Západočeská univerzita v Plzni

Fakulta ekonomická

Tertiary education and its impact on economic development in EU Member States

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disertační práce
k získání akademického titulu doktor
v oboru Ekonomika a management

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Katedra ekonomie a kvantitativních metod

Plzeň 2023

Abstrakt

Cílem práce je analyzovat vztah mezi vzděláním a ekonomickým růstem s důrazem na strukturu vzdělání, která často zůstává opomíjena. Ačkoli pozitivní vliv vzdělání na ekonomiku a ekonomický růst je často považován za samozřejmost a podpořen teorií, na empirické úrovni často překvapivě selhává. Jak dokazují výzkumné práce Holmese (2013) a Holmesa a Mayhewa (2016), odhady ekonomického růstu vyvolaného vysokoškolským vzděláním mohou být citlivé na výzkumná data zahrnutá do analýzy. Navíc autoři naznačili, že se systematicky objevuje měřicí chyba. V současnosti, přestože existuje více vysoce kvalitních dat, může stále způsobovat obtíže při provádění analýz mezi zeměmi, protože "neukazují žádný vliv vysokoškolského vzdělání na růst" (Holmes, 2013, s. 34). Tato práce přispívá k současnému stavu poznatků zejména zaměřením na STEM (science, technology, engineering, maths) vzdělání a také zohledněním genderových rozdílů. Pomocí standardních ekonometrických metod spolu s modelováním strukturálních rovnic (SEM) a Bayesian Model Averaging (BMA) byl prozkoumán vztah mezi vysokoškolským vzděláním, ekonomickým růstem a rozdíly ve mzdách mezi pohlavími. Předběžné výsledky ukazují, že podíl populace s terciárním vzděláním nemá významný vliv na ekonomický růst. Nicméně, pokud se zaměříme pouze na STEM vzdělání, efekt se stal statisticky významným a pozitivním. Poměrně překvapivě se zdá, že ženy s terciárním vzděláním mají nižší vliv na ekonomický růst ve srovnání s mužskými absolventy. To však není způsobeno samotným pohlavím, ale opět skutečností, že je nízký podíl žen ve STEM oborech. Pro podporu míry růstu je důležité nejen přitahovat mladé lidi, zejména ženy, ke STEM vzdělání, ale také zlepšovat podmínky na trhu práce a odstraňovat možné sociální, legislativní a genderové omezení. Skutečnost, že se zvyšuje poměr osob s vysokoškolským vzděláním, sám o sobě nezaručuje budoucí ekonomický růst.

Klíčová slova: vysokoškolské vzdělávání, ekonomický rozvoj, ekonomický růst, metody BMA, ekonomika vzdělávání.

Abstract

The purpose of the thesis is to analyse the relation between education and economic growth with focus on the education structure that is often overlooked. Although the positive effect of education on economy and economic growth is often taken for granted and backed by theory, it is surprisingly often failing on empirical grounds. As demonstrated in the research work of Holmes (2013) and Holmes and Mayhew (2016), the estimations of economic growth effect of higher education might be sensitive to research data included in the analysis. In addition, it was claimed that measurement error appeared persistently. At the moment, despite the fact that there is more high-quality data, it may still cause difficulties while executing cross-country analyses, as they "fail to show any effect of higher education on growth" (Holmes, 2013, p. 34). This thesis contributes to the current state of the art especially by focusing on the STEM (science, technology, engineering, maths) education, and also by taking gender differences into account. Using standard econometric methods along with Structural Equation Modelling (SEM) and the Bayesian Model Averaging (BMA), we explored the relationship between higher education, economic growth and gender pay gap. Initial results showed that education as a share of population with a tertiary degree seemed to have no significant effect on economic growth. However, when the research became focused on education structure, STEM majors in tertiary education and gender differences, the effect has become statistically significant and positive. Quite surprisingly, women with a tertiary degree appear to have a lower effect on economic growth in comparison to male graduates. This is not, however, caused by the gender itself but again by the fact that there is a low share of women in STEM. What seems to be crucial for fostering the growth rate is not only to attract young people, mainly women, towards the STEM education, but also improve the conditions on the labour market eliminating possible social, legislative, and gender constraints. The fact that the ratio of people holding a higher education degree is increasing does not guarantee any future economic growth per se.

Keywords: higher education, economic development, economic growth, BMA methods, economics of education.

Contents

Introduction

The challenges of economic growth currently hold a prominent position in economic discussions among representatives from different nations, peoples, and their respective governments. The expanding volume of actual production partially addresses the issue that every economic system encounters: the scarcity of resources amidst unlimited human needs. Economic growth can be achieved through various strategies and policies aimed at increasing productivity, fostering innovation, promoting investment, and creating favourable conditions for businesses to thrive, such as investing in physical and human capital, promoting innovation and technological advancement, enhancing international trade and many others.

Rising interest in the role of tertiary institutions in regional economic growth is creating space for multi-disciplinary discussions and research in growth economics, economics of education, labour economics, and human resources management. It is crucial to determine what impact universities have on economic growth as producers of human capital and innovation implementers in their regions. Higher education organisations (HEIs) that successfully accomplish these tasks within a short-term perspective might contribute to economic development. Complex issues such as managing human resources in HEIs arise. Yet research reports on human resource management in education, specifically, tertiary education, are limited in number, disintegrate and incongruent.

It was attempted to explore the nexus between higher education, economic development and economic growth identifying the existing research gaps through extensive literature review and setting up econometric models. The goal of the study is to decompose the effect of tertiary education on growth through carrying out a cross-country analysis in European Member states and detect robust relationships among the variables.

In previous studies it was found that while tertiary education does not lead to economic development directly, there is an effect of scientific and technical tertiary education on growth. Well-distributed investment in the development of science, technology, engineering, maths (STEM) majors in HEIs can potentially strengthen universities' positive impact on economic growth. Government spending on research and development at higher education organisations is another significant aspect of higher education to look at. Cadil et al. (2018) argued that R&D policy needs to be further analysed and evaluated, namely, the indicators that may potentially influence university competitiveness. Competition between universities, in turn, could activate the potential to make economic growth *sustainable* – a definition introduced in the United Nations's World Commission on Environment and Development Brundtland Report in 1987. This term typically refers to a pattern of economic development that can be maintained over the long term without depleting natural resources, causing significant environmental damage, or compromising the well-being of future generations. It emphasizes the need to balance economic progress with environmental protection and social well-being. The Sustainable Development Goals (SDGs) were introduced by the UN in September 2015 and are now widely used as a part of the 2030 Agenda for Sustainable Development. According to the UN's website, the goal related to education is SDG 4, which stands for "Quality Education." It aims to ensure inclusive and equitable quality education, and promote lifelong learning opportunities for all. It recognizes education as a fundamental human right and a crucial enabler for sustainable economic growth and development.

The process of building a transparent system that could help to determine the efficiency of a higher education organization would need to be designed, tested and clearly explained to managers and policy makers to find common ground among policy makers, tertiary education organisations' management, human resources managers, professionals, and students. It can help the overall system work more effectively, potentially providing the world with better opportunities for sustainable growth. It is important to have a fuller picture of how social beliefs, stereotypes, backgrounds and bias affect primary and secondary students, what majors they opt for once they choose to study for a tertiary degree, how many of them drop out, switch majors, and transition to the labour market. What economic returns can be expected within an economy of a developed country from tertiary education graduates who opt to do other jobs that do not correspond to the field they have studied in? What is the role of female tertiary graduates and what are possible ways to improve economic results gained from motivating more students to pursue a tertiary degree? In order to attempt to answer these questions, the main terms and the state of the art need to be defined first.

The rest of the thesis consists of three chapters and is organised as follows. The remaining introductory part deals with the statement of the problem, research questions, definition of terms and pre-emptive research results. Problem statement section outlines the specific area addressed by the research. Research aims section states the overall objectives of the research. Research questions section presents specific questions that the research aims to answer. These questions will guide the investigation and help to navigate through Chapter 3. The Definition of Terms section provides definitions and explanations of key concepts used in this research so that the common terminology is used throughout the study. The Pre-emptive Testing Phase section describes a testing phase that was conducted in 2019-2020 prior to the main research. It explains the purpose of and provides the reason for the main research to be carried out in a certain way, the methods employed, and any preliminary findings or insights gained from the testing. Main research questions after the pre-emptive phase introduce the revised research questions that emerged after the pre-emptive testing phase. This section signifies that the research questions were adapted or modified based on the preliminary findings from the testing phase. These sections collectively introduce the research, setting the stage for the subsequent sections that delve into the methodology, analysis, and findings of the study. Chapter 1 addresses literature review and covers the state of the art. Chapter 2 describes methodology used in the thesis, such as Uzawa-Lukas model modification to explain the rationale behind the modification, the changes made to the original model, and the implications of these modifications for the research. The econometric model section introduces the specific econometric model used in the research. Qualitative research and panel data methods sections explain the construction of a variable map based on the results from a bibliometric article which is currently in review. This information could serve as a guide for selecting and organizing variables in the panel data analysis. The section also discusses the advantages and limitations of using panel data in the research. The Structured Econometric Modelling section elaborates on the methodology used to structure the model, such as the inclusion of specific variables, and parameter specifications. BACE and BMA methods section introduces the BACE (Bayesian Averaging of Classical Estimates) and BMA (Bayesian Model Averaging) methods used in the research and highlights the advantages or unique features of using Bayesian methods in the research context.

Chapter 3 is dedicated to answering the research questions of the study. Additional research was carried out in 2023 to study the nexus between higher education majors and the gender pay gap in the EU countries. The dataset and the methods are described in this chapter as well as the results of the main research phase. The final part of the thesis discusses research limitations, political, economic and social implications, and the ideas for further research. The thesis is supported by the appendices and bibliography.

Definition of Terms

Developed countries are classified by the World Bank as having middle or high gross national income per capita, while developing countries have low-middle or low GNI per capita. The purpose of this dissertation is to study the relationship between economic growth and higher education.

Economic development involves qualitative changes and restructuring of a country's economy linked with technological and social progress, which leads to an increase in GDP per capita, while *economic growth* refers to the expansion of a country's economy through the effective use of resources, such as human capital.

Endogenous growth refers to internal factors that influence economic growth. GDP per capita (in purchasing power parity, international $US, 2017) is calculated by dividing the sum of gross value added by all resident producers in the economy, any product taxes, and any subsidies not included in the value of the products by midyear population.

Gender pay gap, GPG (unadjusted form) – according to Eurostat, the indicator calculates the percentage difference between the average gross hourly earnings of male and female paid employees. This unadjusted measure provides a general overview of gender-based pay inequalities, which is broader than the concept of equal pay for equal work. The calculation includes all employees working in firms with a workforce of ten or more, regardless of their age and working hours.

Gross fixed capital formation (million Euro) represents resident producers' acquisitions, less disposals of fixed assets during a given period plus certain additions to the value of non-produced assets realised by the productive activity of government producer or units. Fixed assets are produced assets used in production for more than one year.

Higher Education (HE) – see tertiary education.

Higher Education Institutions (HEIs) – organisations that provide ISCED[1] (international standard classification of education) 6-8 degrees (bachelor, master and doctoral degrees), these could be public or private organisations.

Human capital is defined as the economic value of people's innate abilities, talents, knowledge, skills, and experience, and can be increased by investing in health care, education, and job training.

[1] The standards on international statistics on education are set by the following three international organisations: The United Nations Educational, Scientific, and Cultural Organisation Institute for Statistics (UNESCO-UIS), The Organisation for Economic Co-operation and Development (OECD) and, The Statistical Office of the European Union (EUROSTAT).

Massification refers to government policies aimed at increasing tertiary education enrolment.

STEM graduates[2] – In this research, graduated students from F05-F07 majors, including science, technologies, engineering and mathematics.

Tertiary education includes ISCED 6-8 forms of postsecondary education, carried out within public and private institutions, and is not limited to universities only.

University degrees encompass national degree and qualification structures associated with four-year institutions, including Bologna-recognized three-year degrees and qualifications.

Problem statement

The relationship between the level of education of the workforce within a country and effective functioning within organisations providing tertiary education is crucial to understand in order to build up a system that can deliver quality workforce to the labour market (Faggian & McCann, 2009). In some papers (e.g. Agasisti et al. 2020), it is suggested that effective universities would either employ fewer people to achieve the same results, or keep the same number of employees improving their results. Such universities may ignite more interest and incentives to attract younger generations to take part in their study programmes as well as establish strong bonds and collaborations among successful businesses in the region. For a few decades, a great number of researchers have been working to describe strategies of how universities usually engage in social and economic development of the region. In 1996, Etzkowitz described a triple helix model, other researchers widely use econometric approaches that are based either on macroeconomic or regional development models. Over the last few decades it is becoming increasingly important to calculate and recognise the economic impact of universities and other organisations providing tertiary education. Huggins and Johnston (2009) described universities as drivers of regional innovation. It is important, however, to look at the human capital and ways it is managed (recruited, trained, sustained) in order to determine possibilities of sustainable growth resulting in higher education. It is crucial to define what efficiency in education is because researchers and educators worldwide have not yet agreed on using specific techniques on how to pursue so-called efficiency (Kim et al., 2011). These concerns mainly stem from the idea that if educators and university staff

[2] According to Eurostat, graduates in STEM are calculated as the sum of graduates in the following fields of education (ISCED-F13): F05 Natural sciences, mathematics and statistics; F06 Information and Communication Technologies; and F07 Engineering, manufacturing and construction

in general start focusing more on being efficient, the very concept of higher education might suffer as more attention is given to meeting certain requirements.

Higher education could be provided to society in a number of ways. Understanding the role of higher education and higher education management could also be carried out in various perspectives, namely, human resources, tertiary degree programmes, successful and unsuccessful students, etc. In the thesis, the nexus between economic growth, higher education in terms of students' majors and gender is considered, as well as the impact higher education could have on the gender pay gap. The opportunity to provide the best educational product for a given budget often determines how efficient an organisation is. Generally speaking, the same resources could be used to achieve better results in the future, or fewer resources could be used to obtain the same results. According to the traditional approach, the factors that have an effect on the educational process are input factors, and the results that appear after the education process is finished are called the outputs. In a nutshell, traditional approach is not aimed to define the "production process", which essentially implies that inputs (e.g. number of administrative/teaching staff, educational environment, availability of certain equipment, etc.) are gradually transformed into outputs (e.g. economic growth of the region, number of graduates, etc.).

The studies that were carried out in the last few decades, mainly in the new millennium, indicate that there is an option to improve efficiency without necessarily making the quality of the education and the higher education system worse off. According to Agasisti et al. (2020), universities may be viewed by general society as social and educational venues that help individuals acquire specific skills to be able to meet economic needs and fit the current market demand perfectly well. It was demonstrated by Shattock (2010) that imposing strategic thinking (aligning priorities, values and incentives of the university to the ones defined by local/regional/national authorities) for university management is one of the key elements to enhance university's performance and efficiency. Understanding the role of human resources management in tertiary educational venues helps to tackle a number of management mechanisms in order to select the ones that lead to efficiency and consequently, economic growth.

Statement of the problem: Despite the fact that the cause-effect relationship between tertiary education and economic growth and development has been a focus of multiple research projects, it is still unclear what could be the nexus among tertiary education majors, gender pay gap and economic growth. This study attempts to determine the impact of higher education systems on economic growth within 27 EU Member states over the period of 2013-2020, as well as the effects of total numbers of Bachelor, Master and PhD level graduates and graduates divided by gender in the fields of science, engineering and technology.

Research aims

The aim of the research: this study attempts to carry out reliable empirical estimates of the relationship between tertiary education and economic growth in the European Union countries during the period of 2013 – 2020 in order to determine the potential impact of differences in gender and major on gender pay gaps and economic development of the EU member states. Research limitations of this study are as follows. In the framework of this study, several indicators of economic growth and development were used – the average growth rate of real GDP per capita, average growth of the GDP per capita in PPP price rates, gender pay gap (GPG), and tertiary education system was represented by an education outcome - the share of population holding a tertiary degree and number of graduates of specific majors and genders. The time period for the dataset was chosen due to availability of the new and consistent data on higher education across all EU Member States starting from 2013. Relationships between specific tertiary degrees ISCED F1-F13[3] in social sciences, technical sciences, chemistry, biology, etc. and economic growth were not considered in this paper, which is another limitation of the current research. Alternative measurements of economic growth were not used to proceed with the estimations. Instead, gender pay gap percentage was used as an alternative dependent variable for the main set of models and analyses. Despite these limitations, it is expected that the results of this research can be used to consider further steps towards building a sustainable and transparent education system in the EU Member States.

Research questions

The study began in 2020 with a review of research work carried out worldwide. The literature that supported the view that higher education exerts a significant effect on GDP in its forms included Barro, 2001; Wolf, 2004; Hanushek, 2012; Agasisti and Bertoletti, 2020; and a great number of other authors and research groups. The aim of this study was to narrow down the number of countries used in such international comparisons and consider EU Member States

[3] Fields of education (ISCED-F13).

only. Due to the availability of consistent data on higher education graduates in the EU, it was possible to set the following research questions:

1) to what extent does the general share of ISCED[4] 6-8 graduates towards the total country's population exert a significant positive effect on GDP in 2013-2020?

2) to what extent do country-level tertiary education results from STEM majors compared to Non-STEM majors (percentage of graduates towards total country's population; percentage of ISCED 6, 7 and 8 graduates; percentage of male and female graduates) exert a significant positive effect on GDP?

3) to what extent do female and male graduates of STEM majors exert a significant positive effect on GDP?

4) what extent does the number of STEM graduates in general and the number of female STEM graduates have a positive effect on narrowing the gender pay gap?

To address these research questions, a few models were built and tested using panel data analysis methods and checked by BMA analysis techniques which dealt with the cross-sectional dataset. The study was divided into 3 main stages: pre-emptive research phase, main research and additional research phase. The study estimated four null hypotheses formulated negatively, which correspond to the four research questions stated above:

$H_0 1$: Total percentage of graduated students towards the total countries' population does not significantly impact economic growth (GDP). Due to the fact that the percentage of educated population in EU Member States is high, it is expected that additional graduates will not impact the GDP.

$H_0 2$: Percentage of graduates of STEM and Non-STEM majors of ISCED 6, 7, and 8 levels (bachelor, master and doctoral graduates) is not robustly correlated with economic growth. Due to the fact that students could switch majors, study more years or drop out from universities, insignificant correlation between graduates of various majors and growth is expected.

[4] More on ISCED levels is available at the UNESCO Institute for Statistics uis.unesco.org; in this manuscript we refer to ISCED levels as follows: ISCED 5 = Short-cycle tertiary education. ISCED 6 = Bachelors degree or equivalent tertiary education level. ISCED 7 = Masters degree or equivalent tertiary education level. ISCED 8 = Doctoral degree or equivalent tertiary education level.

$H_0 3$: Female STEM ISCED 6-8 graduates' percentage towards total countries' population does not significantly impact economic growth. Owing to the fact that the share of female graduates in STEM major is low, it is expected that additional female STEM graduates will not impact the GDP.

$H_0 4$: Share of female STEM graduates towards the total female countries' population does not significantly impact gender pay gaps (GPG). Owing to the fact that the share of female graduates in STEM major is low, it is expected that additional female STEM graduates will not impact the GPG.

The research questions addressed in the pre-emptive research phase were as follows: 1: What is the impact of the characteristics of higher education systems on economic growth in European countries? 2: What is the impact of human capital with a tertiary degree in science, technology, and medicine (Bachelor's and Master' level) on economic growth? 3: What is the impact of male and female graduates (Bachelor's and Master' level) of all majors on economic growth? 4: What is the impact of male and female graduates (Bachelor's and Master' level) majoring in science, technologies and medicine on growth? The results of the pre-emptive research were published in 2022 in the ACC Journal (Petrenko, 2022). The data for pre-emptive research was gathered from the Eurostat (2021), OECD (2021) and World Bank (2021) official databases. A list of variables and corresponding data sources can be found in Table 7. The criteria for choosing the variables were as follows: 1) Availability – the data are available for the majority of the current EU Members States from 1990 to present; 2) Consistency – congruent tertiary education data for the 27 EU Member States that was calculated and received by carrying out exactly the same procedure for years 2013-2019. Despite the fact that the period of six years could be considered to be a limitation of the current research, it was expected that a common relationship between tertiary education and economic growth would be found as the list of countries chosen for this study seemed to be homogeneous as it consisted of countries with developed economies according to the World Bank (2019).

More detailed results of the pre-emptive testing phase are described in Chapter 3.1. Following the example of Hanushek and Woessman, 2012; Agasisti and Bertoletti, 2020; to create a novel dataset with the variables for European countries with the data from Eurostat and World Bank, the results of the pre-emptive testing phase allowed to focus the research on tertiary education majors, economic growth and the gender pay gap. We found that such variables as the number of graduated bachelor and master students positively relate to growth. It was discovered that bachelor and master male students who graduated majoring in sciences, technologies and medicine overall have higher robust coefficients associated with growth. Female master students returned a statistically insignificant coefficient according to the OLS regression model, whereas it might be implied from the results of the same coefficients for BACE models that female graduates generally do not correlate robustly with growth. It was also confirmed that the number of graduated bachelor male students might have robust marginal correlation with economic growth. However, female graduate students, both bachelor and master levels, return insignificant correlation with economic growth.

Further development of current research may focus on developing a set of indicators that measure the level of technological development in EU countries and including these into the dataset. Moreover, we found it interesting to perform analyses on STEM education with a further focus on gender, possibly answering the following questions: is STEM tertiary education more important for growth? How many women and men study STEM and does their number have any impact on the gender pay gap and/or the "sticky floor[5]", "glass door" or "glass ceiling".

It is demonstrated that some components of human capital (the share of people with tertiary diploma, the share of young people in the economically active population) in combination with expenditures on higher education have statistically significant robust positive influence on economic growth in the countries of the European Union. It might be interesting to determine the spillover effects. In the future analysis, it can be possible to break down the 27 countries into several groups and possibly include more variables for these groups. During the pre-emptive phrase we admittedly used a limited number of variables which might have possibly caused more biased results, which could serve as a guide only.

The following questions remain relevant for the main research - 1) Is there a set of fixed variables in tertiary education that robustly relate to economic growth? What is the strength of this connection - partial or marginal? 2) Is there a set of fixed variables in tertiary education that robustly relate to the gender pay gap? What is the strength of this connection - partial or

[5] According to the official website of the European Institute of Gender Studies (EIGE) the definition of the term is as follows: "Expression used as a metaphor to point to a discriminatory employment pattern that keeps workers, mainly women, in the lower ranks of the job scale, with low mobility and invisible barriers to career advancement."

marginal? 3) Is there a relationship between economic growth and differences in gender or in major of newly graduating students? If yes, to what extent does it affect the gender pay gap in the EU Member States?

It is crucial to proceed with the research of the STEM tertiary education for bachelor, master and doctoral graduates and explore the relationship of gender differences between male and female graduates on economic growth to find out whether STEM education promotes economic growth in any way more efficiently than higher education in general. The results of this study might help to demonstrate to what extent the EU governments should invest in STEM tertiary education and foster economic development of prominent economies in other parts of the world.

STEM majors generally attract more male students, who have a statistically significant effect on economic growth, that often may mean that women might not have the same opportunities as men do in their careers. This may result in the finding that women may face various challenges at their workplaces, including “sticky floor”, “glass door” and “glass ceiling” (these two latter terms refer to horizontal and vertical discrimination of women in companies, correspondingly). To develop governmental strategies for tertiary education it might also be useful to understand how such a trend affects the pay gap between men and women in the countries of the European Union.

Governments may choose to assess these issues of glass door and glass ceiling among men and women with a focus on STEM tertiary education through designing policies on tertiary education that could motivate more women to participate in education programs majoring in STEM subjects. The initiatives to foster sustainable economic development through constant investment in the spheres of tertiary education that bring the most value to the economy seem undoubtedly helpful. The issue brought to common awareness, however, is that businesses, governments and international organisations may need to create appropriate social and legislative conditions for young women to stay motivated to take up jobs in the STEM sector upon graduation (VanHeuvelen & Quadlin, 2021).

The results obtained by the pre-emptive research, both methodological and empirical, are important to design regional development policies. Thus, calculations based on BACE modelling showed that higher education expenditures and the numbers of graduated (mainly male) bachelor and master students in technologies, sciences and medicine are significant predictors of economic growth in the EU Member States.

Chapter 1 Theoretical Background

Understanding the role of higher education (HE) in the economy of EU countries is an important matter as it may help to use human resources more effectively and allocate them more efficiently across the European Union. How do incomes of male and female graduates differ? What factors play a major role in the economic development of EU countries? To what extent does economic development depend on the value and quality of human capital? Why should women be incentivized further to complete their degrees? What is the role of STEM majors in fostering economic development? These are questions that have received recognition in recent decades. Due to the changing political, economic and social conditions in the modern world, the answers to these questions have to be constantly reviewed so that the system is adjusted to changes accordingly.

The first chapter begins with the definition and characteristics of the terms 'tertiary education', 'human capital', 'economic growth' and 'economic development'. Theories of economic growth are described in connection with their implications. In the second chapter an overview of existing methodological approaches and techniques is provided and the methods used in this dissertation are classified and explained. Author's own research work is demonstrated in Chapter 3. The final part outlines limitations, political implications and ideas for further (postdoctoral) research.

1.1. Definition of basic concepts

In their mission statements, leading European universities mention sustainable development principles (see mission statements on the webpages of e.g. University of Rome Tor Vergata and Technical University of Berlin). Once the relationship between economic development and higher education is examined, it may become possible to identify effective techniques to achieve the strategic goals for sustainable development in less time. The research question for this chapter is to investigate the existing literature which discusses the relationship between higher education and economic development in order to elucidate the concept of unexplored societal challenges (e.g. the number of students who were later employed within their education field versus the number of students who do jobs outside of their training scope).

The goal achieved in the scope of this chapter is to understand how human capital is built within HEIs. To address the issue and to understand multiple notions of the role of tertiary education in economic development, the data from 150 articles published in leading academic journals was explored and described in the bibliometric analysis manuscript by Agasisti and Petrenko submitted to Studies in Higher Education (January, 2023). Certainly, the topic is well-studied and there is much more literature dedicated to the HE-ED relationship than was possible to include in this bibliometric review. Another objective is to observe patterns through which HEIs can potentially contribute to economic development. The research described in the article aimed to recollect the current trend of scientific literature development on the chosen topic as well as look at the object of the current study from a specific angle of contemplating policy implications.

The aim of this section is to define the terms "higher education" (HE) and "economic development" (ED) in order to suggest proper methods to assess how these two terms relate to one another in the literature. One of the most prominent figures to have described the development of HEIs is Burton Clark who stated (1996, p. 417) that researchers have some understanding about the following three areas: "the transition from elite to mass higher education; the changing relationship between governments and universities, […] and the integration and differentiation of higher education system". According to Clark, researchers may need to discover certain features of knowledge exploitation in order to put forward a balanced study agenda and acquire a deeper understanding of current processes and trends. He considered it vital to ensure that HEIs develop and evolve with purpose and strategy. Although it may be thought that universities and other HEIs have been established in the majority of countries to meet the needs of a country's stakeholders, be they businesses, the government or the general public, there is no common view to unify the historical background for higher education. Rather, the information on the development of specific organizations (like universities) is widely available.

An extensive review of the traditional universities and alternative HEIs like learned societies that have been active in research has been done by various researchers (e.g. see Westfall, 1971; Feingold, 1991; Lubenow, 2015; Burke, 2016; Ellis, 2019). The ideas about how to structure, form and transform HEIs have been shaping not only the HEIs as we know them today, but also traditional perception and understanding of what the term "higher education" means for various social groups in different countries at a given time. For example, in the constitution of the USSR it is stated that "...citizens of the U.S.S.R. have the right to free higher education (article 121, edition 1954). At the same time, in the United States and the United Kingdom, higher education may have been seen more as a privilege which changed after the two World Wars due to multiple factors, including ‘privatization’ (regarded as shifting of HE funding from governments to households). In most of the EU member states HEIs continue to be financed largely by local governments (European Commission website, 2022) and are responsible for producing a large share of scientific papers.

