4609	5019.4384765625	15.0326440334697	1356
2	Austria	AUT	2016	395837353031.499	45307.5878620429	1.98943716230463	3.11654996871948	48.5756846289351	52.4063936498056	-7.31091695803709	-6.79971253925712	96015598610.7201	5372.23974609375	14.4530595992607	1135
2	Austria	AUT	2017	417261151844.977	47429.1584564387	2.25857243250671	3.05656003952026	50.8876917912507	54.0511531414978	3.23990497953366	2.42252934331562	103641074465.706	5387.92919921875	12.8819108712796	1102
2	Austria	AUT	2018	454991174096.102	51466.5565633634	2.42538536088061	3.09057998657227	52.4614203877556	55.4622191178234	-6.2871015854224	-5.91530247350789	117053010625.043	5639.0634765625	11.6455714109405	1189
2	Austria	AUT	2019	444621176100.548	50070.4033482901	1.51738858303159	3.12971997261047	52.128791145464	55.7572063557543	-2.95105024640996	-1.50327937488455	112705212081.333	5895.44384765625	11.4767866161765	1112
2	Austria	AUT	2020	435225238000.437	48809.2268762243	-6.45396846689127	3.20128011703491	48.6108163058355	51.6128149281413	-4.18512656172575	-1.89560188237279	111621480249.837	5751.32275390625	12.2643129002498	1058
2	Austria	AUT	2021	480368403893.364	53637.7057109897	4.55685091308877	NA	55.3219834500504	55.9003086234408	1.57666444317182	3.03205978650269	133444981828.099	NA	13.2950459631704	1038
3	Belgium	BEL	1996	279201433224.756	27489.5551770488	1.32145093041325	1.74299001693726	58.0203848015116	61.1923909558718	5.03718760952012	2.87467005709781	60393355048.8599	2461.70361328125	NA	1182
3	Belgium	BEL	1997	252708051420.839	24820.9380503896	3.79365762950188	1.80971002578735	60.902358975732	64.7865810804479	4.74788988021558	2.8697621461308	56354758682.9048	2568.80419921875	NA	901
3	Belgium	BEL	1998	258528339631.029	25338.4432934904	1.96180827198427	1.838250041008	60.5347776108893	64.1743450154283	8.77679407696031	11.1575001955561	57777617248.2774	2695.24267578125	NA	623
3	Belgium	BEL	1999	258245733221.468	25252.8019066564	3.54274346363066	1.90565001964569	60.6069310248626	64.5630595160862	46.3484571485071	47.3596107375427	58593404930.1932	2899.18090820313	NA	1022
3	Belgium	BEL	2000	236792460312.471	23098.8865077401	3.71667938420875	1.93619000911713	69.6827399089776	72.5473951580567	37.4753122979087	36.4714779710626	56316259202.6668	2970.1943359375	NA	822
3	Belgium	BEL	2001	236746141604.37	23015.0712632462	1.09961888777849	2.03278994560242	67.964880914325	71.6119589202939	37.2564694834172	42.512240460582	53584708567.2835	3123.9892578125	NA	839
3	Belgium	BEL	2002	258383599375.177	25006.191397109	1.70688458453354	1.90324997901917	65.2538517924041	70.8312976956765	7.01242443993657	3.45219479750913	53607884006.0785	2958.84497070313	NA	508
3	Belgium	BEL	2003	318082528506.588	30655.2092679024	1.03798254902905	1.8411899805069	63.679044325004	69.0365085088844	10.8648744877518	12.2817329434309	66685072366.745	2967.3701171875	NA	629
3	Belgium	BEL	2004	369214712443.206	35429.4077933344	3.5712043433582	1.82050001621246	66.0121279012141	70.906277447218	12.0521106747569	9.41114900942278	83690121031.6991	3091.60522460938	NA	715
3	Belgium	BEL	2005	385714762230.039	36809.7013403619	2.32173705381926	1.79060995578766	70.2462217485879	74.2822892139353	8.72717720186463	8.43585987028478	91341356615.7198	3142.72998046875	NA	708