It can be suggested that the researchers who study HEIs and their role in economic development should look at the background of educational systems in countries of interest to them, specifying regions, countries and time spans they are working with. Alternatives to universities and colleges may also include private institutions, museums, research venues, societies and academies of various kinds. The discipline called ‘history of knowledge’ might serve as common ground to unite the history of particular universities, their current values, common social perceptions and prejudices towards higher education into a fuller picture which would help to define “higher education” clearly (see Lubenow, 2015; Burke, 2016;). There has been an attempt to define the term by introducing the international Standard Classification of Education (ISCED) in 1976. This United Nations initiative certainly facilitated international comparisons of differing HE systems all over the world. However, for a number of reasons, including different statistical systems in some countries, the reporting systems of higher education may vary (see e.g. Henderson, 2016) and therefore, HEI systems might be defined differently by the researchers. As the purpose of our bibliometric study was to review the studies that refer to the relationship between higher education and economic development, it is important to provide some context for the term ‘economic development’.

The term ‘economic development’ emerged in the twentieth century (see e.g. Crafts, 1999) as it was vital for a number of countries to recover from the adverse consequences of World War II even though the process of economic growth had been observed in multiple countries since the beginning of the Industrial Revolution in the late 18th century. In order to focus thoroughly on economic development, it appears to be important to draw a line between the terms ‘development’ and ‘growth’, consequently, a brief summary of theories is given below.

The origin of theory-building on economic growth and development may be traced back to Adam Smith, who viewed total production (a measure that today would correspond to GDP) as the wealth of a nation (Hudson, 2015, Chapter 7). He described the division of labour that had occurred thanks to specialization. The benefits of establishing free markets were formulated by David Ricardo, a founder of the theory of comparative advantage.

Karl Marx's theory did not seem to explain the reasons why economic development occurs. It stated that in a classless society consumption may be communicated to the state, which produces goods. To ensure such a relationship between people and state, the society needs to be free from private property, wage labour and need. A theoretical inconsistency of Marx's theory might have been in misunderstanding the role of the markets and profits that incentivize the investment which later may lead to development of capitalist economies in the long-term. His theory solely described the adverse effects of developing business relations with labour, as workers were seen as the most disadvantaged stakeholder in the wealth production process. However, it has been shown by some researchers who have reflected upon the experience of a number of developed countries (e.g. see Hudson, 2015, p. 434; Villamil et al, 2020, p. 819) that both labour and capital benefit from growth and as a result, a country becomes more developed and technologically advanced.

Keynes, the founder of modern macroeconomics, explained why some economies were trapped in a situation in which they could not use their resources fully. He provided a practical framework for governments to make certain changes to economic activity, thus moving the economy towards a more productive state with the help of monetary and fiscal policies. The main idea was to increase spending moderately and steadily, which helped to avoid higher inflation rates and depression.

The idea of imposing moderate governmental control of the economy was introduced and developed by Milton Friedman in his research work from 1959-1963. Monetary economics gained popularity worldwide; although it cannot be referred to as a growth theory, it may create conditions for economic growth and potential development. Monetary policy appeared to be successful in practice (Hudson, 2015, chapter 7) and provided incentives to create central banks in many countries to break free from political ruling.

A model of input - output economics was brought forward by Wassily Leontief. He looked at how industries interact with one another at a given time. Economic growth accounting in the U.S. was developed thanks to the efforts of such researchers as Jorgensen, Hudson and many others. Simon Kuznets identified six stages of growth and argued that certain conditions were necessary to ensure economic growth. He highlighted that technical innovation insured economic growth. Walt Rostow created a fuller picture of the process of economic growth. He stressed that only the development of specific industries potentially determined economic growth. Solow and a great many of his followers contributed to the idea of endogenous economic growth.

The Introduction to the U.S. Economy: GDP and Economic growth (p. 1, Updated January 4, 2021) states that "...growth in economic activity is largely governed by the business cycle, which shifts from expansionary phases to contractionary phases (recessions) and to recoveries". Indeed, economic cycles often determine economic growth, and therefore, economic development, which is a target for many modern governments and policymakers. Namely, the website of the World Bank provides readers with the following information: "The World Bank promotes long-term economic development and poverty reduction by providing technical and financial support to help countries implement reforms or projects, such as building schools, providing water and electricity, fighting disease, and protecting the environment".

Some researchers (Jackson, 2009; Drews & van den Bergh, 2016; Kallis, 2018; Raworth, 2018) argue that there is little practical value of growth theory. Essentially, it can be said that the Solow model described the effects of growth on the economy but did not provide much information on the drivers of growth.

While the term 'economic growth' can mean generating more national wealth, economic development has more to do with the elimination of poverty and sharp inequality within a country. Amsden (2001, p.2) said that "economic development is a process of moving from a set of assets based on primary products, exploited by unskilled labour, to a set of assets based on knowledge products, exploited by skilled labour". Schumpeter (2003) defined economic development as an important economic problem because the circular nature of events occurring in the economy cannot be viewed as a static one, unlike it may be claimed in the static theory. Instead, he regards economic development as a dynamic circular process that is changing in time thanks to innovations and entrepreneurs who bring these innovations forward.

Cypher and Dietz suggest that nowadays the concept of economic development is understood mainly (2004, p. 68) as "sustained increases of output and income per capita over time". A group of researchers headed by Feldman (2016, p. 5) argue that "There would be no need for a consensus definition of economic development if over the previous 30 years individual and community needs had been largely satisfied." Robert Lucas, (1988, p.13) said "...we think of (economic) growth and (economic) development as distinct fields, with growth theory defined as those aspects of economic growth we have some understanding of, and development defined as those we don't." The following table 1 consolidates our attempt to summarise economic 'growth' and 'development' similarities and differences.

Table 1 - Similarities and differences between economic 'growth' and 'development'

Similarities	Differences
both can be considered as processes; both concern the issue of national wealth; both might have their prerequisites, or causes, as well as effects on society and national economy; both developed over the course of the XX century.	growth is a quantitative measure, whereas development is focused on improving the quality of life; growth mostly relies on macroeconomic conditions and market forces, whereas development examines the conditions in microeconomics that help an economy to function successfully; growth might be easier to calculate, plan and predict, whereas development requires well-designed long-term flexible strategies in various national institutions and sub-systems.

Source: Authors' own elaboration

The cause of economic growth might be understood as the development of technology and industries implementing innovative solutions. On the other hand, the reason for economic development might be higher rates of economic growth which work closely together with a flexible policy system and developing social institutions.

The result of economic growth is considered to be higher GDP per capita. The result of economic development is often referred to as higher quality of life on average for all social groups as well as greater prosperity for average economic stakeholders. In the framework of the current study, we could use both terms assuming that if tertiary education is positively correlated with economic growth, and can be attributed to changes in the gender pay gap, such long-term positive changes could result in economic development.

Guided by Nobel prize laureate Amartya Sen, Feldman et al (2016, p. 18) understand economic development "as activities that expand capacities to realize the potential of individuals, firms, or communities who contribute to the advancement of society through the responsible production of goods and services. Economic development addresses the functioning of the microeconomics of the economy. Without economic development, economic growth is limited". Indeed, it might be difficult to disagree with the researchers who defined the government to be "a vehicle for collective action" which means that the role of government goes far beyond ensuring the functioning of the markets. Therefore, economic growth might be achieved by developing certain industries, whereas "economic development requires collective action and large-scale investments with long time horizons" (ibid., p. 7).

According to the research team headed by Fagerberg (2013), economic development is associated with institutions, social capital, labour, capital mobility, income and wealth equity. A comprehensive overview of the political dimension for economic development was provided in Chang (2003), who raised a controversial question of the role of the government in the economy and also developed the institutional framework for structural changes to occur. In his article on the semantic history of the term 'economic development', Arndt (1981, p. 460) claims that Marx's term 'development' was often used as a contradiction between the developed and the "backward" countries. At the same time, historians of the British Empire like Knowles used the term to emphasize economic achievements and progress. He pointed out that (ibid.) "Whereas for Marx and Schumpeter, economic development was a historical process that happened without being consciously willed by anyone, economic development for Milner [...] was an activity, especially though not exclusively, of government. In other words, for Marx it is a society or an economic system that 'develops'; in Milner's interpretation, it is natural resources that are 'developed'". He argues that after World War II the terms 'development" and 'growth' were used interchangeably and cites 'standard textbooks' (p. 466) that defined 'development' as 'a sustained increase in per capita income'.

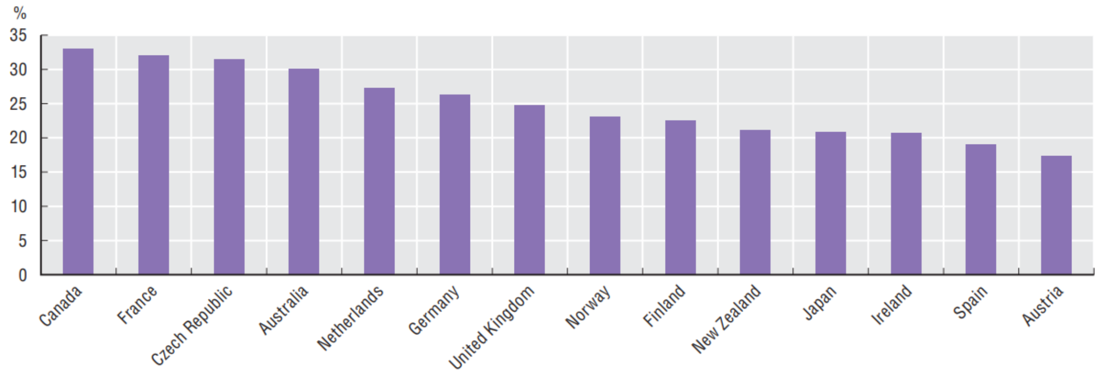
Having considered the opinion of various researchers who attempted to define the terms 'higher education' and 'economic development' from various perspectives, we may conclude that researchers tend to use them in different ways. Therefore, it may be implied that scholars describe different phenomena which can later lead to inconsistent results. This idea is in line with an opinion expressed by Goulet, who claimed that various disciplines formulated a different definition for 'development'. He wrote (1996, p. 6): "Ethics places each discipline's concept of development in a broad evaluative framework wherein development ultimately means the quality of life and the progress of societies toward values expressed in various cultures".

1.2. State of the Art

It is generally believed that the twentieth century was the first time in history when leading countries worldwide invested in mass education, so the attempts of researchers, educators and thinkers to measure the effect of education on economic development do not look unpredictable. As was demonstrated above, not only scholars but also various disciplines have their own concepts and understandings of both terms, making it even more challenging to estimate the impact of higher education on economic development.

According to Papadimitriou (2020), HEIs generally take on three major missions: education, research and development, and the third mission (Compagnucci & Spigarelli, 2020) which includes engaging institutions to work with "communities" located close to them, as well as "provide knowledge, critical reflection and discourse on the larger and more fundamental questions of society". Various large-scale studies have been published to underpin the hypothesis that universities and other HEIs play an important role in the development of their regions and help them prosper (e.g. Agasisti & Bertoletti, 2020). In many cases, more economically developed countries have more funding to direct targeted support for research and innovation. As a result, the objectives of HEIs in developed countries may often include ambitions to reach their goals for the third mission. As an example, European and U.S. universities attract foreign students, many of whom start participating in the social and economic life of the country where they chose to pursue their education (see Figure 1). On the other hand, less developed countries may not always have funds to support their HEIs in their research and development, which essentially may mean that there are fewer innovations and discoveries that might become implemented on the market and they may not potentially create more advanced working positions. One of the key challenges for HEIs in such countries, therefore, might be attracting and educating students according to the needs of the market and ensuring that economic effects from having well-educated human capital are maximized.

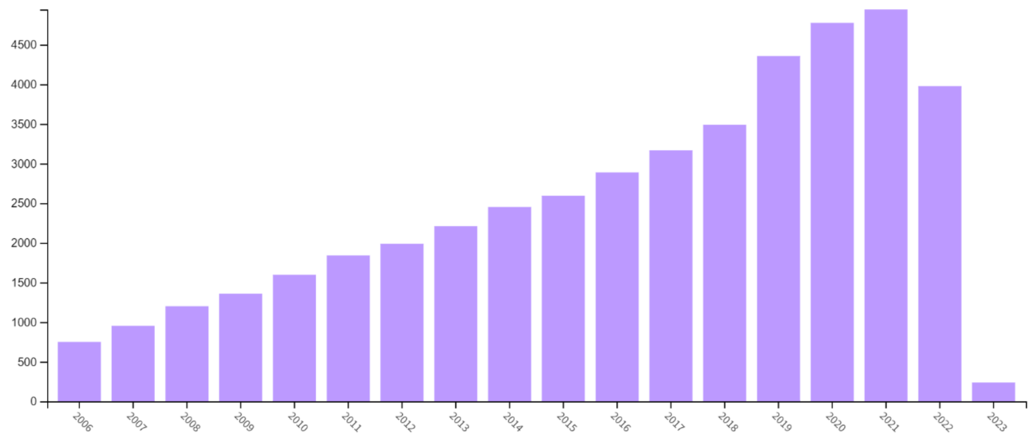
Figure 1 - Stay rates of international students in selected OECD countries in 2008



Source: OECD (2011), Education at a Glance 2011, Table C3.5, available at http://dx.doi.org/10.1787/888932464543

To conclude, universities and other HEIs are playing a major role in the development of the world as a whole as they largely contribute to creating high-skilled human capital. Their active participation is evident in multiple descriptors typically identified by researchers, including but not limited to innovations, knowledge economy, entrepreneurship practices, third mission, globalization, knowledge transfer, human resource development, university-industry collaborative lifecycle, roles of universities and HEIs in terms of their size and tuition programs, HEIs stimuli to become efficient. There is no ready-made recipe for economic development which would function successfully for any given country. However, an existing implication suggests that countries' economies tend to grow through adopting technologies as well as using their human capital effectively and efficiently. Looking at the problem of economic development from this perspective creates incentives to investigate not only the connection between how what is learned by students influences economic growth, but also the effect the skills that are used in practice by people with tertiary education have on economic development of the country. According to Clarivate's statistical analysis displaying the number of articles published with the keywords "Economic growth" and "Tertiary education" and "STEM graduates" in the field of educational studies and economics in 2006-2023 (Figure 2), there has been a growing number of research articles which intend to describe the nexus between the aspects of potential and existing human resources and economic growth (Web Of Science database, 2023).

Figure 2 - Number of publications selected from Web of Science and filtered by discipline (education and economics), document type (article) and years (2006-2023)

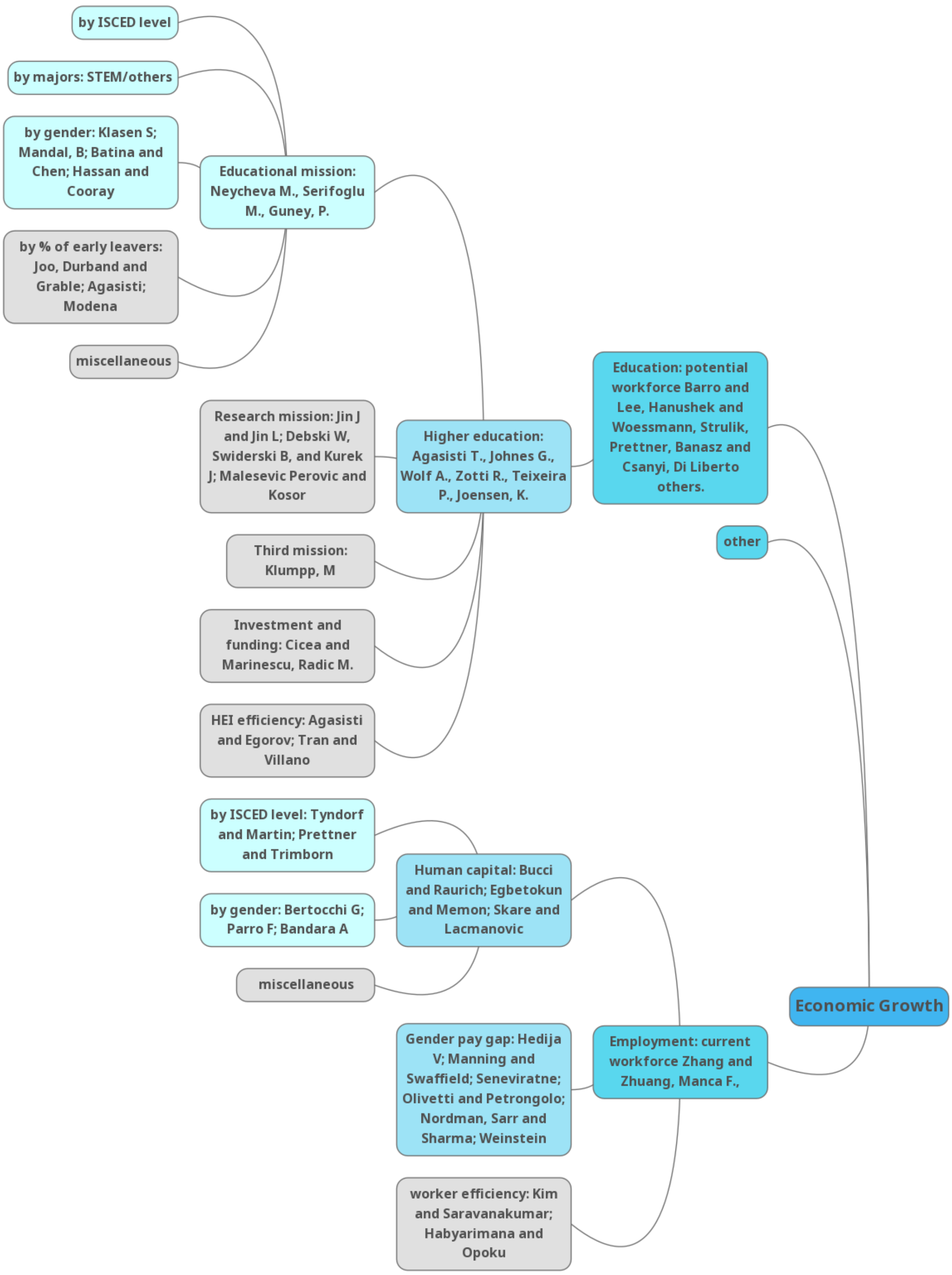


Source: Citation report www.webofscience.com from 31.1.2023 and author's own elaboration

The term 'economic growth' can be described as the increase in the ability of an economy to produce more goods and services over time and is measured in percent rate of increase of the real gross domestic product (real GDP). In 1983, the United Nations created the World Commission on Environment and Development, which highlighted the term 'sustainable development' in 1987 as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987 p. 15). Inclusive sustainable growth is a newer term from the 2000s proposed by organizations as e.g. World Bank and Asian Development Bank as a part of their development program; it outlines economic growth that creates employment opportunities and may serve well in poverty reduction. It means providing access to essential services in health and education to minorities. It is primarily about achieving equal opportunities, empowering people through education and skill development. It also encompasses a growth process that is environmentally friendly, aims for good governance and creation of a gender sensitive society. It is necessary to point out that there is no universal meaning of the term "university efficiency". Researchers focus on various aspects of how to measure the efficiency and what methods to use. It might happen due to the fact that there are a number of higher education systems in the world, culture, society, policies, history and many other factors have an impact on the development of not only the higher education venues but also HRM practices that vary from university to university. Although researchers and officials are becoming increasingly interested in performance measurement in higher education (Ruben, 1999; Broadbent, 2007), very few models of performance measurement were transferred from the for-profit sector and later adjusted to suit such public organizations. Typical approaches to human performance evaluation include audit, qualitative and quantitative methods, balanced scorecard (BSC) method, etc. However, chances are, they might not be able to deal with approaches that measure sophisticated higher education services and education outcomes. The concluding issue that might have a strong connection to efficiency of tertiary education organizations is policy, understood as both internal and external regulations for managing a higher educational organisation. Researchers Capano and Regini (2014) claimed that European universities confronted national reforms that affected teaching and research policies. Therefore, it is useful to analyse literature that describes decision-making processes at universities. Societies and governments generally expect universities to fit in current stages of economic development, play a major part in regional development, and bond with prominent for-profit and non-profit organizations, although the budget on tertiary education has been decreasing in many EU countries. That means the universities may need to seek out patterns to receive funding from joint projects and programmes as well as focus their attention on research grants and scientific progress. Tertiary educational organisations in most EU countries have been attempting to transform according to some commonly accepted rules and policies (Gornitzka et al., 2005, Lazzaretti & Tavoletti, 2006; Maassen & Olsen, 2007; Trakman, 2008). These policies should include quality check of both teaching and research and well-established funding mechanisms that should be competitive. In some European universities it was attempted to reform governance by making higher education institutions more autonomous by giving greater power to the managers, thus the decision-making process could become more independent from committee checks and voting. In particular, researchers Capano and Regini (2014) implied that little attention was given to internal changes within an organization, whereas policy makers and analysts mainly focused on implementing external policies. However, it is obvious that universities obtain different resources, face different obstacles from time to time and are managed by people who perceive and implement policies differently based on their "power resources, culture and learning abilities." Therefore, the role of people managing higher education institutions as well as their cultural background, current obstacles, interests and limitations should not be underestimated.

This chapter's central contribution to the literature on inclusive sustainable economic growth, development and human capital mainly lies in outlining a comprehensive literature review on the topic. The following figure 3 was designed based on Web of Science findings to provide the readers with a mindmap on the bibliographical overview of the aspects discussed in this paper so that the research work that studies the links between types of workforce and economic growth could be visualised. These findings present the research carried out in these aspects accordingly to define the current research gap and the understudied variables which could potentially correlate with economic growth. Light blue areas present relevant perspectives of the current research.

Figure 3 - Aspects of economic growth addressed in the thesis



Source: Author's own elaboration, the image was created in app.mindmup.com

It is visible from the figure that there is insufficient research studying the impact of bachelor, master and doctoral students on EG; it is not clear whether there is any impact of students' gender and HEI majors on growth in developed countries. The goal of the present study, therefore, is to address this research gap using panel data and BMA econometric methods to fit in the Cobb-Douglas production function. The rationale for the choice of theories and methods is described below.

(i) preceding theoretical basis of economic growth theory

It is important to find out the historical origin of the phenomenon of economic development. Spiegel (1955) defines economic growth as "change" and highlights two main sections of the study of economic development: historic-philosophic approaches and approaches of the economists. Each section includes 4 approaches. The approaches of economists described in his work include: (1) change generated by external factors, (2) change generated by the economic system, (3) changes treated incidentally, (4) engines of discovering the treatment of change.

Change generated by external factors: pre-classical and classical economists emphasized the following external factors that may be responsible for changes in demand and supply: luxury, thrift and industry, population growth, social and political institutions.

- *Luxury:* In the seventeenth century there were two contradicting views. The first group of thinkers (Child, Mun, Sandot, Law, Dutot, etc.) believed and showed in their work that the spending on luxurious goods created a large economic value. The other group endorsed an idea of simplicity, the negative effects of overspending by the rich (Petty, Barbon, Mandeville, Berkeley, etc.)
- *Thrift and Industry:* Smith developed an idea of his teacher, Hutcheson, that in order to prosper, industries must find the ways to spend less and save more.
- *Population growth:* Malthus argued that "the adoption of parsimonious habits beyond a certain point, may be accompanied by the most distressing effects at first, and by a marked depression of wealth and population afterward." He was first to develop a theory of population growth that stated in short, that once left unchecked and unattended, a population can outgrow its resources, which may result in a number of issues that may arise.
- *Social and political institutions:* Mill tried to systematize institutional factors in his book "Principles of Political Economy". Economic growth and capital accumulation, in his view, needed a better government, improvements of the public intelligence, importation of foreign arts and foreign capital.

Change generated by the economic system. Marx developed an economic model to demonstrate how the economies that passed the feudalism system could move from capitalism to communism. He did not use the term "economic growth" but operated such terms as "surplus value" (the additional cost created by workers), "surplus labour" he supposed it was additional work that was not paid by capitalists. Capital accumulation and technological improvement determine the higher level of production. Marx essentially viewed the process of economic growth and described how societies moved from primitive communism to slave-owning societies, to feudalism followed by capitalism. At the same time, according to his views, the models of socialism and communism could be developed and maintained in progressive societies only.

Schumpeter described a system in which an entrepreneur was presented as an instrument of change vital for the economic system. His theory was meant to be applied to modern and well-developed economies. The economist predicted that the development of capitalism would grow into corporatism. Due to various social reasons capitalism would transform into a different economic system (mainly, that family institutes are disappearing, "entrepreneurial spirit" is dying out as smaller, more competitive businesses merge with their bigger competitors and the switch of political power from aristocrats towards civil society occurs at the same time). This particular idea clearly shows the difference between Marx's and Schumpeter's theories. Capitalism was believed to be destroyed due to economic reasons.

Change treated incidentally. These theories are so large in number that a relatively small fraction of them is presented below. They include theories of ineffective demand (Malthus, 1836), uninterrupted growth under conditions of full employment, service industries that attempted to find a correlation between education, wage level and economic change (Clark, 1998).

Engines of discovering the treatment of change include various models. The first economic growth model was formed in 1957 by the American economist Robert Solow, followed by an innumerate quantity of research which intended to extend, improve, adjust and deepen his model through time.

(ii) the Solow aggregate production function

Solow successfully attempted to synthesize Keynesian and neoclassical theories removing some limiting hypotheses of the Harrod-Domar model, such as the inflexibility of the capital coefficient, and allowing the interchangeability of production factors. The Solow model is based on a production function with two factors: work and capital. Thus, production occurs exclusively from a combination of a certain amount of capital (means of production) and work (labour force). According to Solow, " ...this fundamental opposition of warranted and natural rates turns out in the end to flow from the crucial assumption that production takes place under conditions of fixed proportions. There is no possibility of substituting labour for capital in production. If this assumption is abandoned, the knife-edge notion of unstable balance seems to go with it" (Solow, 1956 p. 65). Thus, the quotation clearly shows that the stability of economic growth in the neoclassical model could be opposed to the Harrod-Domar model. By hypothesizing decreasing returns on factors of production, their efficient use by major countries, and a "natural" (independent of the economy) rate of population growth, the Solow model may help to predict the following:

1. Capital growth (investment) increases economic growth: as capital increases, the labour force increases its productivity.

2. Backward countries have a higher rate of economic growth than developed countries. In fact, poorer countries accumulated little capital and thus have lower diminishing returns. Therefore, the increase in capital causes them to increase production more strongly than in richer countries.

3. In view of the declining returns on factors of production, countries may reach a point where an increase in factors of production will no longer cause an increase in per capita production. However, the scientist notes that this prediction is unrealistic. In fact, countries might never reach this state due to technological progress that increases the productivity of factors. What is technical progress? According to the definition of Solow (1957, p.312), this is "… any kind of shift in the production function." It is also called "Solow residue", that is, the balance in manufacturing functions, which facilitate the growth of production per man-hour, after subtracting the contributions of factors of production (capital per man-hour and the share of capital as a factor of production in the Solow model).

Solow showed in his calculations of economic growth in the United States from 1909 to 1949 that 87.5 % of economic growth was due to technological progress (Solow, 1957 p. 320). In other words, for a scientist, economic growth in the long term follows from technological progress. However, this technological progress is exogenous in the model, that is, the model does not explain it, but considers it as a given. Thus, the Solow model appears to explain only a part of the actual economic growth.

(iii) Neoclassical models of economic growth

According to Solow (1956), the main characteristics of neoclassical models of economic growth are the following:

1. the assumption that an economy may function in conditions of perfect competition, ensuring a flexible price system and price equality on production factors and their marginal productivity;
2. no aggregate demand function because the flexible price system constantly equates the volume of aggregate demand to the volume of aggregate supply;
3. no investment function as investments equal savings at market equilibrium;
4. technology is presented by a production function with interchangeable production factors and constant economies of scale.

The founders of the neo-classical growth models are Solow and Swan. In the Solow-Swan model developed in 1956 the labour unit is fixed, therefore, the impact on output of the last unit of accumulated capital is always less than the preceding one. Production technology is represented by the Cobb-Douglas production function.

(iv) Endogenous theories of economic growth

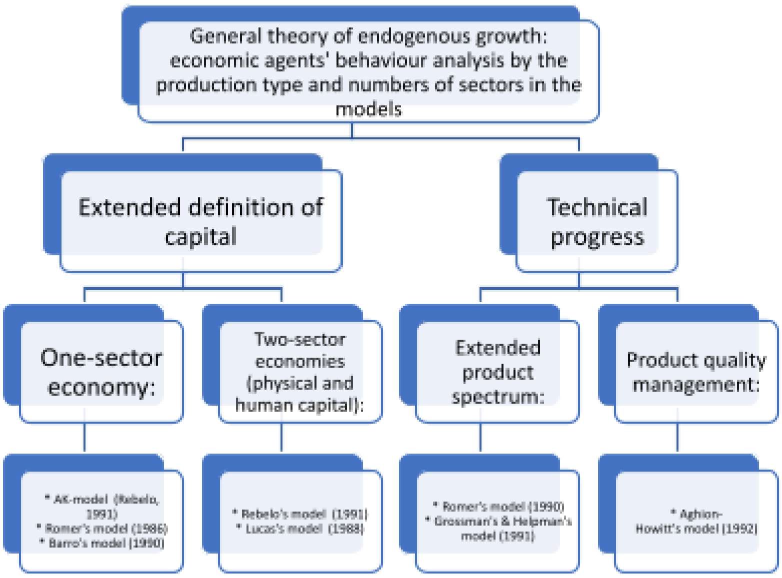
The Solow model evidently formed the basis of a large number of scientific papers and studies, both in terms of the scale of comments and in terms of many additions to the model. Thus, since the 1980s, a new trend has emerged in the development of the theory of economic growth – the theory of endogenous growth. This theory was mainly developed by Paul Romer, Robert Lucas and Robert Barro. It considered the impact of imperfect competition, the role of possible changes in the rate of profit. One of the most prominent features was that technological progress became an endogenous factor of economic growth, produced by internal causes. In other words, endogenous growth models are based on the hypothesis that economic growth itself creates technological progress. As a result, there is no longer the fatality of diminishing returns: economic growth creates technological progress that brings constant returns. The first models of endogenous growth were of the standard neoclassical type, only the concept of capital was expanded to include human components and economies of scale (Romer, 1986; Lucas, 1988). The absence of diminishing returns meant that capital accumulation could support economic growth indefinitely, even if the pace of economic growth and investment was not Pareto optimal.

Subsequent research confirmed that technological progress resulting from new ideas is the only way to avoid diminishing returns in the long run. In these models, the motivational behaviour underlying innovation depends on the prospect of monopoly profits that provide individual incentives for the costly R&D (Romer, 1990; Aghion & Howitt, 1990). The market balance does not have to be Pareto optimal. These studies also revealed several interesting implications in the field of economic policy, in particular, the rationale for allocating R&D subsidies (Barro, 1998, p. 1). According to Arrous (1999), the main elements of the structure of endogenous growth models are:

1. households: viewed as owners of production factors
2. enterprises: acquire capital and labour, produce goods, pay wages, sell goods to households and other businesses;
3. markets: businesses and households exchange their production factors

The differences between models of endogenous growth theory are in the forms of the production function and in the number of sectors considered (Arrous, 1999 p. 187). In general, the structure of the theory of endogenous growth can be represented in Figure 4 followed by a brief description.

Figure 4 – The structure of the theory of endogenous growth



Source: Authors' own elaboration

The AK-model was developed by Rebelo in 1991. The economist assumed there was a linear relationship between total output and a single factor (capital). The rate of return was determined by technology within the goods sector. Consumer goods were produced through the production of capital goods.

Romer suggests that the invention of a new product requires a certain amount of human capital, but the total supply of human capital is constant. Endogenous growth compared to previous models is generated from a different source. The economist actually assumes that the cost of inventing a new product decreases along with the accumulation of ideas in society. According to his view, in the research and development sector, knowledge was non-competitive and non-exclusive assuming that every researcher can use the discoveries of all researchers of all times.

In Barro's model, government activity is presented as one of the key factors that determine endogenous growth. The government buys part of private production and uses these purchases to offer free public services to private producers (Barro, 1995, p. 152-161). These purchases relate to non-competitive and non-exclusive products: using these products, the firm does not reduce their quantity for the rest; in addition, each firm uses the entire set of these products. Returns of the scale are considered constant. Purchases increase the marginal products of work and capital (the amount of work is constant).

Lukas model, along with the Romer model (1986), is generally considered to be the basis of the endogenous growth theory. It separates physical and human capital, as each is produced using a different technology. The production of human capital, especially education, makes intensive use of human capital as a factor of production. The accumulation of human capital differs from the creation of knowledge in technological progress. In fact, if human capital could be considered as a set of employee competencies, then the use of these competencies in one activity excludes their use in another: human capital is thus a competitive commodity. Since individuals have rights to their own competencies, human capital is also an exclusive commodity. In contrast, knowledge can be non-competitive in the sense that it can be distributed free of charge in self-managed activities; it can also be non-exclusive. In the model human capital is the only production factor in the education sector. Constant returns of scale are the source of endogenous growth in the model (Arrow et al., 1961, p. 200-203).

Grossman – Helpman models of endogenous protection state that remuneration takes the form of monopoly rents from production innovations. It means that an innovative monopoly position exists as long as the first owner has a production secret, which is formally covered by certain patent protection. Growth in these models is maintained if there is no diminishing

return, i.e. the return from new research does not decrease in relation to the cost of this research.
Aghion – Howitt model states that economic growth is driven by technological progress, which in turn is provided by competition between firms that generate and implement promising product and technological innovations. Each innovation brings a new resource product (or technology) to the market, which can be used for a more efficient production of final products.

On average, the low level of human and physical capital reduces the rate of return on new capital, which is empirically confirmed. As for human capital, there is a well-known phenomenon: human capital flows to places where it is abundant. Thus, the "spillover effect" models (e.g. Komijani & Mahmoudzadeh, 2009) suggest that countries that start out poor tend to remain poor generally because of weak incentives. Spillover effect models suggest that the accumulation of physical and human capital may not necessarily lead to growth. Growth economists are further advised to shift their focus from increasing investment in physical and human capital to technology adoption, and from improving investment to improving policy on education and entrepreneurship.

It is proposed that the degree of substitutability of capital and labour is fundamentally significant in economic development as noted in Arrow (2001) as well as Solow (1957), who produced some evidence on elasticity of substitution between capital and labour. More flexible production functions were introduced which led to understanding the differences in efficiency that vary from country to country. The scientists suggested a pattern to interpret the Leontief problem if differences in efficiency are considered neutral. The hypothesis of constant returns to scale was rejected. A few questions were raised to be answered in later research works, such as studying organisations with increasing returns to check if they are large enough to have a significant effect on prices.

In one of Solow's preceding papers on technical change the author aimed to describe a process of allocating the output per head caused by technical change from the output caused by the availability of capital per head. Having applied the regression analysis to the American data of 1909-1949, the author concluded that the aggregate production function showed diminishing returns to scale after it was corrected for technical change.

Towards the beginning of the new millennium the empirical and theoretical studies on economic growth, sustainability and prosperity moved from the study of proximate determinants to the analysis of fundamental factors segregated from the historical, geographical and cultural background across populations. There was a steep increase in the number of research papers dedicated to analysing factors on productivity and production per capita. A large number of studies were devoted to the development and progress of post-world war economies, African and South American countries, India and China. From the historical point of view, technology and productivity both are considered to be very important factors by Comin el al. (2010), Olsson and Hibbs (2005), Ashraf and Galor (2011). It is possible to distinguish specific factors: geographical location, populations and genetic distance (genealogical links). Comin et al. found that peculiarly, those countries that used most functional technologies in 1000 B.C. are the ones applying most innovative technologies today (data corrected for the changing ancestry). Long-term historical factors do predict current income per capita according to Putterman and Weil (2010), Comin, et al., (2010). If we correct geographical and historical data to populations' changing ancestry, it helps to understand the shifts of capital and technological know-how.

The research work led by Cerra and Saxena (2008) in the 2000s questioned the recovery of countries after severe political and financial shocks in the sense that output losses were reversed. Having used panel data in their analysis, the authors concluded that permanent output losses occur persistently over a large set of developed and developing countries. Impulse response functions developed by the authors show that at the end of a ten-year period following a financial and/or a political regression only 1% of the deepest output loss is regained. To understand and explain this phenomenon the authors suggest developing a few theoretical models with persistent propagation mechanisms.

The joint work of the University of Cambridge and Asian Development Bank (Felipe & McCombie, 2005) demonstrated the revision and extension to some problems on the process of the production function estimation. The rationale was based on the work of Brown (1969) and further developed by Shaikh (1974), Simon (1979b). It is particularly sceptical on the use of the value data (value added or gross output) as it leads to evident problems while estimating the aggregate production function. Coefficients estimated by a Cobb-Douglas function are claimed to reflect income identity that is used to draw the data. Having used cross-section data, the researchers clarified that while estimating the aggregate production function either the aggregation conditions are violated, or the underlying relations do not belong to the Cobb-Douglas functional relations or there might not be any neoclassical production function at all. Therefore, the authors urge us to pay special attention to the results of regressions that estimate an aggregate production function. They admit that the previous research works that incorporated the aggregate production function need to be reviewed and revisited with criticism as the numbers received might have been misleading. However, it is still not clear what to put in the place of the aggregate production function.

As HEIs play a major role in forming human capital in EU Member States, it might be important to define the term ‘human capital’ to ensure its coherent use in the following chapters. Human capital was defined by the OECD as “the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being” (OECD, 2001). The components of what now is referred to as ‘human capital’ could be traced back to the works of Petty and Smith who both recognized an important role the abilities of individuals play in the economy.

Understanding and estimating human capital may be particularly interesting to policy makers. Therefore, it is important to highlight a few approaches to measure it. There are two basic approaches on how to derive a monetary measure: direct and indirect approach. In the framework of the indirect approach it is assumed that the discounted value of benefits delivered by capital stock is equal to the capital asset’s current value. It is possible to think of the phenomenon of sustainable development as a chain of benefits for the society in the form of future consumption goods produced today. In that case, human capital is the residual estimate of capital stock for which no monetary value is observed. It can be measured as the difference between the current discounted value of consumption and available monetary value of such capital goods as economic capital, market value of natural resource assets, etc. This approach has been widely used by banks and various NGOs as the statistical information used is widely available in the majority of countries. Nevertheless, to date the residual approach cannot measure non-market benefits of capital stocks. It also cannot explain what factors are possibly driving changes in specific regions over time.

To calculate human capital using the direct approach, it is necessary to work with specific components, such as cost, income, indicators, etc. Due to the fact it was used by both economists and mathematicians, several methods used form large measurement systems: parametric methods that use mainly econometric estimations, non-parametric methods which proved to be more popular as they are based directly on the official data available. It is further broken down into a cost-based approach (Shultz, 1961; Kendrick, 1976; Eisner, 1985), an income-based approach (Weisbrod, 1961; Graham & Webb, 1979; Jorgenson and Fraumeni, 1989, 1992a, 1992b) and an indicators-based approach (Ederer et al, 2007, 2011; various issues of Education at a Glance). None of the approaches above appeared to be perfect, however, the income-based lifetime income approach was chosen to become a preferred methodology for the OECD human capital project.

This now widespread approach measures the value of the total stock of human capital of population as the total discounted present value of the expected future labour incomes that could be received by a given society over the lifetime of the people currently living. This measurement puts together a vast number of factors that determine the stock of human capital of all individuals living in a country: these factors include the expected life-span of population, education level and people's skills and experiences.

After the initial use of the term 'skilled labour' there has been a lot of interest and research done to determine the relationship among the following terms: poverty, education (primary, secondary and tertiary), earning potential, well-being, quality of life, long-lasting growth, sustainable economic growth, etc. This thesis mentions only a few of such studies.

Mincer (1958) and Becker (1962, 1975) who expressed the ideas of determining human capital, had seemingly different views on skilled labour as indeed there are a number of factors that could influence the formation and effective use of human capital. The scientists who later used the approaches of endogenous theory, developed their ideas and often ended up creating their own model of human capital, where an output was defined as human capital. Mankiw, Romer, and Weil (1992), Romer, (1989, 1990), Uzawa (1965), and Lucas (1988) used production function model brought about by Solow to create their own models to prove an idea that people are a crucial resource well-worth being invested into.

Other scientific studies followed. Weiss (1995) demonstrated a clear picture of social expenditures in developing countries – the majority of governmental investments were made into primary education. It was shown that people with higher education level and work experience tend to earn more than others. Two years later UNESCO (1997) published research results connecting poverty to education: better educated individuals have more opportunities to enhance their quality of life.

There are economists whose research did not encounter a positive correlation between the rate of economic growth and education investments. To name just a few, in 2010 Nurudeen and Usman published a research paper in 2010 that suggested a negative impact of education expenditures on growth. Benhabib and Spiegel (1994) stated there is no significant correlation between education investments and economic growth. Pritchett (2001) found no significant correlation between schooling and growth.

In 2015 it was claimed that no nation could develop without investments in education (Rehman et al.). The researchers concluded that the increased productivity per capita is the result of the way education reduced poverty. The study showed clear linkages between education and economic growth.

A decade earlier another group of labour economists (e.g. Wolf, 2004) looked at the relationship between higher education level and the labour productivity index. The research demonstrated a high correlation between university enrolment in STEM majors (mainly scientific and technological matters) and labour productivity growth. It was demonstrated that the opportunities that are created within the country strongly depend on the number of students majoring in STEM subjects.

A major research was carried out by a research team headed by Gennaioli (2013). The researchers investigated the influences of culture, institutions, geography, location of natural resources on human capital. They looked over more than 1,500 regions and declared that "regional education influences regional development" (p. 152). It was explained that a Cobb-Douglas production function would not be suitable to describe these data due to its specification. As an alternative, a Lucas-Lucas model was used. It included three features: migration of labour across regions in the same country, the consolidation of talent between work and entrepreneurship and human capital externalities. The first thing observed was that private returns to entrepreneurial education are large, although private returns to worker education are small. The second conclusion drawn from the research is that economic development is seen in regions that gather educated business people conducting profitable businesses. It is therefore crucial to pay special attention to entrepreneurial education to promote economic growth.

An extensive research was done by Henderson, Storeygard and Weil (2012) who questioned the statistical measures of GDP especially in developing countries. It was claimed to be not so reliable due to the fact that in developing countries only a small share of businesses falls into the formal sector. Their governments may have weaker statistical institutes, may not publish statistics consistently and it is particularly difficult to estimate economic integration within a country. The extended branch of research papers dedicate their studies to establishing new alternative methods of measuring economic growth and development. The authors used a different proxy which is lights seen from outer space. It was demonstrated that satellite night lights data gives a detailed picture of current economic growth processes.

However, in a recent research paper of 2020 headed by Lee, it is argued that electrification alone cannot be a real cause for economic development in the world's poorest economies. It is said that providing the poorest citizens with electricity is insufficient for that region to develop. It might be therefore important for economists, researchers and policymakers to find out which households/areas/regions are most likely to benefit from electrification programs to promote the opportunities for households to take the most of electricity connection by implementing incentives that motivate people to make ‘complementary investments’ and ‘exploit new business opportunities’. The risks are that the gap between the wealthier households and the poorest ones in these regions would enlarge creating clear obstacles to ensure economic growth (social tension, inequality, etc).

If we look at the comparisons available on developed and developing countries, it was stated (Becker et al., 1990) that education and other human capital have higher rates of return in developed than developing countries. Consumption growth and fertility are two factors for higher/lower rates of return on physical capital in developed countries. We could imply that countries where human capital is scarce could opt for larger families with lower investments in each member, and vice versa countries with a rising rate of human capital may choose to have fewer family members with higher investments in each individual. Both options lead to stable economic states.

Panel regression estimates the growth effect of education over the period of 30 years (1965-1995) in 100 countries in the study carried out by Barro (1995, 1998, 2001). Growth is significantly related to years of school attainment for males, however, it is claimed to be insignificant for females (secondary and higher education levels). This result depicts a possibility that well-educated females are not utilized in the most effective way in a number of countries. It is said that “scores on science tests have a particularly strong positive relation with growth” (2001, p. 16). Although it is possible to determine the quality of education by evaluating students' tests, it might not be the best option anymore as both the subjects and the testing systems vary across countries.

Researchers Fedderke and Luiz (2007) voice a concern that a great number of input factors in the model which calculates human capital formation create multiple correlation bonds not only between the output and the input, but also amongst the factors themselves. Typically, the indicators are political, economic, social and institutional. The study of South African data suggests that because these input factors are interwoven, human capital responds to economic growth and that „unleashes social and political change both through choice and through conflict" (p. 1039).

(v) empirical research data published over the last two decades

Economic growth is closely intertwined with the political and social system in a country. Sokoloff and Engerman (2000) provided their own argument on why both Canada and the USA developed at a quicker pace than other countries in the Americas. They suggested a pattern in which elites in these two countries recognized the potential of disadvantaged social groups and the institutional changes that followed resulted in sustainable growth rate from the beginning of the eighteenth century. In other works (see e.g. Gradstein, 2008) it is concluded that the mutual feedback between the political and social system (income inequality, institutions) influences economic growth. The good command of institutions could be an advantage when the underlying economic structure corresponds to political and social changes.

Inclusive growth happens to countries that typically do not fail to invest into the public sector. It is also highly crucial to organise structural flexibility and mobility of the resources in the economy. Meaningful institutional reforms and complementary conditions are listed last but not least in academic literature dedicated to economic growth (e.g. Stern School of Business, & New York University, 2016).

There is extensive literature that analyses economic growth in China over recent decades. Specifically, it is suggested that technical progress and productivity are the main drivers of economic growth in three sectors: agriculture, manufacturing and services (Wu et al., 2017). Policy, political systems and economic growth are analysed in the research work of Doucouliagos and Ulubaşoğlu (2008), who proved in their meta-analysis that the net effect of democracy on economic growth is not negative and the direct effect of economic freedom is clearly visible. Neanidis (2010) measured direct and indirect effects between fertility, humanitarian aid and economic growth and suggested that "humanitarian aid has on average a zero impact on both the rate of fertility and the rate of output growth, implying that the two conflicting effects of humanitarian aid outlined by our theoretical illustration fully offset each other. The sole exception applies to countries characterized by high fertility rates, where humanitarian aid is shown to raise fertility" (p. 52). The authors acknowledge the conflicting effects of humanitarian aid and suggest the need to consider other types of aid and study their potential positive impacts. The article also emphasizes the importance of robustness in empirical analysis and underscores the role of improved living conditions in shaping population dynamics and economic growth.

There is research work performed measuring education effects on economic development. One of the studies (Ramirez et al. 2006) concludes from their analysis of a small set of countries with data available 1970-2000 that countries that invested in education of students in mathematics and sciences tend to grow more rapidly than the rest in the group.

In his book, Löning (2004) performed analysis on possible variations between human capital, productivity, and growth in Latin-American countries and concluded that Guatemala, El Salvador and Costa Rica experienced faster growth rates in the 1990s rather than in 1980s. Investments and enhancements of primary and secondary education along with quality labour caused notable changes in these countries' GDPs.

Having described the state of the art in labour economics, growth economics and economics of education, we could conclude that there is a gap in research that covers the transition of graduates with tertiary degrees to the labour market. Specifically, we are interested to find out which university majors impact growth, what could happen if the number of STEM female graduates increases and how it would impact economic growth and gender pay gap of the countries in the European Union. An attempt to answer these questions is pursued in the following pages of this thesis.

Chapter 2 Methodology

It may be derived from the theoretical chapter that the interest in endogenous models of economic growth has not been exhausted. Economists are engaged in intensive research on the creation of new or improvement of already existing models.

Research of the causes, nature and prerequisites of economic growth is guided in part by the global economic theory and literature that explore political, legal and other institutional conditions, i.e. framework in which economic growth occurs. Research in this area shows that the institutional framework has a significant impact on the efficiency of the country's economy. It has a distinctive impact on product per capita growth rate. Private property, robust legal framework of economic activity, market allocation of resources, political freedom and other attributes are viewed as the basic assumptions of growth (Mach, 2001).

In the past few decades, the issue of the human capital investment effects on economic growth has been given more attention. This trend is explained by the findings that apart from production growth there are quite a few intangible factors that are able to determine quantitative dynamics and qualitative nature of economic development. The influence of capital investments, the quality of human resources and the use of natural resources undoubtedly have a clear impact on sustainable development. In the past, the concept of human capital was mentioned in the works of William Petty and Adam Smith. However, today there are a few endogenous methods and models to determine the degree of influence on economic dynamics, the effects are difficult to grasp. Therefore, it might be challenging for educational venues and government officials to develop, adjust and manage the educational system according to the needs of the market. In order to measure and evaluate the extent to which higher education (human capital) may influence economic development, the Uzawa-Lucas model is modified. As it was mentioned in chapter 1, this model defines human capital separately for each economic sector, in contrast to other endogenous growth models. For that reason, this model is selected for further modifications: a measure of the skills and education is added to the sector responsible for human capital.

2.1. Uzawa-Lucas model modification

In his article, Uzawa (1961, p.117) viewed the “neoclassical growth model with neutralities in Harrod’s sense” (Harrod, 1939) meaning neutral level of technological development, and provided evidence that the equilibrium in this model could be stable. The following function 1 was analysed:

$$Y = F[K(t), Au(t), L(t)] \quad (1)$$

in which K and L are referred to capital and labour in the time period t, and Au(t) stands for the rate of increase in labour efficiency. The factors affecting labour productivity were education, health, public goods, etc. The influence of these factors reflects the main scope of the second, educational sector of the economy in this model, which was presented in the form of the equation 2 in Uzawa's article in 1965:

$$\dot{A}_{u^{(t)}}/A_{u^{(t)}} = \varphi[\frac{L_E(t)}{L(t)}] \quad (2)$$

where Au(t) stands for the increase of labour productivity at time t. Therefore, the element $\dot{A}_{u^{(t)}}/A_{u^{(t)}}$ represents labour productivity growth rate. Following this idea with the help of the Pontryagin maximum principle, Uzawa analysed the dynamics of the model, provided that the consumption level is maximized. Due to the fact that both articles were mostly theoretical, the definition of human capital was not explained in detail. In 1988, Lucas published an article that contained a modified Uzawa model which defined and explored the role of human capital. The production function was defined as follows (3):

$$Y(t) = AK(t^{\beta})[b_L(t)h(t)\,L(t)]^{1-\beta}h_a(t)^{\xi} \quad (3)$$

where A is the technological level, which is a constant; b_L(t) – in Lucas' interpretation, the proportion of time that a worker devotes to the production process; h (t) is the specific level of human capital; $h_a(t)^{\xi}$– the external effect of human capital. The second sector (education) in charge of human capital accumulation was presented as (4):

$$\dot{h}(t) = h(t)^{\xi}G(1 - b_L(t)) \quad (4)$$

where 1 – b_L(t) is the time that an employee uses to accumulate human capital; the function G (1 – b_L(t)) has a linear form, and the parameter ʒ reflects the degree of influence of the existing accumulated human capital on its increment. In his analysis, Lucas assumed that ʒ=1. Like Uzawa, he further examined the dynamics of this system using the optimal control theory.

To determine the optimal trajectory of the system development, the methods of optimal control theory may be used in order to maximize the utility function with specific constraints. It is the maximum utility that is the most preferable option for the development of the economic system. To modify the Uzawa-Lucas model, suppose a two-sector model of economic growth of the following type is selected (5) and (6):

$$Y(t) = A(t)K(t)^{\alpha}HE(t)^{\beta}[b(t)H(t)]^{1-\alpha-\beta}, \quad (5)$$

$$H(t)^{\cdot} = H(t)z(1 - b(t)) - \delta_{H}H(t), \quad (6)$$

where $Y(t)$ stands for the GDP; $A(t)$ is the level of technological progress; $HE(t)$ is higher education; $H(t)$ is the accumulated human capital; δ_{H} is the level of depreciation of human capital; $b(t)$ the share of human capital employed in production; z is the efficiency coefficient of human capital accumulation.

The utility received by agents from consumption is provided by the following formula (7):

$$u(c) = \frac{c^{1-\theta}-1}{1-\theta}, \quad (7)$$

where θ is the Arrow-Pratt risk aversion coefficient defined as (8):

$$-\frac{u''(c)c}{u'(c)} = \theta, \quad (8)$$

Subsequently, the elasticity of intertemporal substitution will also be a constant value equal to $1/\theta$. Considering the assumption that economic agents maximize utility, it is possible to acquire the following formula (9) which can be described as:

$$m \int_{0}^{\infty} \frac{c^{1-\theta}-1}{1-\theta} e^{-\rho t} dt \quad (9)$$

where p represents the norm of time preference. To solve the problem of maximizing the utility, suppose we consider the situation in which decisions are made centrally, i.e. in this case, a certain social planner is engaged in the optimization process. It may act favourably to the interest of the stakeholders and attempts to maximize the utility. This problem is described below. The products of the first sector can be used for consumption, investments in fixed assets and investments in the development of new HE systems. Thus, the restriction takes the form of the following formula (10):

$$c + i_K + i_E = y = Ak^{\alpha}e^{\beta}(bh)^{1-\alpha-\beta} \qquad (10)$$

where c stands for consumption, i_K is specific investment in fixed assets; and i_E is a specific investment in higher education. The dynamics of fixed capital and natural resources are described by the following two equations (11) and (12):

$$k^{\cdot} = i_K - \delta_K K \quad (11) \qquad e^{\cdot} = \eta i_E^{\gamma} - \delta_E E \quad (12)$$

where δ_K is the rate of retirement of fixed capital; δ_E is the rate at which people acquire higher education degrees; γ and n are parameters reflecting the availability and possibility of developing new resources in the economy. To solve the optimization problem using formulas (5) and (9)-(12), it is necessary to solve the Hamiltonian presented in the form (13):

$$H^p = \frac{c^{1-\theta}-1}{1-\theta} + \lambda_1\left[Ak^{\alpha}E^{\beta}(bh)^{1-\alpha-\beta} - c - i_E - \delta_K k\right] + \lambda_2\left[hz(1-b) - \delta_H h\right] + \lambda_3\left(\eta i_E^{\gamma} - \delta_E E\right) \qquad (13)$$

where H^p means that in this case scheduler problem is solved, and $\lambda_1, \lambda_2, and\, \lambda_3$ are implicit prices for changes in state variables, which in this case are k, h and e, i.e. a change in utility at time t which occurs as a result of changes in state variables also in time t. The control variables in this case are c, b and i_E^{γ}. The maximization conditions are represented by the following equalities (14):

$$H_c^p = 0, H_b^p = 0, H_{i_e}^p = 0;\ \lambda^{\cdot}_1 = \rho\lambda_1 - H_k^p;\ \lambda_2^{\cdot} = \rho\lambda_2 - H_h^p;\ \lambda_3^{\cdot} = \rho\lambda_3 - H_e^p, \qquad (14)$$

where H_j^p is the partial derivative of j. Proceeding from (13) considering conditions (14), we obtain the following identities (15)-(20):

$$c^{-\theta} - \lambda_1 = 0; \quad (15)$$
$$\lambda_1(1-\alpha-\beta)\frac{y}{b} - \lambda_2 hz = 0; \quad (16)$$
$$-\lambda_1 + \lambda_3\gamma\eta i_E^{\gamma-1} = 0; \quad (17)$$
$$\lambda_1^{\cdot} = \rho\lambda_1 - \lambda_1\left(\alpha\frac{y}{k} - \delta_K\right); \quad (18)$$
$$\lambda_2^{\cdot} = \rho\lambda_2 - \lambda_1(1-\alpha-\beta)\frac{y}{h} - \lambda_2\left[z(1-b) - \delta_H\right]; \quad (19)$$
$$\lambda_3^{\cdot} = \rho\lambda_3 - \lambda_1\beta\frac{y}{e} + \lambda_3\delta_E \quad (20)$$

The conditions of transversality which enable mathematicians to derive one single optimal path among those which satisfy the Euler equation**,** have the form (21)

$$\lim_{t\to\infty}\left[e^{-\rho t}\lambda_1(t)k(t)\right]=0,\quad \lim_{t\to\infty}\left[e^{-\rho t}\lambda_2(t)h(t)\right]=0,\quad \lim_{t\to\infty}\left[e^{-\rho t}\lambda_3(t)s(t)\right]=0. \tag{21}$$

During the following step, a decentralized decision-making process is analysed, i.e. economic agents act independently to maximize the resulting utility. The budget constraint of a single agent looks like this (22):

$$c + i_K + i_e = w(bh) + rk + qe, \tag{22}$$

where w is the wage rate; r is the rental price of capital; q is the price of an individual's education. The dynamics of capital and non-renewable resources have a similar form to (11) and (12). To maximize the utility of (8), we define the Hamiltonian (17):

$$H^d = \frac{c^{1-\theta}-1}{1-\theta} + \lambda_1\left[w(bh) + rk + qs - c - i_S - \delta_K k\right] +$$
$$+ \lambda_2\left[hz(1-b) - \delta_H h\right] + \lambda_3\left(\eta i_S^{\gamma} - \delta_S s\right) \tag{23}$$

where H^d means that in this case a decentralized problem is solved. The state and control variables are the same as in the case of a centralized decision-making process. Based on the maximization conditions (13), we obtain the following identities (24)-(29):

$$c^{-\theta} - \lambda_1 = 0 \quad (24)$$
$$\lambda_1 wh - \lambda_2 hz = 0; \ (25)$$
$$-\lambda_1 + \lambda_3\gamma\eta i_E^{\gamma-1} = 0 \ (26)$$
$$\lambda_1^{\cdot} = \rho\lambda_1 - \lambda_1\left(r - \delta_K\right); \ (27)$$
$$\lambda_2 = \rho\lambda_2^{\cdot} - \lambda_1 wb - \lambda_2\left[z(1-b) - \delta_H\right]; \ (28)$$
$$\lambda_3^{\cdot} = \rho\lambda_3 - \lambda_1 q + \lambda_3\delta_E \ (29)$$

The conditions of transversality are similar to the set of equations (21). Considering the fact that the conditions for maximizing profits for a business in a competitive economy include equality of the marginal productivity of the factor of production and its price, the wage rate and rental prices can be determined as follows (30):

$$r = y_k = \alpha\frac{y}{k};\ q = y_E = \beta\frac{y}{E};\ w = y_{bh} = (1-\alpha-\beta)\frac{y}{bh}, \tag{30}$$

where y_i is the partial derivative of the production function with respect to a certain production factor. By substituting (30) into (24)-(29) the identities identical to expressions (15)-(20) may be obtained. Thus, it can be suggested that the optimality conditions for a centralized decision in this particular case appear to look identical to the optimality conditions for decentralized decision-making. It is natural to imply that it may not always be the case. For example, if the model considered the factor of external influence from human capital $h_a(t)^{\xi}$, which is initially present in Lucas (1988), the conditions would be different, which can be explained by the fact that this external factor would not be considered in decentralized decision-making. This situation is described in Mattana (2004).