3	Belgium	BEL	2006	408259840868.823	38705.1067959147	2.55234994366351	1.8226900100708	72.7625122442923	76.8049970552189	14.4078713936676	12.2791987723086	97862125665.1763	3284.4306640625	NA	548
3	Belgium	BEL	2007	470922156309.453	44319.165448813	3.67688113594973	1.84999001026154	74.1666421724765	78.3018047028263	20.5026740062328	17.7222560450955	115862269152.353	3395.017578125	8.46280131521921	519
3	Belgium	BEL	2008	517328087920.078	48303.397956286	0.446928735275904	1.93684005737305	80.2078278152436	80.8806199752035	36.8029204549977	43.1555707283894	134178198018.437	3411.75268554688	8.94379650936199	526
3	Belgium	BEL	2009	483254171097.812	44760.2912443709	-2.02074306169408	1.99860000610352	66.5720368236699	68.8340037082276	16.0070029161629	6.89894870021208	107153322691.094	3519.85498046875	11.355832517814	364
3	Belgium	BEL	2010	481420882905.001	44184.946353964	2.86429270764155	2.06188011169434	74.14760859514	75.8500644792464	26.0669819962462	13.8811775260981	111337132530	3732.83129882813	9.26259212516684	532
3	Belgium	BEL	2011	523330354138.133	47410.5669277464	1.69451389861332	2.17332005500793	80.7963607521708	80.6973629124622	31.265983348903	24.6700682499188	128252251484.436	3875.64404296875	8.67392750332438	541
3	Belgium	BEL	2012	496152879924.727	44670.5606845101	0.739217283058679	2.28114008903503	80.3415397228249	80.4044905064987	2.38036960149692	8.36327108666319	117538249252.148	4113.263671875	8.94089631117732	795
3	Belgium	BEL	2013	521791015247.06	46757.9518559598	0.459242192907709	2.33072996139526	78.5264966401955	79.3243484015476	-5.68061237430678	-2.37051729187159	117028316331.726	4155.9111328125	10.6391694140643	745
3	Belgium	BEL	2014	535390200131.018	47764.0715120833	1.57853314322614	2.37001991271973	78.982206854526	79.801009073623	-2.84014749508768	-0.0781169299331051	123868881729.098	4528.9150390625	11.9385860860968	373
3	Belgium	BEL	2015	462335574841.484	41008.296719472	2.04145900919961	2.42816996574402	76.3872643576431	77.8052821516798	-4.22079695282357	1.58545696749609	109240420185.156	4711.04541015625	12.3344590113891	567
3	Belgium	BEL	2016	476062757356.927	42012.6227191016	1.26668640902095	2.52338004112244	78.2354105104266	79.4296154739536	12.0862954763607	7.25852898705755	115455750565.448	4780.51708984375	13.3305118312538	1620
3	Belgium	BEL	2017	502764720556.354	44198.4823908691	1.6195802783878	2.66666007041931	82.1434260996683	83.1824102499921	-7.41675753843461	-1.05420184204344	122958227194.941	4729.5537109375	11.4912824414212	1016
3	Belgium	BEL	2018	543299066998.902	47544.9811472757	1.79294519302076	2.86031007766724	83.4151576304182	83.0796294670067	-7.65717995735734	-6.62645482048669	138084759395.137	5003.94580078125	11.7053410060459	1019
3	Belgium	BEL	2019	535830876745.097	46638.6813054855	2.24085824041289	3.16000008583069	81.774363045681	82.4025530403535	-5.61286670069505	-6.49422153574722	134025615315.294	5253.21044921875	14.1411500865747	998
3	Belgium	BEL	2020	525211810652.608	45517.7949301847	-5.36138663334856	3.47720003128052	77.7339834628859	79.4467389098884	-3.3454389101158	-3.70065249453991	127810488175.72	5750.14404296875	15.3076783830173	994
3	Belgium	BEL	2021	594104177539.525	51247.0143531626	6.13386596356445	NA	85.8114962903504	86.862955185586	11.5525963845912	14.967069735591	154518871262.013	NA	18.3350868548937	1005