In the following part, the dynamics of macroeconomic variables on the balanced growth path (BGP) is analysed. On BGP, the growth rates y, k, e, h, c, i_K and i_E are constants. An expression (31) for the capital growth rate can be obtained from (11):

$$g_k = \frac{k^{\cdot}}{k} = \frac{i_K}{k} - \delta_K \quad (31)$$

Considering that δ_K is a constant and that the growth rate of capital on BGP is a constant value, it can be suggested that the ratio of investments in fixed capital to fixed capital is a constant value on BGP, i.e. the growth rate of y is equal to the growth rate of fixed capital. By logarithmizing and differentiating (17), the consumption growth rate (g_c) is obtained:

$$g_c = \frac{c^{\cdot}}{c} = -\frac{1}{\theta}\frac{\lambda_1^{\cdot}}{\lambda_1} \quad (32)$$

Using (32) and (18) the following expression can be obtained:

$$\frac{c^{\cdot}}{c} = -\frac{\rho}{\theta} + \frac{\alpha}{\theta}\cdot\frac{y}{k} - \frac{\delta_K}{\theta} \quad (33)$$

Considering that the parameters ρ, θ, α and δ_K are constants, and the growth rate of specific consumption is a constant value on BGP, it is suggested that the ratio of output to capital on BGP should be constant, which means that the growth rate of output on BGP is equal to the growth rate of fixed capital. Using a logarithm and taking a derivative of (17), the growth rate of investments in education is obtained (g_E):

$$g_{i_E} = \frac{i^{\cdot}_E}{i_E} = \frac{1}{(\gamma-1)}\left(\frac{\lambda^{\cdot}_1}{\lambda_1} - \frac{\lambda_3^{\cdot}}{\lambda_3}\right) \quad (34)$$

As determined from (32), the growth rate of λ_1 on BGP is a constant (as the growth rate of consumption is a constant value on BGP) and the growth rate of investments in education on BGP is also a constant, based on (34) it can be concluded that the growth rate of λ_3 is also a constant value on BGP. Using the identities (17) and (20), the following formula (35) is obtained:

$$i_e^{\gamma-1} = \frac{\left(\rho+\delta_e-\frac{\lambda_3^{\cdot}}{\lambda_3}\right)e}{\beta y\gamma\eta} \quad (35)$$

Having taken a logarithm and after differentiating (35) and considering that the growth rate λ_3 is a constant value on BGP, the following identity is acquired (36):

$$(\gamma - 1)\frac{i_s^{\cdot}}{i_s} = \frac{s^{\cdot}}{s} - \frac{y^{\cdot}}{y}. \quad (36)$$

Based on (12), we obtain an expression for the growth rate of the share of human capital with higher education (g_{HE})

$$g_{HE} = \frac{e^{\cdot}}{e} = \frac{\eta i_E^{\gamma}}{e} - \delta_E \quad (37)$$

As the growth rate of the share of human capital with higher education on BGP is a constant, then, based on (37), the growth rate of the investment function f(i)= i_E^{γ} should equal to the growth rate of the share of human capital with higher education:

$$\frac{f(i)^{\cdot}}{f(i)} = \frac{\gamma i_E^{\gamma-1} \cdot i_E^{\cdot}}{i_E^{\gamma}} = \gamma\frac{i_E^{\cdot}}{i_E} = \frac{e^{\cdot}}{e} \quad (38)$$

From (36) and (38) the growth rate of investments in HE on BGP is equal to the growth rate of output and, as a consequence, the growth rate of capital. Using (10) and (11), we obtain the identity for the rate of capital growth:

$$\frac{k^{\cdot}}{k} = \frac{y}{k} - \frac{c}{k} - \frac{i_E}{k} - \delta_K \quad (39)$$

As it has already been shown above, the rate of output growth on BGP is equal to the rate of fixed capital growth and the rate of investment growth into human capital with higher education. Due to the fact that the rate of fixed capital growth on BGP is a constant, it can be asserted that the ratio of consumption to fixed capital is a constant on BGP, i.e. the rate of consumption growth is equal to the rate of growth of fixed capital. Logarithmizing and differentiating the production function (3), given that the share of human capital involved in the production sector in the BGP is a constant, the identity for the rate of output growth is obtained in (40):

$$\frac{\dot{y}}{y} = \alpha\frac{\dot{k}}{k} + \beta\frac{\dot{s}}{s} + (1 - \alpha - \beta)\frac{\dot{h}}{h} \quad (40)$$

Considering the ratio of the growth rates of investments in HE and the growth rates of the share of human capital with higher education, as well as the equality on the BGP of the growth rates of output, capital and investment in HE, the growth rate of human capital (g_h) is determined (41):

$$g_h = \frac{\dot{h}}{h} = \psi \cdot \frac{\dot{y}}{y} \quad (41)$$

where $\psi = \left(\frac{1-\alpha-\beta\gamma}{1-\alpha-\beta}\right)$.

Considering the value of $\gamma<1$ (if we assume a decreasing marginal return on investment), we can conclude that the growth rate of human capital in BGP is slightly higher than the growth rate of the output. The growth rate of human capital in absolute terms based on (4) is then determined by the formula (42):

$$\frac{\dot{h}}{h} = z(1 - b) - \delta_H \quad (42)$$

Thus, the ratio of the growth rates of the main macroeconomic indicators and their absolute values may look as the following expression (43):

$$\frac{\dot{y}}{y} = \frac{\dot{k}}{k} = \frac{\dot{c}}{c} = \frac{\dot{i_K}}{i_K} = \frac{\dot{i_E}}{i_E} = \frac{1}{\gamma}\frac{\dot{e}}{e} = \frac{1}{\psi}\frac{\dot{h}}{h} = \frac{\left[z(1-b)-\delta_H\right]}{\psi} \quad (43)$$

Similarly, taking g for the growth rate of output on BGP, we may obtain (44):

$$g = g_y = g_c = g_{i_K} = g_{i_e} = \frac{g_e}{\gamma} = \frac{g_h}{\psi} = \frac{\left[z(1-b)-\delta_H\right]}{\psi} \quad (44)$$

On a balanced trajectory we could now introduce the following variable (45):

$$\tilde{x} = \frac{x}{e^{g_x t}} \quad (45)$$

where x stands for any macroeconomic variable. A similar approach was used in Cavalcanti et al. (2011). In this case, the production function (3) can be written as follows (46):

$$\tilde{y} = A\tilde{k}^{\alpha}\tilde{e}^{\beta}(\tilde{b}\tilde{h})^{1-\alpha-\beta} \quad (46)$$

Considering the fact that $g_b = 0$, equation (46) may look like the following formula (47):

$$\tilde{y} = A\tilde{k}^{\alpha}\tilde{e}^{\beta}(b\tilde{h})^{1-\alpha-\beta} \quad (47)$$

Using (45) and (11) we obtain:

$$\tilde{k} = \frac{i_K}{(\delta_K+g)e^{gt}} \quad (48)$$

Substituting (48) by (47) and (46), we take the logarithm of the production function:

$$ln\tilde{y} = lnA + \alpha\left[lni_K - ln\left(\delta_K + g\right) - gt\right] + \beta ln\tilde{e} + (1 - \alpha - \beta)(lnb + ln\tilde{h}).$$

Using (45), we then obtain:

$$\ln ln\, y = \ln ln\, A - \alpha \ln ln\left(\delta_K + g\right) + (1 - \alpha - \beta) \ln ln\, b + \quad (49)$$
$$+ \alpha \ln ln\, i_K + \beta \ln ln\, e + (1 - \alpha - \beta) \ln ln\, h$$

In fact, turning to the growth rate, we may obtain the following expression for the growth rate of the specific output on a balanced trajectory (50) using the equation (49):

$$\frac{\dot{y}}{y} = \alpha\frac{\dot{i_K}}{i_K} + \beta\frac{\dot{e}}{e} + (1 - \alpha - \beta)\frac{\dot{h}}{h} \qquad (50)$$

This expression corresponds to the previously obtained equality of the rates of capital growth and investments in fixed assets. The transition to the growth rate of investments in fixed assets was made with the aim of a more convenient possible empirical assessment of this model, since not all countries keep records of the dynamics of fixed capital, and the use of the continuous inventory method (perpetual inventory system) or another approach to determining the dynamics of fixed capital may to some extent distort the obtained estimates.

As a result, the growth rates of the main macroeconomic indicators characteristic of the Uzawa-Lukas model were received. Using the expression of the identity (43), the following values of the growth rates on BGP are obtained (51)-(53):

$$\frac{\dot{y}}{y} = \frac{\dot{k}}{k} = \frac{\dot{c}}{c} = \frac{\dot{i_K}}{i_K} = \frac{\dot{i_E}}{i_E} = \frac{z-\delta_H}{\psi} - \frac{\left(z-\delta_H\right)(1-\theta)(1-\alpha-\beta)-\rho(1-\alpha-\beta\cdot\gamma)}{\psi[\beta(\gamma-1+\theta)+\theta(\alpha-1)]} \quad (51)$$

$$\frac{\dot{e}}{e} = \frac{\gamma\left(z-\delta_H\right)}{\psi} - \frac{\gamma\left[\left(z-\delta_H\right)(1-\theta)(1-\alpha-\beta)-\rho(1-\alpha-\beta\cdot\gamma)\right]}{\psi[\beta(\gamma-1+\theta)+\theta(\alpha-1)]} \quad (52)$$

$$\frac{\dot{h}}{h} = z - \delta_H - \frac{\left(z-\delta_H\right)(1-\theta)(1-\alpha-\beta)-\rho(1-\alpha-\beta\cdot\gamma)}{\beta(\gamma-1+\theta)+\theta(\alpha-1)} \quad (53)$$

Thus, the modification of the Uzawa-Lukas model may suggest important implications for the analysis of the economic system, as it describes the equilibrium growth rates of the main macroeconomic indicators in a model where production factors do not consist solely of labour and capital, but also include human capital and higher education. Undoubtedly, this complicates the verification process of the model owing to the fact that more statistical information might be required. Capturing country-specific exogenous factors, such as social and human capital in the form of higher education, might not be easy to assess or measure accurately. For that reason, the model described above seems to be advantageous to use as these factors are included in the fixed effects and heterogeneous trends. Moreover, constant or slowly evolving variables become part of the country-specific trends. The Uzawa-Lucas model is a dynamic model that considers the accumulation of knowledge and skills over time and the impact of human capital on productivity and technological progress. It allows for the analysis of long-term effects and the dynamics of economic growth. Owing to the fact that the primary focus of this research work is to examine the overall relationship between tertiary education and economic growth short-term, the Cobb-Douglas production function may be sufficient. The research questions do not intend to examine the mechanisms and dynamics of human capital accumulation and its impact on growth, therefore, using the Cobb-Douglas production function might be more appropriate.

2.2. Qualitative research methods

To understand which variables should be considered in quantitative research, a bibliometric analysis of literature was conducted to reveal the research gaps and construct a map of variables. These variables were used in 150 research papers (published in the Web of Science Core Collection, and Scopus from 1985 to 2022) analysed in the framework of the author's summer internship project in 2022 in collaboration with the School of Management, Polytechnic University of Milan. Therefore, qualitative research methods, namely, content analysis was used to determine the variables used in previous studies.

2.3. The econometric model

The model described in Section 2.1 suggested a long-term relationship between production, investment share of GDP and human capital in the form of the share of population with higher education. Using the equation (45), the following panel model may be depicted by (54):

$$\ln ln\, y \; = \ln ln\, A \; - \; \alpha \ln ln \left(\delta_K + \, g \right) \; + (1 \; - \; \alpha \; - \; \beta) \ln ln\, b \; + \ln ln\, h$$

$$+ \quad \alpha \ln ln\, i_K \; + \; \beta \ln ln\, HE \; + (1 - \alpha - \beta) \; (54)$$

where ln $ln\, HE$ stands for higher education and ln h represents human capital, g denotes GDP growth rate, b depicts the share of human capital employed in production. Importantly, the slope coefficients are closely related to the shares of capital and human capital in the final output. This implication can be described by the expressions (55) and (56):

$$\beta_{j1} = \alpha_{j1} / \left(1 - \alpha_{j1}\right) \; (55)$$

$$\beta_{j2} = \alpha_{j2} / \left(1 - \alpha_{j1}\right) \; (56)$$

Alpha-parameters are not expected to take similar values in any given country, as this is a desired feature of current investigation. According to the econometric specification, the vector of the slope coefficients, beta, might take country-specific heterogeneous values. In addition to α_j *and* β_j, δ_j, which represents the rate of depreciation, variables ***b*** and ***g*** that stand for labour and technological advancements, are all accommodated by the fixed effects and the country-specific deterministic trends.

Panel data model (54) describes long-run dynamics. Nevertheless, the error term u_{jt}($with\; \varepsilon_{jt}$ representing individual specific errors) accounts for the short-run dynamics and the adjustment of countries with higher shares of population acquiring tertiary education to the long-run dynamics across the countries selected for the research (57):

$$u_{jt} = \tau_j^{'} f_t + \varepsilon_{jt} \quad (57)$$

where f_t is a vector of unobserved common shocks, which could be further divided into stationary or nonstationary ones (e.g. Pesaran, 2006; Kapetanios et al., 2011). These multifactor shocks may be serially correlated, and in addition, they can be possibly correlated with the logarithm of the investment share, ln $ln\, i_K$, and the logarithm of higher education, $ln(h)$. The individual-specific errors, ε_{jt} might be serially correlated over time and tend to have weak dependencies within the spectrum of selected countries. These individual errors are often believed to have an independent distribution from regressors and other unobserved factors in the model.

The model described above is very general, however, the advantages of this non-stationary panel approach are as follows: 1) the long-term relationships among the variables are eliminated with the help of using annual data as opposed to taking "traditional" five-year averages to tackle the fluctuations which may be common in the growth literature, additionally, some variables that do not relate to the equation (54) may be fearlessly omitted and the estimators are still robust and consistent under cointegration. 2) all variables are accommodated by the fixed effects and the country-specific deterministic trends 3) alpha-parameters are not expected to take similar values in any given country.

2.4. Panel data methods (based on the map of variables constructed in the bibliometric article)

Panel data methods are statistical techniques that were developed in the 1960s and 1970s by economists and statisticians interested in analysing data that has both a cross-sectional and a time series dimension. One of the earliest panel data methods was the fixed effects model, which was developed by Eisenhart (1947) in a paper published in Biometrics. Such methods can be used to analyse the impact of STEM (science, technology, engineering, and math) majors in higher education on economic growth. These methods are particularly useful when studying the effect of a particular variable (in this case, STEM education) over time, or when comparing the effect of a variable across different groups (such as countries or regions).

One common panel data method is the fixed effects model, which controls for time-invariant variables that may affect the relationship between STEM education and economic growth. This could potentially help to isolate the effect of STEM education on economic growth, while controlling for other factors that may influence the relationship. Another panel data method is the random effects model, which assumes that the effect of STEM education on economic growth may vary across different groups. This model allows for the estimation of both the average effect of STEM education on economic growth, as well as the variation in this effect across different groups.

Other panel data methods that may be used to analyse the impact of STEM education on economic growth include the pooled OLS model, the instrumental variables model, and the difference-in-differences model. These methods can be used to address issues such as endogeneity and omitted variable bias, which can affect the accuracy of the estimated relationship between STEM education and economic growth. However, in the current thesis fixed effects are used followed by previous findings published in Petrenko (2022) and described in the pre-emptive research part of this thesis.

2.5. Structured Econometric Modelling

Structured Econometric Modelling (SEM) involves the use of statistical and econometric methods to estimate the relationships between economic variables. It typically involves specifying a theoretical framework and testing it using data. Structured Econometric Modelling can be used to analyse a wide range of economic issues, including forecasting (Pumjaroen et al, 2020), policy analysis (More & Aye, 2017), and program evaluation (Agasisti & Bertoletti, 2019). Structured Econometric Modelling can be used in growth economics to determine the relationship between economic growth and higher education by completing the following steps:

1. First, a conceptual framework outlining the relationship between economic growth and higher education needs to be developed. This might involve considering factors such as the impact of education on labour productivity, innovation, and technology adoption. In case of the current research, shares of female ISCED 6-8[6] STEM graduates involved in HE and their impact on EG is considered.
2. Next, data would need to be collected on key variables such as GDP, educational attainment levels, and other factors that could impact economic growth. For the current research, a dataset containing 27 EU Member states in 2013-2020 was collected on 76 variables, 37 of which referred to HE. The reason for including this period is the availability of consistent HE data on Eurostat using the ISCED 2011[7] regulation.
3. Model specification can help to capture the relationship between economic growth and higher education. This might involve estimating a regression model that includes education as an independent variable and GDP as a dependent variable.
4. The model would then be estimated using econometric techniques such as ordinary least squares (OLS) which is used in this case. The results of the model could be used to estimate the impact of higher education on economic growth, while controlling for other factors that could potentially impact growth.

[6] ISCED levels are referred to in accordance with UNESCO as follows: ISCED 5 = Short-cycle tertiary education. ISCED 6 = Bachelor's degree or equivalent tertiary education level. ISCED 7 = Masters degree or equivalent tertiary education level. ISCED 8 = Doctoral degree or equivalent tertiary education level.

[7] Regulation (EU) No 912/2013, Document 32013R0912. On education and lifelong learning. European Parliament and Council, 2013. Available at: http://data.europa.eu/eli/reg/2013/912/oj

5. Finally, a sensitivity analysis could be performed to test the robustness of the results. This might involve varying the model specification or data inputs to determine how sensitive the results are to different assumptions. In the case of this research work, Bayesian Model Averaging techniques are used to check the robustness of the results.

In conclusion, the use of Structured Econometric Modelling in growth economics could help to provide valuable insights into the relationship between economic growth and higher education, and could help policymakers to make more informed decisions about investments in education and other areas that impact economic growth.

2.6. Generalised Method of Moments (GMM) in case of an asymmetric relationship between the factors and a dependent variable

Generalised Method of Moments denoted as GMM is a statistical technique used in econometrics to estimate lagged parameters in models, especially when dealing with asymmetric relationships. GMM is particularly useful in situations where conventional methods like Ordinary Least Squares (OLS) may not be appropriate due to issues such as e.g. potential time lags between the time graduates transition to the labour market and the time they start bringing value to the economy. In the case of the current research, it might be useful to produce some estimates of the unknown parameters in the dataset. GMM integrates empirical economic data with the information contained in population moment conditions to generate estimates for the unknown parameters within the economic model. If time lags exist between the independent and dependent variables, GMM analysis will yield specific outcomes which need to be statistically significant for the dependent variable. In this thesis, GMM will be applied to check the third research hypothesis to explore whether the previous period's GDP per capita significantly influences the current one.

2.7. BACE and BMA methods

The Bayesian Averaging of Classical Estimates (BACE) and Bayesian Model Averaging (BMA) approaches were developed by the researchers Sala-I-Martin et al. (2004). Both methods combine the results of multiple classical statistical models (such as OLS or fixed effects models) into a single estimate. These techniques can be used to improve the accuracy and reliability of the estimated relationship between variables of interest, such as the impact of STEM (science, technology, engineering, and math) majors in higher education on economic growth by averaging the estimates from multiple models that have been fit to the data. BACE naturally combines Bayesian statistics with adaptive design principles to make ongoing decisions about sources allocations, sample size adjustments, and other experimental parameters. It enables efficient and flexible trial design and inference. BMA allows for the estimation of parameters and model probabilities by averaging over multiple models based on their posterior probabilities. It provides a framework to address model uncertainty and capture the uncertainty associated with different possible models. The rationale for using these methods in this thesis is the same as for SEM – to verify the results received with the OLS and fixed effect models and ensure the reliability and accuracy of the findings.

The BACE approach has several advantages over traditional model averaging methods, such as the ability to incorporate prior information and to account for model uncertainty. It can help to build robust models and improve the accuracy and reliability of the estimated relationship between STEM education and economic growth. This method was chosen for the pre-emptive research phase.

In the context of conducting robustness checks, it is imperative to note that both Bayesian Model Averaging (BMA) and Bayesian Averaging of Classical Estimates (BACE) analyses primarily serve as robustness checks. Therefore, in this case there is no apparent need to perform additional robust checks after applying BMA or BACE methods to analyse the dataset. Both of these methods are designed to robustly measure the likelihood of a variable's inclusion in numerous Ordinary Least Squares (OLS) models, as indicated by the Posterior Inclusion Probability (PIP) coefficient. A PIP exceeding 0.7 signifies a high probability of significant correlation between the variable in question and the dependent variable. Therefore, it is statistically sufficient to view PIPs of variables and these findings within the thesis, underscoring the robust nature of the results received.

The goal for the main research phase was to choose and estimate the model avoiding uncertainty as much as possible, therefore, BMA method was used in the main part. The first step in using this approach is fitting multiple classical statistical models to the data. These models could include different model specifications (such as linear or nonlinear models), or different control variables, or different estimation techniques (such as OLS or fixed effects). The latter option is used in this research.

Once the models have been fit, the estimates from these models are combined into a single estimate of the relationship between STEM higher education majors and economic growth.

This estimate can be used to assess the overall impact of STEM education on economic growth. This information could be used to form policies and strategies for promoting economic growth and investing in STEM education. The advantages and disadvantages of the four approaches considered in this paper are summarised in table 2.

Table 2 - Comparison of advantages and disadvantages of using OLS (Ordinary Least Squares), BACE (Bayesian Averaging of Classical Estimates), SEM (Structural Equation Modelling) and Panel Data models to estimate the effect of higher education on economic growth

Methods	Advantages	Disadvantages
OLS	• is relatively simple to implement and interpret • has low bias and high efficiency under certain conditions • allows us to test hypotheses about the relationship between variables and to make predictions about the dependent variable.	• is sensitive to outliers • the assumptions about the errors in the model must be met for the estimates to be unbiased
Panel data – fixed effects	• allows to study the relationship between the variables over time • allows to compare the effect of higher education across different groups (such as countries or regions) and to control for time-invariant variables • addresses issues such as endogeneity and omitted variable bias.	• may often be computationally intensive and thus often requires specialized software to implement
SEM	• assesses the efficiency of HEIs • does not rely on assumptions about the underlying functional form of the data. may be relatively easy to interpret • helps to identify the sources of inefficiency within an organization.	• is limited to analysing inputs and outputs • does not allow for the analysis of intermediate variables or complex relationships between variables.
BACE, BMA	• can incorporate prior information and account for model uncertainty • can be applied to a variety of models, including those with missing data or hierarchical structure • provides precise inferences that are dependent on the data • estimates functions of parameters directly • helps to create robust models	• may often be computationally intensive and thus often requires specialized software to implement • does not provide a procedure for choosing prior • past information heavily influences the results

Source: Author's own elaboration

Although Bayesian analysis is a statistical method that combines past information (prior) with new data to update the understanding of a parameter or hypothesis, it relies heavily on the prior as the results of the analysis are dependent on selecting prior information. This fact poses a limitation on using the approach as a stand-alone method. Therefore, in this research it is suggested to apply a few methods to the same dataset to compare and triangulate the findings.

2.6. Dataset description

To obtain the data for this analysis, a few data sources are utilised:

- International organizations: Organizations such as the World Bank, Eurostat, and the International Monetary Fund (IMF) often collect and publish data on economic indicators, including GDP per capita, for countries around the world.
- National statistical agencies: Each European Member State has a national statistical agency that collects and publishes data on a variety of economic and social indicators. These agencies can be a good source of data on GDP per capita and other variables.
- Eurostat database generalises the data from EU Member States and other countries and continuously updates the tables.

HE data may vary in terms of quality and reliability; therefore, it is important to carefully evaluate and compare the sources to ensure that the data used in the research is accurate and reliable. There are several steps that can be taken in this case:

1. Reputable sources: data sources that have a firm reputation for reliability and accuracy, such as international organizations, national statistical agencies, and well-established online databases. In case of this research, the data for GDP was collected from the World Bank as it provides GDP per capita in purchasing power parity (PPP, constant 2017 international $).
2. Consistency: the data gathered from multiple sources could be compared for consistency. In case there are significant discrepancies, it might be possible to use a different source for that particular variable.
3. Limitations of the particular data source. Any potential biases that could possibly stem from the data source need to be evaluated beforehand, e.g. data collected by a government agency may be subject to political influences, while data collected by a private company may be influenced by its commercial interests and scalability issues.

4. Data triangulation to increase the reliability of research results. Triangulating the findings refers to the practice of using multiple sources of data or multiple methods to study the same phenomenon in order to increase the reliability of the data. If economic growth in European Member States is considered, data from multiple sources might be used, such as the World Bank, national statistical agencies, and online databases, to confirm that these findings are consistent across different sources.

The choice of the source of information to gather the dataset on the dependent variable (GDP per capita needs to be explained and rationalised. For our calculations we opted for the variable GDP per capita, PPP (constant 2017 international $, denoted by the World Bank as NY.GDP.PCAP.PP.KD) over a similar Eurostat indicator GDP per capita in Purchasing Power Standards (PPS, denoted as tec00114) for a few reasons. Firstly, the definition of Eurostat indicator tec00114 states that the index is designed for cross-country comparisons only and should not be used in case temporal comparisons are carried out. Secondly, the availability and accessibility of data play a significant role. GDP per capita in constant 2017 international dollars is a statistic widely used in growth economics, making them a convenient choice. Lastly, I considered the consistency and comparability of the data. Raw data can be easily comparable and could help triangulate the findings because it often represents original, unprocessed information directly collected from sources. Arguably, it is generally believed not to have been manipulated, transformed, or adjusted to some average values unlike indices or percentages.