Source: prepared by author based on Microsoft Excel software

Annex 4. *The correlation analysis no. 1 between GDPm and* ***not transformed*** *independent variables*

```
Dependent variable – gross domestic product GDPm
Independent variables - RDEXPp, TIp, TEp, FDIINp, FDIOUTp, GFCFm, RDNO, MHTEXp, TPG

            GDPm RDEXPp   TIp   TEp FDIINp FDIOUTp GFCFm  RDNO MHTEXp   TPG
GDPm        1.00   0.49 -0.54 -0.41  -0.23    0.22  0.99  0.30  -0.07  0.74
RDEXPp      0.49   1.00 -0.11  0.07  -0.12    0.29  0.49  0.83   0.23  0.33
TIp        -0.54  -0.11  1.00  0.96   0.37    0.11 -0.52  0.17   0.40 -0.62
TEp        -0.41   0.07  0.96  1.00   0.36    0.19 -0.40  0.30   0.46 -0.50
FDIINp     -0.23  -0.12  0.37  0.36   1.00    0.58 -0.21 -0.05   0.20 -0.19
FDIOUTp     0.22   0.29  0.11  0.19   0.58    1.00  0.24  0.24   0.29  0.10
GFCFm       0.99   0.49 -0.52 -0.40  -0.21    0.24  1.00  0.28  -0.04  0.75
RDNO        0.30   0.83  0.17  0.30  -0.05    0.24  0.28  1.00   0.34 -0.06
MHTEXp     -0.07   0.23  0.40  0.46   0.20    0.29 -0.04  0.34   1.00 -0.12
TPG         0.74   0.33 -0.62 -0.50  -0.19    0.10  0.75 -0.06  -0.12  1.00

n
            GDPm RDEXPp TIp TEp FDIINp FDIOUTp GFCFm RDNO MHTEXp TPG
GDPm         572    534 572 572    566     566   572  514    339 561
RDEXPp       534    534 534 534    533     533   534  514    313 524
TIp          572    534 572 572    566     566   572  514    339 561
TEp          572    534 572 572    566     566   572  514    339 561
FDIINp       566    533 566 566    566     566   566  513    333 555
FDIOUTp      566    533 566 566    566     566   566  513    333 555
GFCFm        572    534 572 572    566     566   572  514    339 561
RDNO         514    514 514 514    513     513   514  514    310 504
MHTEXp       339    313 339 339    333     333   339  310    339 328
TPG          561    524 561 561    555     555   561  504    328 561

P
            GDPm   RDEXPp TIp    TEp    FDIINp FDIOUTp GFCFm  RDNO   MHTEXp TPG
GDPm               0.0000 0.0000 0.0000 0.0000 0.0000  0.0000 0.0000 0.2285 0.0000
RDEXPp      0.0000        0.0108 0.0960 0.0063 0.0000  0.0000 0.0000 0.0000 0.0000
TIp         0.0000 0.0108        0.0000 0.0000 0.0101  0.0000 0.0000 0.0000 0.0000
TEp         0.0000 0.0960 0.0000        0.0000 0.0000  0.0000 0.0000 0.0000 0.0000
FDIINp      0.0000 0.0063 0.0000 0.0000        0.0000  0.0000 0.2546 0.0002 0.0000
FDIOUTp     0.0000 0.0000 0.0101 0.0000 0.0000         0.0000 0.0000 0.0000 0.0133
GFCFm       0.0000 0.0000 0.0000 0.0000 0.0000 0.0000         0.0000 0.4160 0.0000
RDNO        0.0000 0.0000 0.0000 0.0000 0.2546 0.0000  0.0000        0.0000 0.1845
MHTEXp      0.2285 0.0000 0.0000 0.0000 0.0002 0.0000  0.4160 0.0000        0.0355
TPG         0.0000 0.0000 0.0000 0.0000 0.0000 0.0133  0.0000 0.1845 0.0355
```