Data collection phase revealed HE data scarcity which could create another limitation to address the economic impact of STEM education. The empirical analyses exploit two data sets (panel and time-series) applying two alternative approaches: models with fixed effects and Bayesian Model Averaging (BMA models). The methods are expected to complement one another. Using plain regression analysis to estimate the relationship between various factors and economic growth was criticised for lack of robust results owing to such factors as violation of assumptions, omitted variables bias, endogeneity, measurement errors, and sample size (see, e.g. Angrist & Pischke, 2009; Wooldridge, 2010). These issues can lead to dangerous biases prioritizing some factors (in this case, financial and political support of a specific gender, certain HE majors, or education levels) and incorrect inferences about the causal relationship between the response variable and the regressors. In this study, this method is complemented by BMA, which reported to be advantageous in endogenous growth modelling (Sala-i-Martin, 1997) as:

1. it can check whether specific models are appropriate for different countries in the sample.
2. it produces model-averaged coefficients that represent weighted averages of coefficients from all candidate models, providing a robust estimate of true coefficient values.
3. it provides posterior probabilities of candidate models, allowing for the selection of the most appropriate model based on the relative strength of evidence.
4. it employs various models and variables selecting the most robust models.

The sampling algorithm for setting Bayesian priors was extensively described by Błażejowski and Kwiatkowski (2015) and put into practice in the BMA function package used in the econometric software called gretl.

Chapter 3 Comparing and contrasting the impact of tertiary education in terms of majors, gender and incomes by profession and by gender on economic development in EU Member States

3.1. Pre-emptive testing results

The research questions addressed in the pre-emptive research phase were as follows: 1: What is the impact of the characteristics of higher education systems on economic growth in European countries? 2: What is the impact of human capital with a tertiary degree in science, technology, and medicine (Bachelor's and Master' level) on economic growth? 3: What is the impact of male and female graduates (Bachelor's and Master' level) of all majors on economic growth? 4: What is the impact of male and female graduates (Bachelor's and Master' level) majoring in science, technologies and medicine on growth? The results of the pre-emptive research were published in 2022 in the ACC Journal (Petrenko, 2022). The data for pre-emptive research was gathered from the Eurostat (2021), OECD (2021) and World Bank (2021) official databases. A list of variables with their description and corresponding data sources can be found in Table 3.

Table 3 - Summary statistics, using the observations for 27 EU states, 2013-2019.

Variables	*Data source*	*Mean*	*Median*	*St.Dev.*
Dependent variable: LOG GDP in current PPP per capita	National Statistics Office Eurostat	4.58	4.56	0.162
Independent variables:				
Gross fixed capital formation by industry, deflated, mi. Euro	Data Browser, Eurostat	9.70e+004	3.96e+004	1.53e+005
Share of age group 30-35 with a tertiary diploma	Data Browser, Eurostat: [edat_lfse_03]	40.9	42.7	9.20
Employment by A*10 industry breakdowns, thousand hours worked	OECD.org Average annual hours actually worked	1.22e+007	6.99e+006	1.54e+007
Government expenditures on tertiary education	Data Browser, Eurostat	0.904	0.900	0.350
Growth of population share	Data Browser, Eurostat	0.444	0.0214	4.05
Population in mil	Data Browser, Eurostat	16.4	8.74	21.6
Total graduated bachelor students	Data Browser, Eurostat	7.58e+004	3.88e+004	9.52e+004
Total graduated master students	Data Browser, Eurostat	5.20e+004	2.41e+004	7.22e+004

General government consumption expenditure, % GDP	World Bank National Accounts Data	19.7	19.4	3.26
Openness of the economies: exp-imp/gdp	World Bank National Accounts Data	4.83	3.00	7.61
Gross capital formation GDP	Data Browser, Eurostat	21.6	21.6	4.53
Total Graduated bachelor students	Data Browser, Eurostat	7.58e+004	3.88e+004	9.52e+004
Male Graduated bachelor students	Data Browser, Eurostat	3.00e+004	1.51e+004	3.94e+004
Female Graduated bachelor students	Data Browser, Eurostat	4.58e+004	2.37e+004	5.85e+004
Total Graduated Master students	Data Browser, Eurostat	5.20e+004	2.41e+004	7.22e+004
Male Graduated Master students	Data Browser, Eurostat	2.12e+004	9.58e+003	3.13e+004
Female Graduated Master students	Data Browser, Eurostat	3.08e+004	1.41e+004	4.21e+004
Total Graduated PhD students	Data Browser, Eurostat	3.86e+003	1.91e+003	6.09e+003
Total Graduated bachelors in technologies/sciences/medicine	Data Browser, Eurostat	2.41e+004	1.48e+004	3.04e+004
Total Graduated Master students in technologies/sciences/medicine	Data Browser, Eurostat	1.71e+004	6.41e+003	2.48e+004
Total Graduated PhD students in technologies/sciences/medicine	Data Browser, Eurostat	1.50e+003	835.	2.45e+003

Source: author's own research.

The criteria for choosing the variables were as follows: 1) Availability – the data are available for the majority of the current EU Members States from 1990 to present; 2) Consistency – congruent tertiary education data for the 27 EU Member States that was calculated and received by carrying out exactly the same procedure for years 2013-2019. Despite the fact that the period of six years could be considered to be a limitation of the current research, it was expected that a common relationship between tertiary education and economic growth would be found as the list of countries chosen for this study seemed to be homogeneous as it consisted of countries with developed economies according to the World Bank (2019).

The advantage of analysing such a data set is data coherence – an important data quality component that ensures uniformity as well as existing logical connections and completeness of the dataset. Coherence could also enable the making of a logical distinction between concepts and target populations, which means that most major problems could be easily detected during the data preparation stage. These restrictions resulted in the selection of a few variables, their means and standard deviations are shown in Table 7.

To analyse the data, it was decided to use the Cobb-Douglas production function (CDPF) (1) using capital stock, capital and labour services, despite the fact that CDPF often returned a negative sign for capital (Romer, 1990; Griliches & Mairesse, 1995) and has been considered as a transformation of income identity (Simon & Levy, 1963; Čadil et al, 2017). Nevertheless, the main advantage of this function used in its general form is its ability to explain the aggregate output creation and economic growth visually. The function in its basic form looks as follows:

$$Yt = At^{*} (Kt)^{\alpha}(Lt)^{\beta} \quad (1)$$

where it illustrates constant returns to scale ($\alpha+\beta=1$) when elasticities of production on production factors equal factor shares, with both coefficients are positive numbers ranging [0, 1], A – total factor productivity, K – capital, L – labour.

Due to the fact that most of the uncertainty of the economic growth models hinders agreement on specific factors that cause economic growth, for the pre-emptive research phase it was decided to use panel data models with country-specific fixed effects. Wooldridge (2005) pointed out that it might be more efficient to use Fixed Effects – Random Effects models instead of the regular OLS regressions while working with panel datasets in which there is heterogeneity. This approach to assess long-term and short-term economic growth has been commonly used in the economic literature due to its general simplicity. The main drawback might be a limited number of variables that could be explained empirically; their quantity often depends on "whatever list the first researcher happened to select" (Leamer, 1972 p. 3).

To deal with the issue of biases, quite a few researchers also consider using Bayesian model averaging techniques (Leamer, 1983) which may help to determine model uncertainty so that the relationship between model-specific estimates is assessed, revealed and explained. Following this idea, economists Sala-I-Martin, Doppelhofer and Miller (2004) created a Bayesian Model Averaging of Classical Estimates (a so-called SDM's BACE approach) in order to understand which regressors should be included into cross-country linear regressions to have a robust relationship with a dependent variable. Such models build estimates for every possible combination of variables by applying the weighted averaging OLS method in order to find out which variables do relate to growth robustly and how strong these relationships might be. Therefore, when designing the current research, it was decided to build an alternative model to compare and evaluate the results received from the Fixed Effects model.

More recently, literature on applied econometrics offered "extreme bounds analysis" which was designed to reveal robust empirical relationships for the determinants of economic growth. This test consists of two steps: 1) it is necessary to identify (by prior analysis) which variables could be related to economic growth; 2) to check if a variable z is robust, the following equation (2) for regressions needs to be solved:

$$\gamma = \alpha_j + \beta_{yj} \cdot y + \beta_{zj} \cdot z + \beta_{xj} \cdot x_j + \varepsilon \tag{2}$$

where *y* is a vector that represents fixed positions of the regressors (certain variables which are always included into regressions – e.g. income, investment rate, secondary school enrolment rate, rate of population growth (Levine & Renelt, 1991)), z is the variable to be examined, and *x* is a "tool" vector which typically consists of a combination of three variables selected for the analysis.

The first extreme bounds tests performed at the beginning of the 1990s were widely criticised in the economic literature as they discarded most of the variables as not robust due to the fact that these regressors did not systematically correlate with economic growth. Consequently, Sala-i-Martin et al. (2004) suggested making a transition from "extreme bounds" to variables that would have a certain degree of confidence.

There has been much debate between economists on the subject of whether or not there is a fixed set of variables which can be robustly correlated with economic growth. In order to answer the research questions listed in the introduction of this chapter, it is considered useful to find out estimates for growth from a much larger set of models with the help of the BACE approach.

The null hypothesis to answer the first research question ("What is the impact of the characteristics of higher education systems on economic growth in European countries") was stated as: There is no impact of tertiary education characteristics on economic growth. We constructed an OLS model with fixed effects for the panel dataset having lagged variables of 4 years for Bachelor students and 2 years for Master students. The dependent variable was current GDP per capita in purchasing power parity (table 1) with the R-squared of 0.79.

The regressors used for this model included the ones that are generally used by various researchers: gross capital formation, Thousand hours worked (as K and L variables for the Cobb-Douglas function), general economic variables (unemployment rate, population and population growth share, general government consumption expenditures, openness of the economy) and the variables that referred to tertiary education (total number of graduated bachelors and master students, government expenditures on tertiary education and number of persons aged 30-35 with a tertiary diploma. It could be assumed that graduated bachelor and master students have a positive impact on economic growth. The same dataset was used to form multiple BACE models, the results follow in table 4.

Table 4 Model 1: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	4.89105	0.301363	16.23	<0.0001	***
Thousand hours worked	−0.000162264	0.000206555	−0.7856	0.4392	
Gross capital formation	0.00129016	0.000750301	1.720	0.0974	*
Share of age group 30-35 with a tertiary diploma	−0.000644451	0.00128654	−0.5009	0.6206	
Graduated bachelor students_4	3.11526e-06	1.53880e-06	−2.024	0.0533	*
Graduated master students_2	2.02081e-06	8.50523e-07	2.376	0.0252	**
Graduated PhD students	−2.13229e-06	2.18339e-06	−0.9766	0.3378	
Government expenditures on tertiary education	0.00972116	0.0380232	0.2557	0.8002	
Government consumption expenditures	0.00611585	0.00173563	3.524	0.0016	***
Openness of the economy	−0.00125947	0.00139534	−0.9026	0.3750	

Source: author's own research.

The BACE modelling method applying posterior moments with unconditional and conditional inclusion returned the following results: gross capital formation, unemployment rate robustly and marginally correlates with economic growth. The numbers of graduated bachelor students robustly moderately correlate with growth. The hypothesis of no impact of tertiary education on economic growth is rejected because total number of bachelor and master students robustly and positively correlate with GDP growth per capita both in the fixed effects model and BACE models.

Table 5 - BACE Models (61 models accepted out of 1024). Dependent variable: LOG GDP in current PPP per capita

	PIP	Mean	Std.Dev.	Cond.Mean	Cond.Std.Dev
const	1.000000	4.296766	0.171460	4.296766	0.171460
Government expenditures on tertiary	0.999996	-0.120231	0.022694	-0.120232	0.022693
Thousand hours worked	0.914534	-0.000166	0.000075	-0.000182	0.000058
Gross capital formation	0.596062	0.002394	0.002323	0.004017	0.001592
Graduated bachelor students_4	0.307443	0.000000	0.000000	0.000000	0.000000
Graduated master students_2	0.203128	0.000000	0.000000	0.000000	0.000000
Growth of population share	0.067852	-0.000004	0.000392	-0.000058	0.001503

Source: author's own research.

The hypothesis to answer the second research question was stated as: There is no significant impact of human capital with a tertiary degree in science and technology (Bachelor, Master and PhD level) on economic growth. We constructed an OLS model with fixed effects for the panel dataset having lagged variables of 4 years for Bachelor students and 2 years for Master students. The dependent variable was current GDP per capita in purchasing power parity (table 3) with the R-squared of 0.788. The results for graduated PhD students did not return any statistically significant results which might mean that it is rather costly to educate prospective scientists and it takes time for the economy to positively react to high quality human capital. It could be assumed that graduated bachelor and master students have a positive impact on economic growth. The same dataset was used to form multiple BACE models, the results follow in table 6.

Table 6 - Model 2: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	4.67409	0.341751	13.68	<0.0001	***
Gross fixed capital formation	0.00125257	0.000755304	1.658	0.1093	
Share of age group 30-35 with a tertiary diploma	−0.000698896	0.00136394	−0.5124	0.6127	
Growth of population share	0.000437482	0.000160227	2.730	0.0112	**

Government expenditures on tertiary education	−0.0331373	0.0491954	−0.6736	0.5065	
Government total education expenditures	0.0382560	0.0256607	1.491	0.1480	
Government consumption expenditures	0.00457503	0.00276204	1.656	0.1097	
Openness ratio	−0.000925810	0.00118797	−0.7793	0.4428	
Graduated bachelor students in sciences, technology and medicine 4	4.35001e-06	1.88375e-06	2.309	0.0291	**
Graduated master students in sciences, technology and medicine 2	2.11347e-06	1.32463e-06	1.596	0.0227	**

Source: author's own research.

The BACE method returned the following results: Government consumption expenditures, the share of the population with a tertiary education diploma and government spending on tertiary education robustly and marginally correlated with economic growth. The gross capital formation, unemployment rate and numbers of graduated bachelor students robustly moderately correlate with growth. What changed from the first set of BACE modelling results is that the number of Bachelor students graduating from majors linked to science, technology and medicine might correlate robustly and marginally with economic growth. The hypothesis of no impact of Master and Bachelor science, technologies and medicine students on economic growth is rejected as the number of students in such majors robustly and positively correlates with GDP growth per capita both in the fixed effects model and BACE models.

Table 7 - BACE Models (70 models accepted out of 1024), dependent variable: LOG GDP in current PPP per capita

	PIP	Mean	Std.Dev.	Cond.Mean	Cond.Std.Dev
const	1.000000	4.262602	0.179509	4.262602	0.179509
Government expenditures on HE	0.999910	-0.120103	0.022934	-0.120113	0.022907
Employment by industry breakdowns	0.883652	-0.000154	0.000078	-0.000175	0.000058
Gross fixed capital formation	0.625332	0.002577	0.002358	0.004121	0.001591
Total Graduated bachelor students in sci and tech	0.532771	0.000000	0.000000	0.000001	0.000000

Total Graduated master students in sci and tech	0.180553	0.000000	0.000000	0.000000	0.000000
Growth of population share	0.066751	-0.000000	0.000387	-0.000007	0.001498

Source: author's own research.

The hypothesis to answer the third research question was stated as: There is no significant impact of men and women graduates (Bachelor and Master level) on the economic growth. We constructed an OLS model and underwent the same procedure (table 8) with the R-squared of 0.834 and Durbin-Watson statistic of 1.72. It is visible that both female and male master and bachelor students tend to positively influence economic growth, however, the coefficients for men are larger in this model. These findings may point out that there might be a gender pay gap. It could be derived that male and female graduated bachelor and master students have a positive impact on economic growth. The results received with the application of BACE modelling to check the same hypothesis are demonstrated in table 6 and show that the number of graduated bachelor male students might have robust marginal correlation with economic growth. However, the number of female graduate students, both educated at bachelor and master levels, demonstrate insignificant correlation with economic growth.

Table 8 - Model 3: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	4.74601	0.301638	15.73	<0.0001	***
Gross fixed capital formation	0.00139316	0.000674290	2.066	0.0489	**
Growth of population	0.000551393	0.000192559	2.864	0.0082	***
Government expenditures on HE	−0.0626676	0.0517090	−1.212	0.2364	
Openness ratio	−0.00178661	0.00142337	−1.255	0.2206	
Male Graduated bachelor students	1.19535e-06	5.54429e-07	−2.156	0.0405	**
Female Graduated bachelor students	1.21790e-06	5.84251e-07	−2.085	0.0471	**
Male Graduated master students	3.09333e-06	8.97448e-07	3.447	0.0019	***
Female Graduated master students	2.51806e-06	7.73175e-07	3.257	0.0031	***

Source: author's own research.

Table 9 - BACE Models (237 models accepted out of 1094), dependent variable: LOG GDP in current PPP per capita

	PIP	Mean	Std.Dev.	Cond.Mean	Cond.Std.Dev
const	1	4.247664	0.185112	4.247664	0.185112
Government expenditures on HE	0.999	-0.11801	0.023213	-0.11802	0.023194
Employment by industry	0.848	-0.00015	0.000082	-0.00017	0.000059
Gross fixed capital formation	0.602	0.002442	0.002344	0.004055	0.001607
Male graduated bachelor students	0.412162	0	0	0	0
Male graduated master students	0.238469	0	0	0.000001	0
Female graduated master students	0.15891	0	0	0	0.000001
Female graduated bachelor students	0.133351	0	0	0	0
Growth of population share	0.064747	-1E-06	0.000382	-1.3E-05	0.001499

Source: author's own research.

The hypothesis to answer the last research question was stated as: There is no significant impact of male and female graduates (Bachelor and Master level) majoring in science, technologies and medicine on economic growth. The OLS model demonstrated that male bachelor and master students have a statistically significant positive effect on economic growth (0.0141 and 0.0108 correspondingly). Female bachelor graduates also have a positive correlation with growth, however, female master students returned a statistically insignificant coefficient of 0.22. The results received with the application of BACE modelling to check the same hypothesis are described below.

With the help of BACE analysis it might be possible to conclude that the number of graduated male bachelor students majoring in technologies, sciences and medicine might be robustly partially correlated with economic growth (0.64 value of PIP). Graduated male master students as well as female graduate students, both of bachelor and master levels, return insignificant correlation coefficients with economic growth (0.188 for male bachelor students, 0.15 for female bachelor students and 0.13 for female master students in sciences, technology and medicine). These results differ from the panel regression model where coefficients for graduated male bachelor and master students as well as female graduated bachelor students appeared to be significant.

Having performed OLS regression and Bayesian Averaging of Classical Estimates we found that such variables as the number of graduated bachelor and master students positively relate to growth. It was discovered that bachelor and master male students who graduated majoring in sciences, technologies and medicine overall have higher robust coefficients associated with growth. The results of OLS panel data regression analysis are not always confirmed by BACE: female bachelor graduates also have a positive correlation with growth. However, female master students returned a statistically insignificant coefficient according to the OLS regression model, whereas it might be implied from the results of the same coefficients for BACE models that female graduates generally do not correlate robustly with growth. Therefore, it was particularly interesting to carry out the procedure for the final research question – What impact do male and female graduates (Bachelor and Master level) majoring in science, technologies and medicine have on the economic growth? It was confirmed that the number of graduated bachelor male students might have robust marginal correlation with economic growth. However, female graduate students, both bachelor and master levels, return insignificant correlation with economic growth.

Further development of current research may focus on developing a set of indicators that measure the level of technological development in EU countries and including these into the dataset. Moreover, we find it interesting to perform analyses on STEM education with a further focus on gender, possibly answering the following questions: is STEM tertiary education more important for growth? How many women and men study STEM and does their number have any impact on the gender pay gap and/or the "sticky floor[8]", "glass door" or "glass ceiling".

It is demonstrated that some components of human capital (the share of people with tertiary diploma, the share of young people in the economically active population) in combination with expenditures on higher education have statistically significant robust positive influence on economic growth in the countries of the European Union. It might be interesting to determine the spillover effects. We find it useful for future analysis to break down the 27

[8] According to the official website of the European Institute of Gender Studies (EIGE) the definition of the term is as follows: "Expression used as a metaphor to point to a discriminatory employment pattern that keeps workers, mainly women, in the lower ranks of the job scale, with low mobility and invisible barriers to career advancement."

countries into several groups and possibly include more variables for these groups. In this research we admittedly used a limited number of variables which might possibly have caused more biased results.

3.2. Research questions and hypotheses

The aim of the research is to study the relationship between tertiary education and economic growth using SEM and BMA methods and describe the relationship between graduates of ISCED 6-8 in EU countries considering the following factors:

1) graduates from all majors to graduates from STEM majors
2) graduates of different ISCED 6-8 levels
3) graduates of STEM majors by gender
4) gender gaps and female STEM graduates' percentage.

During the empirical stage, I analysed data on a comprehensive list of 27 EU Member states (as of 2020) from The World Bank's World Development Indicators dataset along with Eurostat's statistics databases, using the Barro-Lee endogenous growth model. I attempted to answer the following research questions, which were put forward for the 27 EU Member states:

1) to what extent does the general share of ISCED 6-8 graduates towards the total country's population exert a significant positive effect on GDP in 2013-2020?

2) to what extent do country-level tertiary education results from STEM majors compared to Non-STEM majors (percentage of graduates towards total country's population; percentage of ISCED 6, 7 and 8 graduates; percentage of male and female graduates) exert a significant positive effect on GDP?

3) to what extent do female and male graduates of STEM majors exert a significant positive effect on GDP (in total and in terms of gender or ISCED 6-8 levels)?

4) to what extent does the number of STEM graduates in general and the number of female STEM graduates have a positive effect on narrowing the gender pay gap?

To address these research questions, 4 models were tested using panel data analysis methods and 4 sets of BMA models which dealt with the cross-sectional dataset.

The study estimated four hypotheses:

H1: Total percentage of graduated students towards the total countries' population does not significantly impact economic growth (GDP).

H2: Percentage of graduates of STEM and Non-STEM majors of ISCED 6, 7, and 8 levels (bachelor, master and doctoral graduates) is not robustly correlated with economic growth.

H3: Female STEM ISCED 6-8 graduates' percentage towards total countries' population does not significantly impact economic growth.

H4: Share of female STEM graduates towards the total female countries' population does not significantly impact gender pay gaps (GPG).

The model follows the formative research work of Barro and Sala-i-Martin (1992) which lists the basic equation for the average growth rate of GDP per capita in purchasing power parity (PPP) as:

$$g = [(\ln Y^{\alpha} - \ln Y^{0}) / T] \qquad (3)$$

where g is the average annual growth rate of GDP per capita in PPP, ln Yt is the natural logarithm of real GDP per capita in PPP at time a, ln Y0 is the natural logarithm of real GDP per capita in PPP at time 0 (the initial year, 2013), and T is the number of years between time t and time 0, which is eight years for the case of this dataset.

3.3. Research design and novelty

The scientific novelty of the research is creating a modified Uzawa-Lukas model based on bachelor's and master's tertiary education programs. The modification of the model includes a specific type of education as a factor of GDP production. It is expected to see the need for a higher human capital growth rate on the balanced growth path, compared to the GDP growth rate. A possible limitation would be that the great number of existing research papers with the help of well-known neoclassical models provide little confidence that they do measure the growth accurately. The other important limitation is that there might be little impact of these results on actual policy-making. A way to overcome some of these limitations would be to investigate and later choose multiple models that may shed light on various ways of determining growth. The strategy of narrowing down possible options and contradictory evaluation (that typically happens because of cultural influences, social and economic institutions, different approaches of data collection) would allow us to opt for statistically significant outcomes that could be explained from the economic point of view.

3.4. Data Collection

The study involves repeated observations of the same variables over a period of time from 2013 to 2020. The study might include one or more of these processes such as generalizations, analysis and interpretations. The models will be tested in calculations with real statistical information. As a result, the following calculations may be necessary to make:

a) For each country, a series of specific cumulative human capital. The highest level of specific accumulated human capital might be particularly important.

b) The dynamics of the specific GDP of EU countries in the long-term

These are the variables that would be necessary to define the relationship between STEM higher education and economic growth in European Member States using the OLS, Panel data, SEM and BACE methods:

- Dependent variable: Economic growth (measured by GDP per capita in real international dollars 2017 - World Bank Database)
- Independent variable: STEM higher education (measured by the percentage of the population with a degree in a STEM field - Eurostat)
- Control variables: It would be useful to control for other factors that could affect economic growth, such as political stability, infrastructure, and access to capital.

3.5. Research Results

The first part of research results intends to demonstrate Exploratory Factor Analysis (EFA) performed to build a system of equations that were used for Structural Econometric Modelling (SEM). SEM results are presented to understand the extent of the connection between ISCED 5-8 education and economic growth. The second part of research results describes the nexus between growth, higher education and gender pay gap (GPG) and answers the research questions. The problem of finding and exploring the connection EG-HE-GPG was described in the articles by Petrenko and Cadil (2023, accepted to Journal of European Education, multi-journal special issue Gender Equality in Education), Petrenko et al. (2023, currently in review in Labour Economics), Petrenko et al. (2024, working paper, will be submitted to World Development). Tables 10-30 are the author's own work and calculations.

3.5.1. Using Exploratory Factor Analysis and Structural Econometric Modelling methods to find the connection between higher education and economic growth

Factor analysis is often used by econometricians and statisticians to narrow down the number of variables in the equation as well as understand the nature of the dataset. First, latent (unobserved) variables need to be identified so that they could be used in SEM. There is a choice of factor analysis methods. For the sake of this research work, we explain the rationale to choose exploratory over confirmatory factor analysis methods.

Both Confirmatory Factor Analysis (CFA) and Exploratory Factor Analysis (EFA) are two statistical methods used to study the relationship between observed variables and some latent constructs. CFA is a hypothesis-driven method used to test a pre-specified hypothesis about the number and nature of latent constructs that underlie a set of observed variables. Because of the fact that it is typically used when there is a well-established theory or previous empirical evidence suggesting the presence of specific latent constructs and their interrelationships, it cannot be used for the purpose of this research. EFA, on the other hand, is a data-driven approach used to explore the underlying structure of a set of observed variables when there is no prior evidence to guide the analysis. In this case, EFA is used to identify the number and nature of the latent constructs that best explain the patterns of correlation among the observed variables. We opted for EFA over CFA because there might be some theoretical information missing on the relationship between the variables due to the fact that each dataset is unique. This way the problem of incorrect model specification could be partly avoided. Moreover, there seems to be no a priori hypotheses about the structure of the latent constructs and their relationships. During step 1 we will analyse the dataset using EFA to determine the number of variables, latent factors that may influence them and their relationship. Step 2 presents SEM analysis.

STEP 1: run EFA in the statistical program called JASP with the panel data including all the variables we have for higher education for 27 EU Member States from 2013 to 2020. The variables for the study are presented in Appendix 1. At first, the results of this test suggested that the third unobserved variable, factor 3, was often correlated with more than 1 variable which were already associated with factor 1 or factor 2. As this would make the factor labelling procedure more difficult, it was decided to divide general numbers of graduated students into majors (STEM vs Non-STEM) and genders (male/female graduates). The input variables were also adjusted by excluding 2 variables (Annual expenditure on educational institutions per pupil/student (pre-primary to tertiary education) and Ratio of pupils and students to teachers and academic staff in ISCED 06-08 - tertiary level) as they had high rates of uniqueness, meaning that they were explained by some other latent factors which may not be present on our list. Final EFA results suggested that factors 1 and 2 received its place in the correlation chart. The factor loadings in EFA indicate the strength and direction of the relationship between each observed variable and the underlying factors. Factor loadings represent the correlation between each observed variable and the corresponding factor. They range from -1 to 1, where values closer to 1 indicate a strong positive relationship, values closer to -1 indicate a strong negative relationship, and values close to 0 indicate a weak or negligible relationship. Factor loadings help determine which variables are strongly related to a particular factor and provide insights into the interpretation of the underlying factors. Uniqueness values range from 0 to 1 and show the degree of the relationship between a specific variable and factors which is not explained by the analysis. The higher the uniqueness level, the less likely the variable would be included into the set of final variables. In this case, factor 3 is excluded from the final set of equations.

Table 10 - Final EFA factor loadings

	Factor 1	Factor 2	Factor 3	Uniqueness
ISCED 6 male Non-STEM grads	0.948			0.161
ISCED 6 female Non-STEM grads	0.931			0.176
ISCED 6 female grads STEM	0.886			0.229
ISCED 6 male grads STEM	0.823			0.307
ISCED 7 female Non-STEM grads	0.695			0.242
ISCED 7 male Non-STEM grads	0.677			0.282
ISCED 7 female grads STEM	0.604			0.265
ISCED 7 male grads STEM	0.541	0.457		0.255
ISCED 8 female grads STEM		0.936		0.112
ISCED 8 male grads STEM		0.935		0.101
ISCED 8 male Non-STEM grads		0.891		0.196
ISCED 8 female Non-STEM grads		0.864		0.302
Hours worked			0.732	0.440
Capital stock			0.746	0.470
X1 GDP current PPP per capita, $ to 2017			0.624	0.580

Note. Applied rotation method is promax. STEM majors were calculated as the sum of graduates of F05-F07 majors in the Eurostat dataset.

The following table 11 demonstrates the correlations between factor 1 and 2. It was decided to label them economic development and human capital in higher education, correspondingly.

Table 11 - EFA factor 1 and factor 2 correlations

	Factor 1	Factor 2
Factor 1	1.000	0.451
Factor 2	0.451	1.000

The table below shows additional indices calculated in the econometric package called JASP for EFA analysis to ensure the model can be used for SEM analysis. RMSEA (Root Mean Square Error of Approximation) measures the discrepancy between the model and the observed covariance matrix, taking into account the complexity of the model. Lower values of RMSEA, in this case, 0.008, indicate better fit. TLI (Tucker-Lewis Index) compares the fit of the proposed model with that of a baseline model (usually a null model). Values closer to 1 indicate better fit, with values above 0.95 often considered acceptable. The same role applied to the CFI (Comparative Fit Index), which compares the fit of the proposed model with that of a baseline model. Values closer to 1 indicate better fit, with values above 0.95 often considered acceptable. BIC (Bayesian Information Criterion) balances model fit and complexity. Lower BIC values indicate better fit, suggesting the proposed model is simple enough and explains the data fairly well.

Table 12 - Additional fit indices for EFA

RMSEA	**TLI**	**CFI**	**BIC**
0.008	0.956	0.967	1213.473

STEP 2: prepare a set of equations for the SEM analysis in econometric package JASP. First, the model with the variables selected in EFA was used to create a set of 2 equations. Each of those 2 equations refers to one of the observed variables, economic development and human capital. The conditions for JASP are depicted below:

```
# latent variables
    (1) economic_development =~ x1 + x2 + x3
    (2) hes_human_capital =~ x4 + x5 + x6 + x7 + x8 + x9
# regressions
edev ~ hes_hc
#where
#x1= GDP per capita
#x2=capital stock
#x3=hours worked
#x4= ISCED 6 female graduates in STEM majors, % to population
#x5 = ISCED 6 male graduates in STEM majors, % to population
#x6 = ISCED 7 female graduates in STEM majors, % to population
```

#x7= ISCED 7 male graduates in STEM majors, % to population
#x8= ISCED 8 female graduates in STEM majors, % to population
#x9 = ISCED 8 male graduates in STEM majors, % to population

Model fit and factor loadings are presented in the tables 13-14. The criteria AIC and BIC stand for Akaike and Bayesian information criteria, correspondingly for the dataset of 216 observations. The lower are the values, the better the proposed model fits the actual dataset. The negative sign in this case may be neglected. The second reason why the model seems to be a good fit is that multiplying the degrees of freedom (df) by 10, we get 420, but the χ^2 is smaller than that, approximately 185.2.

Table 13 - Model fit for SEM

				Baseline test		
	AIC	BIC	n	χ^2	df	p
Model 1	-243.538	-232.403	216	185.195	42	< .001

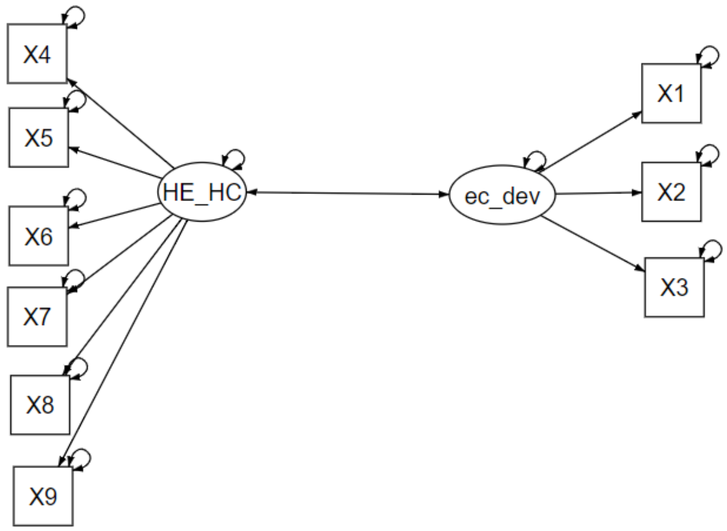
P-values for x4-x9 that represent STEM graduates of ISCED 6-8 of both genders are smaller than 0.001, which may indicate that these variables are important for the set of equations.

Table 14 - Factor Loadings for SEM

						95% Confidence Interval	
Latent	Indicator	Estimate	Std. Error	z-value	p	Lower	Upper
edev	x1	1.000	0.000			1.000	1.000
	x2	-0.179	0.121	-1.479	0.139	-0.417	0.058
	x3	1.505	1.252	1.202	0.229	-0.949	3.960
hes_hc	x4	1.000	0.000			1.000	1.000
	x5	1.675	0.113	14.851	< .001	1.454	1.897
	x6	1.495	0.108	13.787	< .001	1.283	1.708
	x7	1.828	0.120	15.217	< .001	1.592	2.063
	x8	1.611	0.116	13.830	< .001	1.382	1.839
	x9	1.513	0.114	13.220	< .001	1.289	1.738

Path diagram is presented on fig. 5 and describes the model in the graphic form. For this model's settings, the path diagram looks as follows:

Figure 5 - Path diagram for SEM



Therefore, the results of EFA and SEM analyses suggest there is a connection between HE outcomes in the form of STEM graduates and economic development of the EU countries. We shall proceed to other econometric analyses in order to answer the research questions and explore the cause-effect relationship between STEM students, economic growth and gender pay gap (GPG) and define the strength of this relationship.

3.5.2. Using Panel data, Bayesian Model Averaging methods to explore the connection between HE graduates grouped by majors and gender, economic growth (EG) and gender pay gap (GPG)

For the purpose of this part of the research, a dataset of 86 variables was collected and adjusted using mainly the Eurostat database. Some of the variables that could not be encountered there, were found in WorldBank or OECD databases. The list of these variables is presented in Appendix 2.

To address each of the following research questions and check the results for robustness, the models were tested using panel data analysis regression methods with fixed effects and BMA which dealt with the cross-sectional dataset. Each of the following four sections will start with a short problem statement and research hypothesis. Then the panel data fixed effect results are presented and described followed by the cross-sectional data results achieved with BMA. In the end of each section, the results are compared to draw the conclusion and possibly form further research questions.

Research question 1: to what extent does the general share of ISCED 6-8 graduates towards the total country's population exert a significant positive effect on GDP in 2013-2020?

Some researchers suggested that the more people obtain HE degrees, the higher the growth rates might be in the long run (see e.g. Barro & Lee, 2001 who found a positive association between higher levels of education, including higher education degrees, and economic growth). However, the saturation effect for the educated labour force might be achieved in most of the developed countries and therefore, it may not be economically desirable for a developed country to have increasing rates of population obtaining any tertiary degrees at all. Such countries may potentially have to decide on the optimal share of population with tertiary degree and the type of the degree needed for the economy to develop at a certain pace. To begin breaking down higher education graduates into majors and genders, it might be useful to explore the general effect of higher education on economic growth. The study estimated the following hypothesis:

> H1: Total percentage of graduated students on ISCED 6-8 levels does not significantly impact economic growth (GDP).

Model 1 compares the impact of male and female graduated students towards total countries' population aged 25-34 and 35-55 of GDP growth rates:

$$Y1(av.gr.) = b0 + a \times logGDP_{per\ capita\ PPP} + b1 \times Gt_m^{25-34} + b2 \times Gt_f^{25-34} + b3 \times Gt_m^{35-55} \quad (4)$$

where Gt stands for the share of total country's male/female population with a tertiary diploma towards total country's male/female population respectively. Five countries were excluded (Bulgaria, Croatia, Cyprus, Malta, and Romania) due to lack of these data cells. Dependent variable is the average growth related to 2013 as the base year. During the analysis, 176 observations were monitored for 22 countries in the 8-year period.

Table 15 - Model 1 Fixed effects, robust standard errors

	Coefficient	*Std. Error*	*z*	*p-value*	
const	−157.965	38.2769	−4.127	3.68e-05	**
logGDPcurrentPPP	40.5945	8.83388	4.595	<0.0001	***
25-34yo men	−0.233071	0. 0769139	−3.030	0.0024	***
25-34yo women	0.157130	0.0773180	2.543	0.0110	**
35-55yo men	−0.100814	0. 202831	−0.4970	0.6192	
rho		0.038395			
R-squared		0.652285	Durbin-Watson	1.644135	

It is possible to infer from the table that the level of autocorrelation is relatively low (Durbin-Watson's criterion is above 1.5, rho tends towards zero. The significant variables are logGDP per capita in PPP (purchasing power parity) prices, and share of younger male and female population with tertiary degrees.

BMA analysis is applied to the same model but a cross-sectional dataset is used to carry out the analysis using the benchmark prior visiting and accepting 32 models of 32. Again, 5 countries were missing due to lack of data. The following table presents the results, R-squared equals to 0.49:

Table 16 - BMA analysis for Model 1

	coefficient	std. error	t-ratio	p-value	
const	99.8277	1.69203	59.00	4.69e-022	***
25-34yo men	0.110335	0.0614514	1.795	0.0894	*
35-55yo men	−0.175589	0.0720566	−2.437	0.0254	**
35-55yo women	0.0757615	0.0470468	1.610	0.1247	

According to the information obtained on posterior moments, probability of inclusion (PIP) in most of the 32 models is above 0.5 only for the share of 35-55-year-old women. It means that the share of total population with a tertiary diploma does not exert a significant effect on economic growth, the first hypothesis is not rejected. However, the share of women aged 35-55 with tertiary diplomas towards the total female population of the 22 EU countries might have an effect on economic growth. From this simplified model it might be inferred that even if there is a connection between the percentage of total population with higher education and economic growth, it is rather tentative and therefore, the model needs to be rebuilt to include diversified variables for gender and education level (ISCED 6, 7, 8), which brings forward the second research question.

Research question 2: to what extent do country-level tertiary education results from STEM majors compared to Non-STEM majors (percentage of graduates towards total country's population; percentage of ISCED 6, 7 and 8 graduates; percentage of male and female graduates) exert a significant positive effect on GDP?

Male- and female-dominated majors have been long outlined in research (e.g. Kugler et al., 2021), the career and financial results of women pursuing male-dominated education majors in many cases differs from the outcomes for women who opt for education in female-dominated majors (Albrecht et al., 2004; 2018; Kugler et al., 2021). What is particularly interesting is how to optimise the numbers of graduates by gender and by majors in higher education so that human capital returns would be maximised in terms of economic growth and development. In EU Member States, where higher education is mostly free for end-users to pursue, people with specific preferences and characteristics should be incentivised to opt for certain majors to minimise the drop-out rates, change-of-major costs, and lower the rates of the jobs undertaken out of professional scope. The hypothesis estimated to address this research question is as follows:

> H2: Percentage of graduates of STEM and Non-STEM majors of ISCED 6, 7, and 8 levels (bachelor, master and doctoral graduates) is not robustly correlated with economic growth.

Model 2 compares the impact of STEM majors graduates at bachelor, master and doctoral level on economic growth.

$$Y1(av.gr.) = b0 + a \times logGDP_{per\ capita\ PPP} + b1 \times Gb_{total}^{STEM} + b2 \times Gm_{total}^{STEM} + b3 \times Gd_{total}^{STEM} \qquad (5)$$

where Gb, Gm, and Gd stand for the share of bachelor, master and doctoral graduates in the country's total population. One country was excluded (Netherlands) due to lack of specific data cells for doctoral students. Dependent variable is the average growth related to 2013 as the base year. During the analysis, 189 observations were monitored for 26 countries in the 8-year period.

Table 17- Model 2 Fixed effects, robust standard errors

	Coefficient	*Std. Error*	*z*	*p-value*	
const	105.521	13.7585	7.670	<0.0001	***
logGDPcurrentPPP	0.814124	3.04855	0.2671	0.7894	
Gb_{total}^{STEM}	2.75928e-05	2.44201e-05	1.130	0.2585	
Gm_{total}^{STEM}	3.16660e-05	1.64430e-05	1.926	0.0541	*
Gd_{total}^{STEM}	−0.00017653	0.000253916	−0.6952	0.4869	
rho	0.280188	Durbin-Watson		1.715761	

It is possible to infer from the table that the level of autocorrelation is relatively low (Durbin-Watson's criterion is above 1.5, rho tends towards zero. The significant variables include logGDP per capita in PPP (purchasing power parity) prices, and share of STEM graduates of ISCED 7 level. The results suggest that STEM majors may bring significant economic value and result in higher growth rates.

BMA analysis is applied to the same model but a cross-sectional dataset is used to carry out the analysis using the benchmark prior visiting 1572 models and accepting 595 models of 8192. Again, the Netherlands were missing due to lack of data. The following table presents the results, R-squared equals to 0.41:

Table 18 - BMA analysis for Model 2

	coefficient	std. error	t-ratio	p-value

----

const 99.4753 0.946438 105.1 1.13e-15 ***

logGDPcurrentPPP 3.03875e-06 1.65676e-06 1.834 0.0684 $*Gb_{total}^{STEM}$ 23.9281 8.17473 2.927 0.0039 ***

Gm_{total}^{STEM} −22.3508 13.1363 −1.701 0.0907 $*Gd_{total}^{STEM}$ −12.5343 6.64356 −1.887 0.0609 *

According to the results obtained on the posterior moments, probability of inclusion (PIP) in most of the 595 models is above 0.5 only for male bachelor graduates in STEM majors (PIP=0.711). It means that the share of ISCED 6 graduates in STEM majors may exert a significant effect on economic growth, the second hypothesis is not accepted. Moreover, from this model it might be inferred that there is a connection between the percentage of STEM graduates and economic growth. However, the evidence is still rather tentative and therefore, the model needs to be rebuilt to include diversified variables for gender and STEM majors at each education level (ISCED 6, 7, 8), which brings forward the third research question.

Research question 3: to what extent do female and male graduates of STEM majors exert a significant positive effect on GDP?

According to Eurostat data from 2020, there are 4.7% more women than men in EU Member states, but female graduates (ISCED 5-8 levels) majoring in STEM (science, technologies, engineering, math) account for 33.58% of total STEM students in 2020 as opposed to 33.12% in 2013. Gender pay gap in unadjusted form by activity in construction, industry and services (except public administration, defence, and compulsory social security) is reported to be 13% in 2020. It may imply that more women involved in these fields earn less than men. Economists typically explain such a phenomenon by two main reasons: 1) women may develop their professional qualities in a different way than men as they have to pause their careers to have families and raise children; 2) women working in male-dominated environment might be discriminated against. These two explanations may support and develop one another, resulting in pay and income inequality. From an economic perspective, pay inequality can potentially limit productivity and economic growth: when women are employed to be paid less and have fewer opportunities to advance, they may become disincentivised to invest their resources into their education over time. It can perpetuate the lack of job opportunities, thus resulting in a vicious cycle and cause a loss of potential economic output. This, in turn, could limit the ability of businesses and economies to compete globally. Not only is it interesting to explore the economic effect of more women graduating from STEM majors, but it would be also helpful to find out how many women currently pursue the jobs within the scope of the obtained major. The latter along with the transparency of the transition of STEM graduates to the labour force on the EU labour market may become the topic for my post-doc research. The hypothesis estimated to address this research question is as follows:

> H3: Female STEM ISCED 6-8 graduates' percentage towards total countries' population does not significantly impact economic growth.

Model 3 compares the impact of STEM majors graduates at bachelor, master and doctoral level on economic growth, differentiating between men and women.

$$Y1(av.gr.) = b0 + a \times logGDP_{per\ capita\ PPP} + b1 \times Gb^{STEM}_{male} + b2 \times Gm^{STEM}_{male} + b3 \times Gd^{STEM}_{male} + b4 \times Gb^{STEM}_{female} + b5 \times Gm^{STEM}_{female} + b6 \times Gd^{STEM}_{female} \quad (6)$$

where Gb, Gm, and Gd stand for the share of bachelor, master and doctoral graduates in total country's total population. This time all 27 EU Member states were included in the analysis. Dependent variable is the average growth related to 2013 as the base year. During the analysis, 213 observations were monitored for the 8-year period.

Table 19 - Model 3 Fixed effects, robust standard errors

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	20.7673	20.5233	1.012	0.3209	
logGDPcurrentPPP	17.4216	4.45390	3.912	0.0006	***
Gb^{STEM}_{female}	0.000468136	0.000272132	1.720	0.0973	*
Gm^{STEM}_{female}	2.84579e-05	0.000347180	0.08197	0.9353	
Gd^{STEM}_{female}	0.00530788	0.00116867	4.542	0.0001	***
Gb^{STEM}_{male}	0.00030332	7.12357e-05	4.258	0.0002	***
Gm^{STEM}_{male}	4.54495e-05	0.000189881	0.2394	0.8127	
Gd^{STEM}_{male}	−0.00061915	0.00116175	−0.5330	0.5986	
rho	−0.004516		Durbin-Watson 1.517		

It is possible to infer from the table that the level of autocorrelation is relatively low (Durbin-Watson's criterion is above 1.5, rho tends towards zero. The significant variables include logGDP per capita in PPP (purchasing power parity) prices, and share of STEM female graduates of ISCED 6 and 8 levels and STEM male bachelor graduates. The results suggest that female STEM students (if they do not change majors to female-dominated ones and graduate successfully) may bring significant economic value and result in higher growth rates.

BMA analysis is applied to the same model but a cross-sectional dataset is used to carry out the analysis using the benchmark prior visiting 1572 models and accepting 595 models of 8192. Again, all member states were included in the analysis. The following table presents the results, R-squared equals to 0.41:

Table 20 - BMA results for Model 3

	coefficient	std. error	t-ratio	p-value	
const	99.4753	0.946438	105.1	1.13E-158	***
logGDPcurrentPPP	3.03e-06	1.66E-06	1.834	0.0684	*
Gb_{female}^{STEM}	23.9281	8.17473	2.927	0.0039	***
Gm_{female}^{STEM}	−22.3508	13.1363	−1.701	0.0907	*
Gd_{female}^{STEM}	−12.5343	6.64356	−1.887	0.0609	*
Gb_{male}^{STEM}	14.4521	10.0674	1.436	0.1529	
Gm_{male}^{STEM}	15.5497	9.45692	1.644	0.1019	
Gd_{male}^{STEM}	−10.1818	14.2792	−0.7130	0.4768	

According to the results obtained on the posterior moments, probability of inclusion (PIP) in most of the 595 models is 0.49 only for male doctoral graduates in STEM majors. It means that this model's results suggest that there is a connection between the percentage of male STEM graduates and economic growth. It would be necessary to check the results for robustness and consistency, replacing the dependent variable by GPG. Therefore, the model needs to be rebuilt to include diversified variables for gender and STEM majors at each education level (ISCED 6, 7, 8), which brings forward the final research question.

To check for possible lags between the dependent and independent variables, a simple Generalised Method of Moments (GMM) was carried out using gretl. The dependent variable (y01) is GDP per capita in constant international 2017 dollars, x01 and x02 stand for shares of ISCED 6 male STEM graduates and ISCED 7 female STEM graduates to total population, x03 is a control variable logGDP. The results of the 1-step dynamic panel, using 126 observations are demonstrated in the table 21:

Table 21 - GMM

	coefficient	std. error	z	p-value
y01(-1)	0.229241	0.286325	0.8006	0.4233
x01 (ISCED 6 male STEM grads)	−0.0973712	0.0161049	−6.046	1.48e-09 ***
x02 (ISCED 7 female STEM grads)	0.0589524	0.0192327	3.065	0.0022 ***
x03 (logGDP)	0.0310518	0.0232384	1.336	0.0815 *
const	−0.00677495	0.00164798	−4.111	3.94e-05 ***

Test for AR(1) errors: z = -2.08456 [0.0371]

Test for AR(2) errors: z = 2.52442 [0.0116]

Sargan over-identification test: Chi-square(88) = 118.647 [0.0164]

Wald (joint) test: Chi-square(4) = 44.2141 [0.0000]

Source: author's own calculations

The lagged value of the dependent variable y01 has a coefficient of 0.2292. However, it is not statistically significant at the 5% level (p=0.4233), indicating that the previous period's GDP per capita does not significantly influence the current y01. The output for the variable x02 (ISCED 7 female STEM grads) suggests that for each unit increase in the number of ISCED 7 female STEM graduates, GDP per capita increases by approximately 0.0589 units. This coefficient is statistically significant at the 1% level (p<0.01).

AR(1) and AR(2) suggest there might be autocorrelation with 5% likelihood and 1% likelihood correspondingly. In the given output, the z-scores for the AR(1) and AR(2) tests are -2.08456 and 2.52442, respectively. These z-scores typically indicate the number of standard deviations away from the mean. The Sargan test checks the validity of the over-identifying instruments. The chi-square statistic is 118.647 with a p-value of 0.0164, indicating that the instruments are over-identifying at the 5% level. The Wald test assesses the joint significance of all coefficients in the model. The chi-square statistic is 44.2141 with a p-value of p<0.01, indicating the joint significance of the independent variables at the 1% level.

These results suggest that ISCED 6 male STEM graduates and ISCED 7 female STEM graduates have a significant impact on the GDP per capita. The over-identification test and joint significance test suggest that the chosen instruments are valid and the model as a whole is statistically significant. As the lag of one year does not significantly influence the dependent variable, current use of Panel data methods along with BMA analysis seems to be sufficient.

Research question 4: to what extent does the number of STEM graduates in general and the number of female STEM graduates have a positive effect on narrowing the gender pay gap?

In the global literature, the prevailing understanding of the GPG is that it arises from two primary sources. Firstly, individuals possess specific labour-market attributes, such as work experience in distinct sectors and organizations, as well as education-specific human capital. As a result, women may have less work experience than men due to interruptions in their careers owing to family responsibilities. Secondly, women may face labour market discrimination, which often leads to lower remuneration for the same characteristics as men. These two factors may act as mutual reinforcements. The academic literature regarding GPG with respect to personal and labour-market characteristics, as well as horizontal and vertical segregation (HS and VS), encompasses a multitude of studies (see e.g. Weichselbaumer & Winter-Ebmer, 2005; Olivetti & Petrongolo, 2008; Kassenboehmer & Sinning, 2014; Janssen et al., 2016). The concepts of HS (gender representation in various industries) and VS (gender representation on various levels within one industry) are key frameworks for understanding the gender pay gap (Blau & Kahn, 2003). Boosting the representation of women in STEM fields has the potential to generate a significant positive impact on the GDP of the European Union. According to EIGE (How Gender Equality in STEM Education Leads to Economic Growth, n.d.), once the gender pay gap is closed within the EU, the cross-country GDP per capita is expected to rise by 2.0-3.0% by 2050, the estimated monetary benefit listed on the website is €610 - €820 billion to the EU GDP by 2050. To ensure this growth, professionals working in public education and in private companies dealing with human resources, economists, businessmen and policymakers need to act now and be in line with the notion of motivating more girls to study STEM majors, in accordance with the EU Gender Equality Strategy. Therefore, for economists and policy makers it is particularly important to understand the GPG-EG relationship (Schober & Winter-Ebmer, 2011). The hypothesis estimated to address this research question is as follows:

> H4: Share of female STEM graduates towards the total female countries' population does not significantly impact gender pay gaps (GPG).

Model 4 compares the impact of female STEM graduates at bachelor, master and doctoral level on the gender pay gap.

$$Y2(GPG) = b0 + a \times logGDP_{per\ capita\ PPP} + b1 \times Gb^{STEM}_{male} + b2 \times Gm^{STEM}_{male} + b3 \times Gd^{STEM}_{male} + b4 \times Gb^{STEM}_{female} + b5 \times Gm^{STEM}_{female} + b6 \times Gd^{STEM}_{female} \quad (7)$$

where Gb, Gm, and Gd stand for the share of bachelor, master and doctoral graduates in total country's total population. This time Greece was excluded from the analysis as there was no data available on GPG for the panel dataset. Remaining 26 EU Member states were included in the analysis. Dependent variable is the average growth related to 2013 as the base year. During the analysis, 173 observations were monitored for the 8-year period.

Table 22 - Model 4 Fixed effects, robust standard errors

	Coefficient	*Std. Error*	*z*	*p-value*	
const	5432.66	2301.80	2.360	0.0183	**
logGDPcurrentPPP	1177.50	499.704	2.356	0.0185	**
Gb^{STEM}_{male}	34.1835	19.2061	1.780	0.0751	*
Gm^{STEM}_{female}	−59.7711	31.7014	−1.885	0.0594	*
Gd^{STEM}_{female}	−23.1016	18.0739	−1.278	0.2012	
Gd^{STEM}_{male}	36.4290	21.1430	1.723	0.0849	*
Gb^{STEM}_{female}	−254.397	132.864	−1.915	0.0555	*
Gm^{STEM}_{male}	361.534	177.004	2.043	0.0411	**
rho	0.178	Durbin-Watson	1.864		

It is possible to infer from the table that the level of autocorrelation is relatively low (Durbin-Watson's criterion is above 1.5, rho tends towards zero. The significant variables include logGDP per capita in PPP (purchasing power parity) prices, and share of STEM female and male graduates of ISCED 6, 7 (and doctoral level for male graduates) except for STEM female doctoral graduates. The coefficient signs correspond to the research hypothesis – the more male students graduate from STEM majors (and fewer females) the higher is the GPG. The results suggest that female STEM students (if they do not change majors to female-dominated ones and graduate successfully) may help to significantly lower the gender pay gap overall and possibly contribute to economic growth.

BMA analysis is applied to the same model but a cross-sectional dataset is used to carry out the analysis using the benchmark prior visiting 120 models and accepting 98 models of 128. Again, all member states were included in the analysis except for Greece. The following table presents the results, R-squared equals to 0.53:

Table 23 - BMA results for Model 4

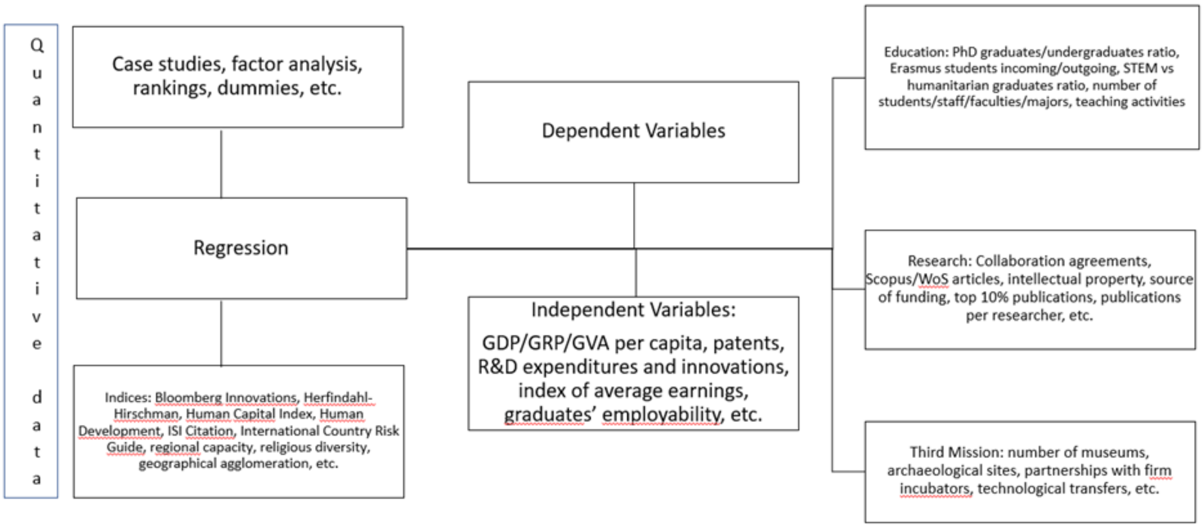
	coefficient	std. error	t-ratio	p-value	
const	69.1727	37.1824	1.86	0.0763	*
logGDPcurrentPPP	2.76753	1.82777	1.714	0.0442	*
Gb_{male}^{STEM}	4.03141	1.9676	−2.049	0.0526	*
Gm_{female}^{STEM}	−2.6433	1.11866	−2.363	0.0274	**
Gd_{female}^{STEM}	−12.2360	8.09098	−1.512	0.1447	
Gd_{male}^{STEM}	14.143	1.6796	2.932	0.1526	
Gb_{female}^{STEM}	−3.346	1.8644	−2.782	0.0367	*
Gm_{male}^{STEM}	11.063	9.07060	1.916	0.0489	*

The results of the BMA analysis suggest that the share of ISCED 6-7 female and male graduates in STEM majors may exert a significant effect on the pay gap, the final hypothesis is not accepted. Moreover, it might be inferred that there is a negative relationship between the percentage of male STEM graduates and the gender pay gap (the more males opt for STEM, the fewer females do the same, the wider is the gender pay gap overall). It would be necessary to insert more variables into the regression models to check the results for robustness and consistency. The results of SEM analysis, panel data analysis and BMA helped to focus the research on STEM majors to explore the relationship between higher education, gender pay gap and economic growth, which is highly likely multifaceted and interconnected. The following section contains replicated results from the four research papers submitted to peer-reviewed journals over the last 2 years.