Source: prepared by an author according Rstudio results

Annex 5. *The correlation analysis no. 2 between pc_GDPm and* ***transformed*** *independent variables*

```
Dependent variable – Percentage change of gross domestic product pc_GDPm
Independent variables – d_RDEXPp, d_TIp, d_TEp, d_FDIINp, d_FDIOUTp, pc_GFCFm, pc_RDNO,  d_MHTEXp, pc_TPG

          pc_GDPm d_RDEXPp d_TIp d_TEp d_FDIINp d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp pc_TPG
pc_GDPm      1.00    -0.12  0.13  0.06     0.01      0.06     0.83    0.11    -0.27  -0.03
d_RDEXPp    -0.12     1.00  0.00 -0.04    -0.04     -0.08    -0.10    0.35     0.11   0.03
d_TIp        0.13     0.00  1.00  0.85     0.19      0.15     0.34    0.15    -0.14  -0.04
d_TEp        0.06    -0.04  0.85  1.00     0.19      0.16     0.10    0.10    -0.15  -0.02
d_FDIINp     0.01    -0.04  0.19  0.19     1.00      0.62     0.07    0.02    -0.04  -0.04
d_FDIOUTp    0.06    -0.08  0.15  0.16     0.62      1.00     0.08    0.07    -0.13   0.02
pc_GFCFm     0.83    -0.10  0.34  0.10     0.07      0.08     1.00    0.13    -0.20  -0.05
pc_RDNO      0.11     0.35  0.15  0.10     0.02      0.07     0.13    1.00    -0.07   0.06
d_MHTEXp    -0.27     0.11 -0.14 -0.15    -0.04     -0.13    -0.20   -0.07     1.00   0.02
pc_TPG      -0.03     0.03 -0.04 -0.02    -0.04      0.02    -0.05    0.06     0.02   1.00

n
          pc_GDPm d_RDEXPp d_TIp d_TEp d_FDIINp d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp pc_TPG
pc_GDPm       550      505   550   550      544       544      550     479      317    536
d_RDEXPp      505      505   505   505      505       505      505     479      290    492
d_TIp         550      505   550   550      544       544      550     479      317    536
d_TEp         550      505   550   550      544       544      550     479      317    536
d_FDIINp      544      505   544   544      544       544      544     479      311    530
d_FDIOUTp     544      505   544   544      544       544      544     479      311    530
pc_GFCFm      550      505   550   550      544       544      550     479      317    536
pc_RDNO       479      479   479   479      479       479      479     479      286    466
d_MHTEXp      317      290   317   317      311       311      317     286      317    303
pc_TPG        536      492   536   536      530       530      536     466      303    536

P
          pc_GDPm d_RDEXPp d_TIp  d_TEp  d_FDIINp d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp pc_TPG
pc_GDPm           0.0096   0.0018 0.1626 0.7549   0.1869    0.0000   0.0130  0.0000   0.5142
d_RDEXPp  0.0096           0.9372 0.3301 0.3678   0.0869    0.0232   0.0000  0.0634   0.5051
d_TIp     0.0018  0.9372           0.0000 0.0000   0.0004    0.0000   0.0014  0.0109   0.4137
d_TEp     0.1626  0.3301   0.0000         0.0000   0.0001    0.0144   0.0240  0.0091   0.6272
d_FDIINp  0.7549  0.3678   0.0000 0.0000           0.0000    0.1275   0.7158  0.4437   0.3497
d_FDIOUTp 0.1869  0.0869   0.0004 0.0001 0.0000             0.0764   0.1202  0.0268   0.7219
pc_GFCFm  0.0000  0.0232   0.0000 0.0144 0.1275   0.0764             0.0042  0.0003   0.2490
pc_RDNO   0.0130  0.0000   0.0014 0.0240 0.7158   0.1202    0.0042           0.2690   0.2291
d_MHTEXp  0.0000  0.0634   0.0109 0.0091 0.4437   0.0268    0.0003   0.2690           0.7205
pc_TPG    0.5142  0.5051   0.4137 0.6272 0.3497   0.7219    0.2490   0.2291  0.7205
```

Source: prepared by an author according Rstudio results

Annex 6. *The correlation analysis no. 3 between pc_GDPm and* ***transformed*** *decreased number of independent variables*

```
Dependent variable – Percentage change of gross domestic product pc_GDPm
Independent variables – d_RDEXPp, d_TIp, d_FDIOUTp, pc_GFCFm, pc_RDNO,  d_MHTEXp

             pc_GDPm d_RDEXPp d_TIp d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm        1.00    -0.12  0.13      0.06     0.83    0.11    -0.27
d_RDEXPp      -0.12     1.00  0.00     -0.08    -0.10    0.35     0.11
d_TIp          0.13     0.00  1.00      0.15     0.34    0.15    -0.14
d_FDIOUTp      0.06    -0.08  0.15      1.00     0.08    0.07    -0.13
pc_GFCFm       0.83    -0.10  0.34      0.08     1.00    0.13    -0.20
pc_RDNO        0.11     0.35  0.15      0.07     0.13    1.00    -0.07
d_MHTEXp      -0.27     0.11 -0.14     -0.13    -0.20   -0.07     1.00

n
           pc_GDPm d_RDEXPp d_TIp d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm        550      505   550       544      550     479      317
d_RDEXPp       505      505   505       505      505     479      290
d_TIp          550      505   550       544      550     479      317
d_FDIOUTp      544      505   544       544      544     479      311
pc_GFCFm       550      505   550       544      550     479      317
pc_RDNO        479      479   479       479      479     479      286
d_MHTEXp       317      290   317       311      317     286      317

P
           pc_GDPm d_RDEXPp d_TIp  d_FDIOUTp pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm              0.0096 0.0018 0.1869    0.0000   0.0130  0.0000
d_RDEXPp  0.0096             0.9372 0.0869    0.0232   0.0000  0.0634
d_TIp     0.0018   0.9372           0.0004    0.0000   0.0014  0.0109
d_FDIOUTp 0.1869   0.0869   0.0004           0.0764   0.1202  0.0268
pc_GFCFm  0.0000   0.0232   0.0000 0.0764             0.0042  0.0003
pc_RDNO   0.0130   0.0000   0.0014 0.1202    0.0042           0.2690
d_MHTEXp  0.0000   0.0634   0.0109 0.0268    0.0003   0.2690
```

Source: prepared by an author according Rstudio results

Annex 7. *The correlation analysis no. 4 between pc_GDPm and* ***transformed*** *final set of independent variables*

```
Dependent variable – Percentage change of gross domestic product pc_GDPm
Independent variables – d_RDEXPp, d_TIp, pc_GFCFm, pc_RDNO,  d_MHTEXp

          pc_GDPm d_RDEXPp d_TIp pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm     1.00    -0.12  0.13     0.83    0.11    -0.27
d_RDEXPp   -0.12     1.00  0.00    -0.10    0.35     0.11
d_TIp       0.13     0.00  1.00     0.34    0.15    -0.14
pc_GFCFm    0.83    -0.10  0.34     1.00    0.13    -0.20
pc_RDNO     0.11     0.35  0.15     0.13    1.00    -0.07
d_MHTEXp   -0.27     0.11 -0.14    -0.20   -0.07     1.00

n
          pc_GDPm d_RDEXPp d_TIp pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm       550      505   550      550     479      317
d_RDEXPp      505      505   505      505     479      290
d_TIp         550      505   550      550     479      317
pc_GFCFm      550      505   550      550     479      317
pc_RDNO       479      479   479      479     479      286
d_MHTEXp      317      290   317      317     286      317

P
          pc_GDPm d_RDEXPp d_TIp  pc_GFCFm pc_RDNO d_MHTEXp
pc_GDPm           0.0096   0.0018 0.0000   0.0130  0.0000
d_RDEXPp 0.0096           0.9372 0.0232   0.0000  0.0634
d_TIp    0.0018  0.9372          0.0000   0.0014  0.0109
pc_GFCFm 0.0000  0.0232   0.0000          0.0042  0.0003
pc_RDNO  0.0130  0.0000   0.0014 0.0042           0.2690
d_MHTEXp 0.0000  0.0634   0.0109 0.0003   0.2690
```

Source: prepared by an author according Rstudio results

Annex 8. *Pooled Ordinary Least Squares (POLS) primary regression case results*

```
Pooling Model

Call:
plm(formula = pc_GDPm ~ d_RDEXPp + d_TIp + pc_GFCFm + pc_RDNO +
    d_MHTEXp, data = pdf, model = "pooling", index = c("Countrycode",
    "Years"))

Unbalanced Panel: n = 22, T = 9-17, N = 286

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-31.13203  -2.72425   0.19441   2.83999  19.12022

Coefficients:
             Estimate Std. Error t-value  Pr(>|t|)
(Intercept)  1.043184   0.371949  2.8046   0.00539 **
d_RDEXPp    -0.289441   2.953496 -0.0980   0.92200
d_TIp       -0.425362   0.086581 -4.9129 1.529e-06 ***
pc_GFCFm     0.472538   0.026277 17.9829 < 2.2e-16 ***
pc_RDNO      0.045090   0.052591  0.8574   0.39197
d_MHTEXp    -0.543903   0.209997 -2.5900   0.01010 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares:    21288
Residual Sum of Squares: 8571.6
R-Squared:      0.59735
Adj. R-Squared: 0.59016
F-statistic: 83.0789 on 5 and 280 DF, p-value: < 2.22e-16
> vif(pool.mod2)
d_RDEXPp    d_TIp pc_GFCFm  pc_RDNO d_MHTEXp
1.184481 1.606190 1.638525 1.204143 1.035650
```

Source: created by an author based on Rstudio software output

Annex 9. *Pooled Ordinary Least Squares (POLS) regression model without insignificant regressors*

```
Pooling Model

Call:
plm(formula = pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp, data = pdf,
    model = "pooling", index = c("Countrycode", "Years"))

Unbalanced Panel: n = 22, T = 13-24, N = 317

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-32.68141  -2.80063   0.28415   3.15159  18.49180

Coefficients:
             Estimate Std. Error t-value  Pr(>|t|)
(Intercept)  1.447473   0.317842  4.5541 7.546e-06 ***
d_TIp       -0.361543   0.078890 -4.5829 6.634e-06 ***
pc_GFCFm     0.464548   0.023819 19.5031 < 2.2e-16 ***
d_MHTEXp    -0.461202   0.196025 -2.3528   0.01925 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares:    25036
Residual Sum of Squares: 9705.2
R-Squared:      0.61235
Adj. R-Squared: 0.60864
F-statistic: 164.812 on 3 and 313 DF, p-value: < 2.22e-16
> vif(pool.mod2.1)
   d_TIp pc_GFCFm d_MHTEXp
1.595929 1.617676 1.023888
```