Further research carried out in 2022-2023

In order to design and carry our research aiming to explore the relationship between higher education and economic development it was crucial to find out what sort of variables have been used for research. Due to the fact that there are multiple papers published on higher education and economic development I cooperated with the head of the School of Management of the Polytechnical University of Milan to write a bibliometric article. Not only did it give us a good understanding of the state of the art and most/least popular methods in the research, but we also managed to construct a map of variables which were often used by economists and researchers. Thanks to this bibliometric analysis I decided to perform my analysis based on specific majors and genders of graduates.

Figure 6 – A map of variables used in quantitative research in selected articles



Source: Agasisti and Petrenko own elaboration

During the stage of pre-emptive testing I chose logGDP as a dependent variable, further substituting logGDP by two other dependent variables, such as Human Development Index (HDI) or gender pay gap (GPG) to check and evaluate the results of panel data regressions and BMA. As the pre-emptive tests appeared to be statistically meaningful just for GPG, me and prof. Cadil decided to answer a question whether female STEM graduates could possibly contribute to closing the gender gap in the European Union. Owing to the fact that higher education addresses horizontal form of segregation as it is a significant component of the GPG, studying the vertical form of segregation within HE is also crucial in tackling the gender pay gap as women are underrepresented in higher-ranking positions (Krause, 2017). Some of the other challenges faced by HEIs worldwide include the following: male students tend to drop out and female STEM students change majors (Astorne-Figari & Speer, 2018), gender inequality in education may negatively relate to economic growth (Minasyan et al., 2019), percentage of population with tertiary education working outside their majors, horizontal and vertical segregation in labour market, etc. If left unaddressed or improperly managed, they may potentially slow down the growth rates.

A number of economists (see e.g. Wolf, 2004; Agasisti & Bertoletti, 2019) pointed at the complex relationship between HE and economic growth, revealing the importance of developing a more sophisticated approach to HE transformation evaluating demographic shifts, technological and institutional changes, gender inequalities in education, and current political and social context. Further research findings provided by a study on the effects of female labour force participation (FLFP) on economic growth featuring over 100 countries

(Baerlocher et al., 2021) suggest a positive relationship between FLFP and growth. Although an extensive study by Ceci et al. (2014) finds a decreasing gender gap in math ability, a number of studies in social and psychological sciences continue to claim otherwise (see e.g. Wang et al., 2013; Dasgupta & Stout, 2014; Makarova et al., 2019), suggesting that barriers to women's participation in math-intensive academic science fields are rooted in pre-college factors and subsequent major choices, as well as historical factors. A closer look at the economic literature on higher education results of both genders, however, does not define the role of female STEM graduates in economic growth, which may constrain policy makers, HE authorities, and students. Well-designed policies and exemplary guidelines around women in STEM can possibly affect knowledge transmission and human capital transformation in developed countries to foster leading global economic trends. This part of the research deals with the answer to the following research question: to what extent does the general share of ISCED 6-8 graduates towards the total country's population exert a significant positive effect on GDP in 2013-2020? The research hypotheses were formulated as follows: H1: Total percentage of graduated students towards total countries' population does not significantly impact economic growth (GDP). In simple terms, to begin dividing all university graduates into groups and to form these groups it is important to understand whether the number of total graduates impacts economic growth in any way.

The sampling algorithm for setting Bayesian priors was extensively described by Błażejowski and Kwiatkowski (2015) and put into practice in the BMA function package of gretl, free econometric software. The following 3 models with cross sectional data were estimated using (1) OLS and (2) BMA methods.

Model 1 compares the impact of male and female bachelor graduates, ISCED6 by major (STEM, F05-F07 vs Non-STEM, all other majors) on GPG:

$$Y1(GPG) = b0 + b1 \times Gb_m^{STEM} + b2 \times Gb_f^{STEM} + b3 \times Gb_m^{non-STEM} + b4 \times Gb_f^{non-STEM}$$

where Gb stands for the share of bachelor graduates in the total male or female country's population respectively.

Model 2 compares the impact of male and female master graduates, ISCED7, by major on GPG:

$$Y1(GPG) = b0 + b1 \times Gm_m^{STEM} + b2 \times Gm_f^{STEM} + b3 \times Gm_m^{non-STEM} + b4 \times Gm_f^{non-STEM}$$

where Gm stands for the share of master graduates in the total male or female country's population respectively.

Model 3 compares the impact of male and female doctoral graduates, ISCED 8, by major on GPG:

$$Y1(GPG) = b0 + b1 \times Gd_{m}^{STEM} + b2 \times Gd_{f}^{STEM} + b3 \times Gd_{m}^{non-STEM} + b4 \times Gd_{f}^{non-STEM}$$

where Gd stands for the share of doctoral graduates in the total male or female country's population respectively.

These ISCED 6-8 variables were split into three different models as it is assumed each year one student can graduate at a given level only once. For each OLS models (1-3), 32 BMA models were constructed to check the input variables for their robust presence in the models.

Table 24 – OLS and BMA results for 3 sets of models.

Variables	Mean	Median	S.D.	OLS (p-value)	BMA coefficients (p-value)
Dependent: GPG, % unadjusted	12.964	13.225	5.968	n/a	n/a
List of independent variables expressed in percent to male/female countries' population, Mx provides the model number:					
M1: ISCED 6 male grads STEM F05-F07	0.1653	0.1588	0.0706	45.87 (0.009)	45.87 (0.096)
M1: ISCED 6 female grads STEM F05-F07	0.0703	0.0652	0.0266	−116.74 (0.126)	−116.74 (0.092)
M2: ISCED 7 male grads STEM F05-F07	0.0917	0.0933	0.0328	193.22 (0.0003)	193.22 (0.0027)
M2: ISCED 7 female grads STEM F05-F07	0.0511	0.0506	0.0183	−271.30 (0.017)	−271.30 (0.0215)
M3: ISCED 8 male grads STEM F05-F07	0.0123	0.0123	0.0062	510.51 (0.181)	510.51 (0.245)
M3: ISCED 8 female grads STEM F05-F07	0.0069	0.0069	0.0033	−542.8 (0.376)	−542.8 (0.57)
M1: ISCED 6 male grads other majors	0.2583	0.2341	0.0988	−16.70 (0.258)	−16.70 (0.506)
M1: ISCED 6 female grads other majors	0.4977	0.4390	0.1835	7.78 (0.445)	7.78 (0.567)
M2: ISCED 7 male grads other majors	0.1744	0.1748	0.0556	−23.98 (0.46)	−23.98 (0.47)
M2: ISCED 7 female grads other majors	0.3149	0.3114	0.1088	18.65 (0.247)	18.65 (0.307)
M3: ISCED 8 male grads other majors	0.0117	0.0116	0.0053	989.88 (0.024)	989.88 (0.041)
M3: ISCED 8 female grads other majors	0.0149	0.0135	0.0086	-584.07 (0.006)	-584.07 (0.075)

Source: Authors' own research

A set of 3 OLS models with heteroskedasticity-robust (HC) standard errors in Table 24 shows a positive statistically significant relationship between male STEM bachelor graduates and GPG depicted by both OLS and BMA models that were accepted. Female STEM graduates of the same level robustly negatively relate to GPG, which implies that a potential growth in percentage of female STEM graduates could possibly narrow the pay gap. Statistical results for non-STEM graduates did not show a significant relationship with GPG. A very similar picture can be recognised for master-level male and female STEM graduates, with a robust positive connection between the shares of male graduates and pay gap. In other words, the higher the share of male master graduates of STEM majors, the wider the gender gap. Shares of female STEM master graduates in the female population of EU countries robustly strongly negatively affects GPG. Shares of graduates of other majors did not seem to have a relationship with the pay gap. ISCED 8 level STEM graduates are much less frequent among the female population and it might be one of possible explanations for the lack of statistically significant relationship they may have with GPG. Male doctoral STEM graduates' shares in male population do not seem to have an effect on GPG either. Despite this fact, shares of doctoral non-STEM graduates of both genders showed a robust relationship with the pay gap, positive for males and negative for females. The overall results overall suggest that increasing the share of female graduates in STEM majors may cause the pay gap to shrink.

Therefore, STEM majors might be viewed as central in carrying out HE policies that may incentivize young women to enter these programs and successfully obtain their bachelor and master degrees. These education levels are strongly associated with gender pay gaps. The following step is to explore how probable graduates of certain genders, majors and education levels may be included in the models. Probability of Inclusion (PIP) in BMA refers to the probability that a variable is included in the model, based on the data and prior distribution. The following Table 25 provides PIPs to identify important components of the models, which are ranked according to their importance.

Table 25 – PIP and ranking of variables presented in 96 BMA models

List of independent variables expressed in percent to male/female countries' population, Mx provides the model number:	PIP	Rank
M1: ISCED 6 male grads STEM F05-F07	0.291	2
M1: ISCED 6 female grads STEM F05-F07	0.296	1
M1: ISCED 6 male grads other majors	0.1741	4
M1: ISCED 6 female grads other majors	0.1744	3
M2: ISCED 7 male grads STEM F05-F07	0.861	1
M2: ISCED 7 female grads STEM F05-F07	0.632	2
M2: ISCED 7 male grads other majors	0.171	4
M2: ISCED 7 female grads other majors	0.201	3
M3: ISCED 8 male grads STEM F05-F07	0.308	3
M3: ISCED 8 female grads STEM F05-F07	0.212	4
M3: ISCED 8 male grads other majors	0.446	1
M3: ISCED 8 female grads other majors	0.368	2

Source: Authors' own research

In the first set of models, shares of female bachelor graduates are included into the models with higher probability than those of the opposite gender. On the contrary, in the second set depicting master students, shares of male STEM graduates have higher probability ranks. It might be explained by the fact that female bachelor graduates may opt for a non-STEM major for their master-level education.

During the second stage of the research on the relationship between STEM education and GPG we carried out BMA analysis on a cross-sectional dataset that included the following set of variables.

Table 26 - Further research analysis dataset mapping

y1	Y1 growth rate related to each previous year 2
y2	Y2 Gender pay gap in unadjusted form, %
y3	Y3 HDI 2015-2021
x1	Public expenditure on tertiary education, general government spending
x2	Public expenditure on E02-08 (primary, secondary and tertiary) education as % of GDP
x3	Employment by educational attainment level (tertiary education) 15-64 y.o.
x4	Employment of males educational attainment level (tertiary education) 15-64 y.o.
x5	Employment of females educational attainment level (tertiary education) 15-64 y.o.
x6	Unemployment by sex and age – annual data, % towards total population
x7	Gross domestic expenditure on R&D (GERD) at national level (higher education ONLY), Million Euro
x8	Expected years in tertiary education
x9	Total high-tech trade, exports from EU to the rest of the world
x10	Employment in knowledge-intensive service sectors
x11	Human resources in science and technology, persons with tertiary education
x12	Employment by all industries
x13	inflation rate 2
x14	LOG GDP current PPP
x15	GDP current PPP per capita in dollars to 2017
x16	Population
x17	gross fixed capital formation
x18	Hours worked per 1 worker OECD.org Average annual hours actually worked
x19	Population males
x20	Population females
x21	Ratio of annual expenditure per student at the tertiary level and primary level of education, in public educational institutions
x35	Total ISCED 6-8 male grads STEM F05-F07
x38	ISCED 6 male grads STEM F05-F07
x39	ISCED 6 female grads STEM F05-F07
x41	ISCED 7 male grads STEM F05-F07
x42	ISCED 7 female grads STEM F05-F07
x44	ISCED 8 male grads STEM F05-F07
x45	ISCED 8 female grads STEM F05-F07
x50	ISCED 6 male grads all majors except F05-F07
x51	ISCED 6 female grads all majors except F05-F07
x53	ISCED 7 male grads all majors except F05-F07
x54	ISCED 7 female grads all majors except F05-F07
x56	ISCED 8 male grads all majors except F05-F07
x57	ISCED 8 female grads all majors except F05-F07
x58	women to men ratio
x71	Life expectancy at birth
x72	School enrolment, primary (% gross)
x73	School enrolment, secondary (% gross)
x74	School enrolment, tertiary (% gross)
x75	Suicide mortality rate (per 100,000 population)
x76	Taxes on income, profits and capital gains (% of revenue)
x77	Fertility rates by age [DEMO_FRATE__custom_5632248]
x78	Mean age of women at birth of first child

The following table demonstrates BMA results received for this dataset with GPG taken as a dependent variable in 27 EU Member states in 2013-2020. Currently, a research paper with the results of the study we carried out together with Kwiatkowski & Błażejowski is under review in the journal „Labour Economics". In Bayesian model averaging (BMA), the choice of prior distributions has a crucial impact on the estimation and model selection process. Two commonly used prior distributions in BMA are the binomial prior and the g-prior, both of which are associated with the work of Hannan and Quinn (1979). The binomial prior is a prior distribution used to assign prior probabilities to models in BMA. It assumes that each model has *an equal probability of being selected*, making it a non-informative prior. In other words, the binomial prior treats all models as equally likely a priori, without favouring any particular model. This allows for an objective assessment of model probabilities based solely on the observed data. The g-prior is another prior distribution used in BMA and unlike the binomial prior, the g-prior incorporates some level of information about the models into the prior probabilities. The g-prior assumes a normal distribution for the regression coefficients, with a mean of zero and a covariance matrix proportional to the inverse of the Fisher information matrix. The scaling parameter g controls the amount of information included in the prior, with higher values of g corresponding to stronger prior information and lower values to weaker prior information. The g-prior strikes a balance between non-informative priors (e.g., binomial prior) and fully informative priors. It allows the data to have a greater influence on model selection, while still providing some regularization by incorporating prior information. This time we opt for a g-prior called Hanna and Quinn (HQC) in gretl's package called Bayesian Model Averaging as we have some information on the models tested during the pre-emptive and the first research stages. The model size for the number of variables shown in table 26 is 12.5 which corresponds to roughly ¼ of the variables present in the model. The significance level is 60%, meaning that only the significant models are chosen for the analysis. The number of possible models is 33554432, out of which 382443 models were visited and 130959 were accepted during the analysis. The R-squared value for the model is quite high, 0.95352, which means that the model is capable of describing the real-world settings with a very high degree of certainty.

Table 27 - BMA results for GPG using a wider range of variables

	coefficient	std. error	z	p-value
const	12.6116	0.454161	27.77	<0.001***
x2	-2.05443	0.445350	-4.613	<0.001***
x4	1.42189	0.187862	7.569	<0.001***
x8	6.91508	1.06412	6.498	<0.001***

x10	0.193909	0.09150	2.119	0.0341 **
x21	6.76027	1.53465	4.405	<0.001***
x39	**-164.521**	**23.8416**	**-6.901**	**<0.001*** **
x41	**551.280**	**72.1519**	**7.641**	**<0.001*** **
x42	**-483.756**	**108.113**	**-4.475**	**<0.001*** **
x58	95.2993	14.4534	6.594	<0.001***
x77	-29.5756	5.43715	-5.440	<0.001***

The share of female STEM graduates of ISCED 6-7 levels and master male STEM graduates appear to be highly likely connected to the GPG. The fewer women graduate with STEM bachelor and master degrees, the higher are the GPG rates in developed countries of the EU. The other significant variables include expenditure in education (x2), expected years in tertiary education, employment in knowledge-intensive sectors as well as the ratio of annual expenditure per student at the tertiary level and primary level of education, in public educational institutions. There is also an interesting connection between fertility rates – the lower the fertility rates, the higher is the GPG. Negative correlation between fertility rates, denoted as x77, and GPG might be quite concerning because these results essentially imply that the later women have children, the smaller the GPG rate becomes. Encouraging more women to pursue STEM majors could potentially help reduce the GPG by providing more opportunities for women to engage in research and development sectors, and overcome barriers such as the 'glass door' or 'glass ceiling', which contribute to higher growth rates in developed countries. Moreover, if we take a look at the posterior probabilities (how likely these variables are to be included in the majority of the models), we can see that 11 variables belong to an interval [0.5; 1], which means that their presence in the models is expected to be consistent and robust. These are the employment of males with tertiary education, male/female ratio, fertility rates, public expenditure on education, the ratio of annual expenditure per student at the tertiary level and primary level of education, expected years in tertiary education, employment in knowledge-intensive sectors. The other significant variables that address STEM higher education are total ISCED 6-8 male grads STEM F05-F07, female STEM graduates of ISCED 6-7 and master male STEM graduates.

Table 28 - Posterior moments for GPG (unconditional and conditional on inclusion)

	PIP	Mean	Std.Dev.	Cond.Mean	Cond.Std.Dev
x4	0.96	1.29	0.46	1.35	0.37
x58	0.93	74.93	31.36	80.35	24.88
x77	0.85	-21.65	12.70	-25.58	9.48
x2	0.80	-1.33	0.84	-1.66	0.59
x21	0.79	4.82	3.30	6.09	2.46
x8	0.77	5.10	3.76	6.63	2.86
x41	0.72	367.36	2449.17	506.73	2864.16

x39	0.56	-109.03	2446.79	-195.79	3276.22
x35	0.51	25.51	2445.40	49.55	3407.67
x10	0.50	0.18	0.26	0.35	0.27
x42	0.50	-372.67	5191.70	-745.46	7323.81
x73	0.44	-0.04	0.07	-0.10	0.07
x36	0.43	121.93	5187.79	285.57	7936.31
x38	0.36	250.47	5181.32	-693.58	8604.24
x74	0.31	0.03	0.09	0.09	0.13
x6	0.30	0.08	0.70	0.28	1.25
x71	0.28	-0.18	0.61	-0.65	1.03
x45	0.27	430.69	5475.45	1605.32	10481.53
x44	0.24	-108.16	2478.77	-455.22	5069.68
x11	0.24	-0.02	0.10	-0.09	0.18
x57	0.23	-92.77	369.44	-403.18	684.14
x5	0.23	-0.04	0.12	-0.17	0.19
x12	0.21	1.11	28.74	5.21	62.14
x1	0.20	5.90	26.22	29.20	52.18
x78	0.19	-0.02	0.53	-0.10	1.23

The following step is to verify these results using the same variables to see how they impact economic growth, replacing GPG by the annual growth rate of the GDP per capita in PPP prices with 2013 as base year. Currently, a research paper with the results of the study we carried out together with Kwiatkowski and Błażejowski is under review in the journal „World Development". This time we opt for a g-prior called Hanna and Quinn (HQC) in gretl's package called Bayesian Model Averaging as we have some information on the models tested during the pre-emptive and the first research stages. The model size for the number of variables shown in table 26 is 12.5 which corresponds to roughly ¼ of the variables present in the model. The significance level is 60%, meaning that only the significant models are chosen for the analysis. The number of possible models is 33554432, out of which 342250 models were visited and 111236 were accepted during the analysis. The R-squared value for the model is quite high, 0.9962, which means that the model is capable of describing the real-world settings with a very high degree of certainty.

Table 29 - BMA results for average economic growth using a wider range of variables

	coefficient	std. error	t-ratio	p-value	
const	−3.17381	0.6723	−4.721	0.042	**
x2	−0.0273371	0.0064	−4.242	0.051	*
x4	0.0114	0.0026	4.377	0.048	**
x6	0.0113	0.0027	4.219	0.052	*
x8	0.2874	0.0566	5.078	0.037	**
x10	0.0201	0.0045	4.433	0.047	**
x12	−9.49590e-06	0.0000	−3.624	0.068	*
x18	0.0002	0.0000	7.054	0.020	**
x19	0.0000	0.0000	4.069	0.055	*

x21	0.0746	0.0180	4.142	0.054	*
x74	−0.0101517	0.0019	−5.469	0.032	**
x75	−0.00604350	0.0011	−5.567	0.031	**
x76	−0.00491876	0.0011	−4.413	0.048	**
x77	−0.0630966	0.0412	−1.533	0.265	
x71	−0.00395794	0.0015	−2.666	0.117	
x35	0.0014	0.0003	4.327	0.050	**
x38	**−0.00145241**	**0.0003**	**−4.327**	**0.050**	**
x39	**0.0001**	**0.0000**	**4.407**	**0.048**	**
x41	**−0.00131039**	**0.0003**	**−4.302**	**0.050**	*
x42	**−9.67414e-05**	**0.0000**	**−4.625**	**0.044**	**
x44	**−0.00108763**	**0.0002**	**−4.437**	**0.047**	**
x45	**−0.00135620**	**0.0003**	**−4.237**	**0.051**	*
x57	0.0006	0.0001	4.514	0.046	**
x58	1.2836	0.2763	4.646	0.043	**

The share of female and male STEM graduates of ISCED 6-8 levels appears to be highly likely connected to the average GDP per capita growth rates. The more women graduate with STEM degrees, the higher are the average GDP per capita growth rates in developed countries of the EU. The other significant variables include expenditure in education, hours worked, expected years in tertiary education, employment in knowledge-intensive sectors as well as the ratio of annual expenditure per student at the tertiary level and primary level of education. There seems to be also a negative relationship between fertility rates, life expectancy at birth, tertiary school enrolment, suicide mortality rate and taxes on income, profits and capital gains. The latter 2 variables and fertility rates make perfect sense, however, the negative relationship of tertiary school enrolment in general and the average GDP per capita growth rates may result in 2 conclusions: 1) overall high level of education has been reached, the share of population with tertiary education might satisfy the market needs and now it is important to not raise the number of people enrolled in tertiary degree programmes, but to adjust the number of students in majors; 2) the rate of student drop-outs, students changing their major or people who opt not to work within the scope of their tertiary education might be high. The key is to understand what the optimal number of people holding a specific degree is, what is the percentage of drop-out rates, rates of students switching majors and how graduates transition to the labour market, if they begin their work life with the jobs they were educated to do. The relationship between life expectancy and growth may imply that people might exceed expectations by living longer, thus positively influencing average growth rates. If they happen to die earlier than expected, life expectancy may have a negative relationship on the average growth.

Moreover, if we take a look at the posterior probabilities (how likely these variables are to be included in the majority of the models), we can see that again, 11 variables belong to an interval [0.5; 1], which means that their presence in the models is expected to be consistent and robust. These are hours worked, tertiary school enrolment, expected years in tertiary education, fertility rates, suicide mortality rates, employment by all industries, unemployment by sex and age, the employment of males with tertiary education, male/female ratio, fertility rates, public expenditure on education, the ratio of annual expenditure per student at the tertiary level and primary level of education and male/female ratio. The other significant variables that address STEM higher education are total ISCED 6-8 male grads in STEM majors F05-F07, especially male bachelor and master STEM graduates.

Table 30 - Posterior moments for average economic growth (unconditional and conditional on inclusion)

	PIP	Mean	Std.Dev.	Cond.Mean	Cond.Std.Dev
x18	**0.999**	**0.000**	**0.000**	**0.000**	**0.000**
x74	**0.997**	**-0.002**	**0.000**	**-0.002**	**0.000**
x8	**0.997**	**0.042**	**0.009**	**0.042**	**0.009**
x77	**0.996**	**0.093**	**0.018**	**0.093**	**0.017**
x75	**0.915**	**-0.001**	**0.001**	**-0.001**	**0.000**
x12	**0.684**	**0.000**	**0.000**	**0.000**	**0.000**
x38	**0.664**	**0.000**	**0.000**	**0.000**	**0.000**
x58	**0.653**	**0.066**	**0.061**	**0.101**	**0.046**
x35	**0.599**	**0.000**	**0.000**	**0.000**	**0.000**
x41	**0.513**	**0.000**	**0.000**	**0.000**	**0.000**
x6	**0.512**	**0.001**	**0.002**	**0.002**	**0.001**
x44	0.405	0.000	0.000	0.000	0.000
x78	0.395	-0.001	0.002	-0.003	0.003
x45	0.352	0.000	0.000	0.000	0.000
x71	0.323	-0.001	0.001	-0.002	0.002
x57	0.321	0.000	0.000	0.000	0.000
x42	0.321	0.000	0.000	0.000	0.000
x39	0.302	0.000	0.000	0.000	0.000
x10	0.287	0.000	0.000	0.000	0.000
x19	0.273	0.000	0.000	0.000	0.000
x17	0.256	0.000	0.000	0.000	0.000
x4	0.254	0.000	0.001	0.001	0.001
x21	0.215	0.001	0.003	0.004	0.005
x76	0.187	0.000	0.000	0.000	0.000
x2	0.155	0.000	0.000	0.000	0.001

A correlation coefficient of 0.867144 between the analytical and numerical probabilities of the models in Bayesian model averaging (BMA) suggests a strong positive linear relationship. This indicates a high degree of agreement or similarity between the probabilities calculated using different methods. In BMA, the "analytical probabilities" refer to the probabilities of the models obtained through mathematical calculations or closed-form solutions. These probabilities are often derived based on specific prior distributions and the observed data, using Bayesian inference techniques. The "numerical probabilities" indicate the probabilities of the models computed using numerical methods or algorithms. These methods involve approximate calculations, such as Markov Chain Monte Carlo (MCMC) simulations or numerical optimization techniques, to estimate the model probabilities. The correlation coefficient between the analytical and numerical probabilities quantifies the linear relationship between these two sets of probabilities. It ranges from -1 to 1, where 1 indicates a perfect positive linear relationship, meaning that the analytical and numerical probabilities move in perfect alignment, which means that they increase or decrease proportionally and have a strong positive relationship. On the contrary, a correlation coefficient of -1 indicates a perfect negative linear relationship, suggesting that the analytical and numerical probabilities move in perfect opposition. For example, as numerical probabilities increase, the analytical set decreases proportionally and they have a strong negative relationship. If this coefficient tends to 0, it is suggested that there is no linear relationship between the analytical and numerical probabilities, there is no systematic pattern of movement between the two sets of probabilities. Low correlation may suggest discrepancies or inconsistencies between the two approaches, indicating a need for further investigation or potential issues with the numerical calculations. In this case, the correlation coefficient of 0.867144 suggests a robust agreement between the analytical and numerical probabilities, indicating a consistent and reliable estimation of model probabilities in the BMA framework. In other words, the results of this analysis are considered to be robust and reliable.

Higher education, particularly in the field of STEM, plays a vital role in preparing individuals for careers in industries that drive economic growth and innovation. At the moment, a great number of STEM fields often offer higher wages and are in high demand due to technological advancements and the need for specialized skills. Despite some progress in recent years, a gender pay gap still exists in practically all careers. When women are underrepresented in certain jobs or face barriers that limit their career advancement, it narrows the opportunities for talented people to bring diversity and professionally develop in these critical sectors. This can slow down overall productivity, and economic growth. Addressing the gender pay gap through promoting gender equality in STEM may help to unlock the full potential of talent and contribute to economic development in the long-term perspective. Aiming for higher percentage of female representation in STEM majors requires efforts to address systemic biases, provide equal opportunities in primary and secondary education. Several potential implications could be given closer attention:

1. In terms of finding causal relationships we could seek to determine the relationship between promoting gender equality in STEM and its impact on economic development. This could involve studying the effects of gender diversity in STEM fields on productivity, innovation, and firm performance. Research might involve conducting case studies, carrying out interviews with graduates and using statistical techniques to establish causal links.
2. In terms of exploring the Labour Market we may seek to identify the specific mechanisms that contribute to the gender pay gap. This could involve analysing specific groups of graduates over a period of time of 5-8 years to obtain a quantitative dataset that could help to determine factors such as occupational segregation, discrimination, and the role of education and training in influencing earnings disparities. Research could also focus on understanding the dynamics of career progression and the impact of gender biases and stereotypes on women's advancement in STEM occupations.
3. To understand the strategies of Human Capital investment we could examine the determinants of educational choices and career decisions in STEM fields, particularly among women. This would involve investigating the role of primary and secondary education, dropout rates and switching major rates, access to resources, mentorship programs, and initiatives aimed at reducing gender imbalances in STEM enrolment and retention. Researchers might also explore what exactly happens to graduates once they obtain their tertiary diplomas, how many of them wok within the scope of the field they were educated in. It might be useful to monitor the effectiveness of policy interventions to encourage women's participation in STEM education and careers.
4. We believe it would be practical to assess the effectiveness of policy interventions aimed at promoting gender equality in STEM and reducing the gender pay gap. Such analysis might involve evaluating the impact of action policies, diversity and inclusion initiatives, workplace flexibility measures, and family-friendly policies. We could analyse the costs and benefits of different policy approaches and investigate the potential trade-offs associated with various interventions.