Source: created by an author based on Rstudio software output

Annex 10. *Pooled Ordinary Least Squares (POLS) regression model with dummy variables*

```
Pooling Model

Call:
plm(formula = pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec + cov,
    data = pdf, model = "pooling", index = c("Countrycode", "Years"))

Unbalanced Panel: n = 22, T = 13-24, N = 317

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-32.38606  -2.70345   0.10003   2.98100  17.48565

Coefficients:
             Estimate Std. Error t-value  Pr(>|t|)
(Intercept)  0.799714   0.451486  1.7713  0.077491 .
d_TIp       -0.418027   0.081266 -5.1439 4.772e-07 ***
pc_GFCFm     0.485148   0.024331 19.9391 < 2.2e-16 ***
d_MHTEXp    -0.454669   0.194090 -2.3426  0.019782 *
rec1         1.805984   0.668319  2.7023  0.007265 **
cov1        -1.575355   1.309947 -1.2026  0.230042
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares:    25036
Residual Sum of Squares: 9376.3
R-Squared:      0.62549
Adj. R-Squared: 0.61947
F-statistic: 103.885 on 5 and 311 DF, p-value: < 2.22e-16
> vif(pool.mod2.2)
   d_TIp pc_GFCFm d_MHTEXp      rec      cov
1.741734 1.736062 1.032352 1.141261 1.165263
```

Source: created by an author based on Rstudio software output

Annex 11. *The Fixed Effects (FE) primary regression model's analysis results*

```
Oneway (individual) effect Within Model

Call:
plm(formula = pc_GDPm ~ d_RDEXPp + d_TIp + pc_GFCFm + pc_RDNO +
    d_MHTEXp, data = pdf, effect = "individual", model = "within",
    index = c("Countrycode", "Years"))

Unbalanced Panel: n = 22, T = 9-17, N = 286

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-29.45436  -2.32518   0.34715   2.92771  17.52870

Coefficients:
          Estimate Std. Error t-value  Pr(>|t|)
d_RDEXPp  0.808448   3.036737  0.2662    0.7903
d_TIp    -0.452296   0.087663 -5.1595  4.93e-07 ***
pc_GFCFm  0.470834   0.026513 17.7587 < 2.2e-16 ***
pc_RDNO   0.070711   0.053846  1.3132    0.1903
d_MHTEXp -0.689423   0.217391 -3.1714    0.0017 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares:    20245
Residual Sum of Squares: 7843.4
R-Squared:      0.61257
Adj. R-Squared: 0.57368
F-statistic: 81.901 on 5 and 259 DF, p-value: < 2.22e-16
```

Source: created by an author based on Rstudio software output

Annex 12. *The Fixed Effects (FE) secondary regression approach without insignificant variables and with dummy variables*

```
Oneway (individual) effect Within Model

Call:
plm(formula = pc_GDPm ~ d_TIp + pc_GFCFm + d_MHTEXp + rec + cov,
    data = pdf, effect = "individual", model = "within", index = c("C
ountrycode",
        "Years"))

Unbalanced Panel: n = 22, T = 13-24, N = 317

Residuals:
     Min.   1st Qu.    Median   3rd Qu.      Max.
-30.32858  -2.67440   0.22145   3.06231  16.87411

Coefficients:
          Estimate Std. Error t-value  Pr(>|t|)
d_TIp    -0.449366   0.082945 -5.4176  1.27e-07 ***
pc_GFCFm  0.487451   0.024881 19.5915 < 2.2e-16 ***
d_MHTEXp -0.564356   0.201755 -2.7972  0.005499 **
rec1      2.057194   0.674890  3.0482  0.002515 **
cov1     -1.447635   1.314069 -1.1016  0.271530
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Sum of Squares:    23998
Residual Sum of Squares: 8782.6
R-Squared:      0.63403
Adj. R-Squared: 0.60122
F-statistic: 100.482 on 5 and 290 DF, p-value: < 2.22e-16
```

Source: created by an author based on Rstudio software output