Despite the fact that economic growth and development is a topic which is discussed in a myriad of research papers not only by economists, but also by educators, sociologists, statisticians and policy makers, there is still a lot to accomplish in terms of high-quality research. It is still necessary to provide empirical evidence, quantitative analysis, and policy recommendations to guide efforts in addressing the gender pay gap, promoting gender equality in STEM, and harnessing the full potential of talent for long-term economic development. Therefore, in the scope of this study, we could assume that the terms “economic growth” and “economic development” are both affected by tertiary education, with a specific focus on STEM education of women. These research results suggest that while tertiary education is positively correlated with economic growth, it can also be attributed to substantial changes in the gender pay gap. In case such long-term positive changes occur, they could result in economic development of the 27 Member countries in Europe.

Conclusion

The study attempted to carry out reliable empirical estimates of the relationship between tertiary education and economic development in the 27 European Union countries during the period of 2013–2020 in order to determine the impact of tertiary education on the economic development of the EU member states. In the framework of this study, several indicators of economic growth and development were used – the growth rate of real GDP per capita, GDP per capita in PPP price rates, gender pay gap, and tertiary education represented by a share of the population holding a tertiary degree. Relationships between specific tertiary degrees in social sciences, technical sciences, chemistry, biology, etc. and economic growth were not part of this research. The first part of the conclusion summarises the answers to the research questions formulated in the introduction to this research work, followed by economic, social and political implications, discussion, limitations and questions for further research.

1) to what extent does general share of ISCED[9] 6-8 graduates exert a significant positive effect on GDP in 2013-2020?

The overall share of ISCED 6-8 graduates does not seem to exert a significant effect on the gross domestic product per capita in purchasing power parity prices. It may be implied from tables 15-16 that the general effect of having just more people with tertiary education is quite vague and blurred for developed countries. It might be explained by the overall economic development and saturation of the quality labour force on the labour market. Once the optimal level of obtaining economic gain from quality human resources is reached, it might be necessary to start matching the "production" of high-quality, well-educated labour force within higher education organisations to the needs of the labour market more precisely. In order to detect such market needs, it is necessary to answer the question: graduates of which ISCED majors in particular drive economic development of already developed EU countries? Which majors make the economies grow more rapidly? Therefore, the second research question was formulated as follows:

2) to what extent do country-level tertiary education results (percentage of graduates towards total country's population; percentage of ISCED 6, 7 and 8 STEM graduates; percentage of male and female graduates) exert a significant positive effect on GDP?

[9] More on ISCED levels is available at the UNESCO Institute for Statistics uis.unesco.org; in this article we refer to ISCED levels as follows: ISCED 5 = Short-cycle tertiary education. ISCED 6 = Bachelors degree or equivalent tertiary education level. ISCED 7 = Masters degree or equivalent tertiary education level. ISCED 8 = Doctoral degree or equivalent tertiary education level.

The results of panel data analysis with fixed effects presented in table 17 suggest that STEM majors may bring significant economic value and result in higher growth rates as the percentage of ISCED 6-8 graduates is statistically significant. According to the BMA results obtained on the posterior moments, probability of inclusion (PIP) in most of the 595 models is above 0.5 only for male bachelor graduates in STEM majors (PIP=0.711). It means that the share of ISCED 6 male graduates in STEM majors may exert a significant effect on economic growth. Moreover, from this model it might be inferred that there is a connection between the percentage of STEM graduates and economic growth. It was decided to break down the majors into STEM and non-STEM ones and explore possible individual effects of male and female graduates.

3) to what extent do graduates of STEM and non-STEM majors exert a significant positive effect on GDP (in total and in terms of gender or ISCED 6-8 levels)?

In the scope of panel data fixed effects analysis, the significant variables included logGDP per capita in PPP (purchasing power parity) prices, the share of STEM female graduates of ISCED 7 and 8 levels and STEM male doctoral graduates, with bachelor male graduates being close to significant. The results suggest that female STEM students (if they do not change majors to female-dominated ones and graduate successfully) may bring significant economic value and result in higher growth rates. Once BMA analysis was carried out using a cross-sectional dataset, probability of inclusion (PIP) in most of the 595 models is 0.49 only for male doctoral graduates in STEM majors. It means that this model's results suggest that there is a connection between the percentage of male STEM graduates and economic growth (tables 19-21). It would be necessary to check the results for robustness and consistency, replacing the dependent variable by GPG. Therefore, the model was rebuilt to include diversified variables for gender and STEM majors at each education level (ISCED 6, 7, 8), which brings forward the final research question.

4) to what extent does the number of STEM graduates in general and the number of female STEM graduates have a positive effect on narrowing the gender pay gap?

It is possible to infer from the table 22 that the significant variables include logGDP per capita in PPP (purchasing power parity) prices, and share of STEM female and male graduates of ISCED 6, 7 (and doctoral level for male graduates) except for STEM female doctoral graduates. The coefficient signs corresponded to the research hypothesis – the more male students graduate from STEM majors (and fewer females) the higher is the GPG. The results suggest that female STEM students (if they do not change majors to female-dominated ones and graduate successfully) may help to significantly lower the gender pay gap overall and possibly contribute to economic growth. Once BMA analysis was carried out (table 23) with a cross-sectional dataset using the benchmark prior, it was possible to conclude that the share of ISCED 6-7 female and male graduates in STEM majors may exert a significant effect on the pay gap. Moreover, it might be inferred that there is a negative relationship between the percentage of male STEM graduates and the gender pay gap (the more males opt for STEM, the fewer females do the same, the wider is the gender pay gap overall).

Because the research hypotheses do not take into account a myriad of other factors that may influence both average growth rates and gender pay gaps, such as skills mismatch, labour market needs, legislative and social system, individual professional and personal preferences and bias, it would be necessary to insert more variables into the regression models to check the results for robustness and consistency. The results of SEM analysis, panel data analysis and BMA helped to focus the research on STEM majors to explore the relationship between higher education, gender pay gap and economic growth, which is highly likely multifaceted and interconnected. Additional research submitted for review in Economics Letters (Petrenko & Cadil, 2023) described a set of 3 OLS models with heteroskedasticity-robust (HC) standard errors (tables 22-3). The results suggest a positive statistically significant relationship between male STEM bachelor graduates and GPG depicted by both OLS and BMA models. Female bachelor STEM graduates‘ shares robustly negatively relate to GPG, which implies that a potential growth in percentage of female STEM graduates could possibly narrow the pay gap provided that the legislative and social system do not push women out of the STEM jobs market. Statistical results for non-STEM graduates did not show a significant relationship with GPG. A very similar picture can be recognised for master-level male and female STEM graduates, with a robust positive connection between the shares of male graduates and pay gap. In other words, the higher the share of male master graduates of STEM majors, the wider the gender gap. Shares of female STEM master graduates in the female population of EU countries robustly negatively affect GPG. Shares of graduates of other majors did not seem to have a relationship with the pay gap. ISCED 8 level STEM graduates are much less frequent among the female population and it might be one of possible explanations for lack of statistically significant results obtained within that part of the research. As for the final stage of the research, larger models that included 78 variables in total were built and analysed with the help of BMA methods. These research results were described in two articles which are currently under review, featuring gender pay gap as the dependent variable (Petrenko et al., 2023, Labour Economics, unpublished, submitted for review on Oct 25, 2023) and average GDP growth with 2013 as base year (Petrenko et al., 2023, World development, working paper, currently not submitted for review). The results of this research work underpin not only importance of the quantity of female STEM students at all ISCED levels, but also the quality of education and the legislative and social conditions for women to take up jobs in STEM sectors after graduation.

Current study estimated four main hypotheses that addressed the research questions and the following part of the conclusion is intended to recap on them and provide rationale and reasoning for the results.

H1: Total percentage of graduated students towards total countries' population does not significantly impact economic growth (GDP). This hypothesis was not rejected. The lack of significant effect of the total percentage of tertiary education graduates on economic growth could be explained by some of the following factors:

1. Mismatch of skills and job requirements. In a perfect situation with 100% of population holding a tertiary degree, a large share of a country's nationals will have to either do a different job that would require other skills (e.g. manual jobs) or change the country of their residence in search for the jobs that could suit their education level. Therefore, the share of population with a tertiary degree does not guarantee economic development of the country as it might not suit the current market needs of the region.
2. Labour market needs. These needs have to be monitored and forecasted in advance to create suitable study programs for prospective entrants to apply for.
3. Quality of education over the quantity of the graduates. There has to be a balance between the system of tertiary education and the economy of the country, so that the study programs aim to educate individuals to fit into the economic system successfully once they graduate. If the education system does not effectively equip students with the necessary knowledge and skills for the workforce, the impact on economic growth may be diminished.
4. Other factors of economic development. Innovations, technical advancement, gender and social inequalities, and other factors may often serve as externalities which could

potentially slow the growth rates of the economies. Such factors need to be considered to minimise their negative effects.

5. Time lapse factors. Positive economic effects from education may take time to occur. Economists and researchers have not yet agreed on a "perfect" time lapse between the time students enrol/graduate from selected majors and the time there is a significant economic effect from their work at the labour market.

H2: Percentage of STEM graduates is not robustly correlated with economic growth if compared to percentage of graduates from other majors. From the results demonstrated in tables 17 and 18, the second hypothesis is not accepted. There seems to be a robust relationship between male STEM ISCED 6 graduates and economic growth according to the BMA analysis of the cross-sectional data and STEM 6-8 graduates' percentages appeared to be significant in the panel data analysis. Therefore, the percentage of STEM graduates is highly likely robustly correlated with economic growth, male and female STEM graduates' effect on growth needs to be studied in more detail. Within one of the avenues for further research it seems reasonable to compare the results of macro analysis to the data obtained at micro level, which is further discussed at the end of this thesis.

H3: Female STEM graduates' percentage towards total countries' population does not significantly impact economic growth. From the results demonstrated in tables 19, 20, 21, 29, and 30, the third hypothesis is not accepted. It could be implied that female STEM graduates' percentage may exert a positive effect on narrowing the gender pay gap. Despite the fact that the role of higher education is important in providing equal educational opportunities to both genders, it is clearly not the only factor at play. STEM job market, its entry conditions, legislative and social incentives have to be balanced so that women who already hold STEM degrees would be incentivised to take up these jobs (VanHeuvelen & Quadlin, 2021).

H4: Share of female STEM graduates towards the total female countries' population does not significantly impact gender pay gaps (GPG). According to the results demonstrated in tables 21, 24, 27, and 28, this final hypothesis is not accepted. The share of female STEM graduates of ISCED 6-7 levels and master male STEM graduates appear to be highly likely connected to the GPG. The fewer women graduate with STEM bachelor and master degrees, the higher are the GPG rates in developed countries of the EU. The other significant variables include expenditure in education, expected years in tertiary education, employment in knowledge-intensive sectors as well as the ratio of annual expenditure per student at the tertiary level and primary level of education, in public educational institutions. Once the posterior probabilities (how likely these variables are to be included in the majority of the models) are considered, it is visible that 11 variables belong to an interval [0.5; 1], which means that their presence in the models is expected to be consistent and robust. These are the employment of males with tertiary education, male/female ratio, fertility rates, public expenditure on education, the ratio of annual expenditure per student at the tertiary level and primary level of education, expected years in tertiary education, employment in knowledge-intensive sectors. The other significant variables that address STEM higher education are total ISCED 6-8 male grads STEM F05-F07, female STEM graduates of ISCED 6-7 and master male STEM graduates.

Owing to the fact that most of the variables used in the study demonstrated consistent results with both OLS and BMA modelling, it seems to be appropriate to use both complementary methods with other growth-related explanatory variables in future analyses to study the relationship between higher education, GPG and economic growth.

Using Structural Econometric Modelling can help to explore specific factors that contribute to the relationship between higher education and economic growth, so that the strategies for promoting economic growth through investment in STEM education could be developed. Such strategies' agenda could include the following actions:

- Providing additional resources to support STEM education can help to attract and retain top faculties, improve internal facilities and technology, and support student scholarships and research opportunities in developed EU Member States.
- Developing partnerships with industry. Universities and other institutions of higher education can partner with industrial businesses to provide experiential learning opportunities for students, such as internships and other relevant programs. Students might be better prepared for careers in STEM fields and thus, the number of qualified workers in the job market could be increased.
- Promoting diversity and inclusion in STEM education. Encouraging and supporting the participation of underrepresented groups in STEM education can help to create a more diverse and innovative workforce.
- Providing support for STEM education at the secondary level can help to build a strong foundation and interest for students to pursue careers in STEM fields. Such practices often include providing resources and training for teachers, as well as creating engaging

STEM curricula, specific learning methods, such as flipped classroom and extracurricular activities, such as collaborative learning.

- Supporting research and development in STEM fields can potentially drive innovation and, as a consequence, economic growth and it may influence economic development. Examples may include providing funding for basic and applied research, as well as supporting the commercialization of new technologies.

The author acknowledges space for theoretical contribution by attempting to identify factors in tertiary education that have an effect on the general well-being of a country with a developed economy. These factors are critical to understand in order to develop a successful education system. A possible limitation would be that a great number of existing research papers with the help of neoclassical models provide little confidence that they do measure the growth accurately. There is little impact of these results on real policy-making. A way to overcome these limitations could be to investigate and later choose multiple models that shade light on various ways of how to determine growth. Alternatively, other determinants of economic growth apart from GDP could be tested in the models.

Contradicting evaluation outcomes (that typically happens because of cultural influences, social and economic institutions, different approaches of data collection) would allow us to opt for statistically significant outcomes that could be explained with the help of econometric analysis. The share of women with tertiary education in many EU member states is today higher in comparison to men. However, their participation in scientific and technical study programs remains low. In future we intend to explore on both micro and macro levels what labour market, legislative and social conditions may counter-incentivise women from doing the jobs they've studied for.

Is there a direct link between tertiary education and growth as theory predicts? Using the data on all tertiary education graduates for 2013-2020 from the 27 EU Member states, Cobb-Douglas production function and OLS and BMA methods, the link does not appear to be visible. However, once STEM education majors are introduced separately from the others, the situation is different – the share of STEM graduates have a positive effect on growth. In this case, what might be particularly interesting is gender. Many studies argue that while the share of highly educated women in comparison to men has been rising over the past century (and may be reflected in higher competitiveness of companies and therefore, in their salaries, spending and economic growth), the simple increase in population share with a tertiary degree does not necessarily guarantee economic growth, neither it can guarantee higher competitiveness or better salaries. There are relatively few women in STEM education and STEM jobs compared to men (Maceira, 2017; VanHeuvelen & Quadlin, 2021), which means the growth could be potentially fostered through creating an attractive image of STEM majors for female candidates. The key to higher competitiveness and higher growth rates might lay in attracting more girls during secondary education to enter STEM majors once they start their tertiary education and then create appropriate labour market, social and legislative conditions for female STEM degree holders to step in.

Whilst the statistical methods have significant uses in macroeconomic analysis, they remain a guide and these findings should not be treated as absolute. The econometric models have to be based on simplifications and assumptions that may not be consistent with the real processes. By using these two tools, however, the authors intend to put forward an idea that BMA modelling should be used to cross-check the results of regular regressions. Moreover, the member states in the EU could be compared as there are likely to be differences in the relationship between STEM graduates and economic growth across countries. These differences should be revealed and well-addressed to eliminate additional investment and ensure transparency in the functions of HEIs and liquidity and transferability of human resources in the EU labour market.

The analysis of differences in working hours across graduated students by economic sectors of employment, by part-time versus full time jobs in STEM economic sectors remains to be carried out to understand why a number of women fail to complete their STEM degrees (OECD Education at Glance, 2022), how male and female graduates transition to the labour market (the problem often referred to as the "leaky pipeline"), whether they do the jobs relevant to their field of study and what happens to female STEM graduates on the labour market.

Discussion and Limitations

Higher education system and labour market in the EU is gradually becoming more transparent. However, in order to understand each stage of the transition process from education to the job market, namely, 1) incentives and benefits offered to secondary school students to opt for a tertiary education degree; 2) specific majors they choose; 3) the number of students who drop out of the HE system completely; 4) the number of students who return; 5) the number of students who change major; 6) what jobs students opt for upon graduation;

7) what are the gender gaps once students enter labour market; 8) what are the gender gaps in 5-years' time and 10-years' time after graduation; 9) how many graduates take up the jobs in the field they have actually studied; 10) how many graduates keep developing professionally in the fields they have actually studied; 11) what happens to those who do other jobs they have not studied for – where they work and what the pay gaps between men and women are – more data needs to be gathered accurately both on micro- and macro- level. At the moment, most of the data described in the list above is not available, only a macro- level research was carried out. Once the results of micro research become widely available (e.g. Labour survey results, etc.) it might be useful to compare micro- and macro- level results for consistency.

Needless to say, each EU Member state is unique as it operates its own legislative, economic and social system. Therefore, a limitation of this study is that all countries were analysed as a large group. It would be interesting to break down the dataset into clusters using geographical, legislative or historical characteristics, e.g. Southern European countries (such as Italy, Spain, Portugal, Greece), Eastern European countries (such as Bulgaria, Czech Republic, Poland, Latvia, Lithuania, Estonia), Scandinavian countries, etc.

The time period 2013-2020 used in the current study may appear quite limited as well due to lack of consistent data on higher education across all EU Member States. The author also acknowledges the fact that the only perspective used to research the problem appears to be the economic perspective. In order to understand the problematics of the transition of human capital from the education system to the labour market, more perspectives need to be used in future research, such as social, political, and legislative.

Studying gender pay differences across various professions in Europe by clusters would help to match the data received on ISCED 6-8 graduates with dependent variables, such as economic growth and gender pay gap.

Further research ideas

Data shortages may incentivise researchers to conduct surveys or carry our case studies to determine the following information: 1) incentives and benefits offered to secondary school students to opt for a tertiary education degree; 2) specific majors they choose; 3) the number of students who drop out of the HE system completely; 4) the number of students who return; 5) the number of students who change major; 6) what jobs students opt for upon graduation; 7) what are the gender gaps once students enter labour market; 8) what are the gender gaps in 5-years' time and 10-years' time after graduation; 9) how many graduates take up the jobs in the field they have actually studied; 10) how many graduates keep developing professionally in the fields they have actually studied; 11) what happens to those who do other jobs they have not studied for – where they work and what the pay gaps between men and women are. Once the missing on incomplete data becomes available, the two avenues for further research are: 1) to understand the effect of individual STEM education graduates on regional economic development and 2) tackle the gender pay gaps within STEM and non-STEM professions to explore social, legislative and economic conditions that may possibly discourage women from working in STEM fields. It could be done in NUT regions or by combining EU Member States into clusters. It might be appropriate to utilise political, social, legislative and economic perspectives to investigate the extent to which higher education, economic development, and gender pay gaps are interrelated.

The relationship between higher education, economic growth and gender pay differences lies in between four major research fields: growth economics, economics of education, social economics, and labour economics. Growth economics examines the factors that contribute to economic growth and development within a society. It focuses on understanding the drivers of long-term economic prosperity, such as technological advancements, human capital, innovation, and investment. In the context of higher education, growth economics explores how educational attainment and the quality of education influence a country's economic growth and competitiveness. It is important to analyse the role of education in fostering innovation, productivity, and the creation of a skilled workforce necessary for sustainable economic development which would serve as a prerequisite for reaching the sustainability development goals (SDGs) set by the United Nations.

Economists and researchers working in the field of the economics of education, on the other hand, specifically investigate the relationship between education and economic outcomes. Such issues as access to higher education and its affordability, educational quality, returns on investment in education, and the impact of education on individuals' earning potential and labour market outcomes are crucial to investigate. This field examines the effectiveness of different educational policies, programs, and interventions in promoting equitable access to education and enhancing educational outcomes.

Social economics focuses on the social dimensions of economic phenomena and the impact of social factors on economic behaviour and outcomes. Researchers from Europe and United States recognise the fact that economic decisions and outcomes are shaped not only by market forces but also by social norms, institutions, power dynamics, and cultural factors (Cohen &

Levinthal, 1990; Caniels & van der Bosch, 2011, Toivanen & Väänänen, 2016; Maceira, 2017; Hanushek & Woessman, 2020; VanHeuvelen & Quadlin, 2021, Kempton et al., 2021). In the context of higher education and gender pay differences, social economics explores the social and cultural factors that contribute to gender-based disparities in educational opportunities, career choices, occupational segregation, and wage gaps. It examines how societal norms, biases, discrimination, and institutional barriers affect women's access to education, career progression, and earnings. In turn, labour economics examines the relationship between educational attainment and labour market outcomes. It investigates how individuals' level of education affects their employment prospects, earnings potential, job satisfaction, and career mobility.

Our main argument is that it is vital to view the HE-GDP-GPG relationship by establishing a holistic approach drawing upon the research carried out in these three major economic fields. Only by integrating insights from growth economics, economics of education, labour economics, and social economics, researchers and policymakers can gain a comprehensive understanding of the multifaceted relationships between higher education, economic growth, and gender pay differences. Such a multidisciplinary approach enables the identification of effective policy interventions and reforms that promote inclusive and equitable higher education systems, foster economic growth, and reduce gender disparities in pay and opportunities. It highlights the need for collaborative efforts and interdisciplinary research to address the complex challenges and promote sustainable and inclusive development in the realm of higher education and beyond.

Additional ideas for future research include the following. First, it might be advantageous to view HE as a system consisting of education, research and third mission and address STEM majors and gender differences in these three dimensions. Secondly, a question remains how exactly graduates transition to the labour market, if they do the jobs related to their education field. Lastly, it might be useful to explore gender pay gaps of student groups after graduation, as compared to more years of work experience of the same groups. Despite these suggestions, we acknowledge that there are considerable discussions among researchers on how to address the influence of STEM majors in different countries. A solution for studying EU countries might be to see the effects of tertiary education in specific country clusters which might be built according to the history of EU creation stages. In agreement with Silva and Klasen (2021), the number of years the economies stayed open to global trade might be also included into the analyses.

Comparing member states within the EU may highlight variations in the relationship between gender gaps and STEM graduates. Addressing these differences is crucial to ensure efficient investment and promote transparency within higher education institutions. It is also important to examine the variations in working hours among STEM graduates, specifically within economic sectors and between part-time and full-time jobs, to better understand why some women fail to complete their STEM degrees. This analysis can provide insights into the transition of male and female graduates into the labour market and their alignment with their field of study. Additionally, it can help identify obstacles that hinder women from creating economic value due to inadequate work-life balance, lack of quality daycare facilities, work overload, and career limitations.

Acknowledgements

I would like to thank the University of West Bohemia and especially the support, help and guidance of prof. Ing. Čadil, Ph.D., Ing. Svoboda, Ph.D., doc. Ing. Hommerová, Ph.D., MBA, doc. PaedDr. Eger, CSc., doc. RNDr. Gangur, Ph.D. and Mrs. Ing. Trojanowska from the Faculty of Economics who sparked my inspiration to work on the current topic. I am thankful to prof. Riccardo Lucchetti, Ph.D. for inspiring me to carry out BMA analysis. I value the help and support of the team from the School of Management, Polytechnic University of Milan, Italy headed by prof. Agasisti. I appreciate help and practical advice on using BMA and BACE methods from Jacek Kwiatkowski, Ph.D. from Nicolaus Copernicus University in Toruń and Marcin Błażejowski, Ph.D. from WSB Merito University in Toruń, Poland. I would like to extend my gratitude to Mgr. Vendula Kokošková and Varvara Donová, CSc. I thank my family and friends for their continuous support and encouragement.

Appendices

Appendix 1

Variable	Units of measurement	Source of data
Y1 growth rate related to each previous year	%	Own calculations, based on GDP per capita in PPP
Y2 Gender pay gap in unadjusted form,	%	Eurostat
Public expenditure on tertiary education, general government spending	mil EURO	Eurostat
Annual expenditure on educational institutions per pupil/student (pre-primary to tertiary education), total	GDP per capita	Eurostat
Expected years in tertiary education	number of years	Eurostat
gross fixed capital formation	mil EURO	Eurostat
Hours worked per 1 worker	number - Average annual hours actually worked	OECD
Total ISCED 6-8 graduates all majors both genders	number of people	Eurostat
women to men ratio	coefficient	own calculations
Total ISCED 6-8 graduates all majors both genders	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 male graduates all majors	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 6 all majors both genders	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 7 all majors both genders	% in relation to total population of each EU country that year	own calculations
ISCED 7 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 8 all majors both genders	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates all majors	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 graduates STEM F05-F07 both genders	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 both genders graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 both genders graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 both genders graduates STEM F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 both genders graduate all majors except F05-F06	% in relation to total population of each EU country that year	own calculations

Total ISCED 6-8 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 both genders graduates all majors except F05-07	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 both genders graduates all majors except F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 7 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 both genders graduates all majors except F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
School enrolment, tertiary	% gross	Eurostat

Appendix 2

Variable	Units of measurement	Source of data
27 Member states	country dummies	own
2013-2020	time dummies	own
Y1 growth rate related to each previous year	%	Own calculations, based on GDP per capita in PPP
Y2 Gender pay gap in unadjusted form,	%	Eurostat
Public expenditure on tertiary education, general government spending	mil EURO	Eurostat
Public expenditure on E02-08 (primary, secondary and tertiary) education as	% of GDP	Eurostat
Employment by educational attainment level (tertiary education) 15-64 y.o.	% of total population, total	Eurostat
Employment of males educational attainment level (tertiary education) 15-64 y.o.	% of total population, males	Eurostat
Employment of females educational attainment level (tertiary education) 15-64 y.o.	% of total population, females	Eurostat
Unemployment by sex and age – annual data	thousand persons from 25 to 74, % to total population	Eurostat
Production in industry Industries B-D (all)	Index, 2015=100	Eurostat
Gross domestic expenditure on R&D (GERD) at national level (higher education ONLY)	mil EURO	Eurostat
Annual expenditure on educational institutions per pupil/student (pre-primary to tertiary education), total	GDP per capita	Eurostat
Expected years in tertiary education	number of years	Eurostat
Total high-tech trade, exports from EU to the rest of the world	mil EURO	Eurostat
Employment in knowledge-intensive service sectors	Percentage of total employment	Eurostat
Human resources in science and technology, persons with tertiary education	Percentage of population in the labour force	Eurostat
Employment by all industries	thousand persons	Eurostat
Ratio of pupils and students to teachers and academic staff in ISCED 06-08 - tertiary level	rate	Eurostat
inflation rate	Annual average rate of change	Eurostat
GDP current PPP per capita	in dollars to 2017	Eurostat
Population	number	Eurostat
gross fixed capital formation	mil EURO	Eurostat
Hours worked per 1 worker	number - Average annual hours actually worked	OECD
Population males	number	Eurostat
Population females	number	Eurostat
Ratio of annual expenditure per student at the tertiary level and primary level of education, in public educational institutions	rate	Eurostat
Population with tertiary education total 25-34-year-olds /total 55-64-year-olds; 25-34-year-old men / 25-34-year-old women; 55-64-year-old men/55-64-year-old women	% in same age group, 2013 – 2020	Eurostat
Total ISCED 6-8 graduates all majors both genders	number of people	Eurostat
women to men ratio	coefficient	own calculations
Total ISCED 6-8 graduates all majors both genders	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 male graduates all majors	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 6 all majors both genders	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 7 all majors both genders	% in relation to total population of each EU country that year	own calculations

ISCED 7 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 8 all majors both genders	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates all majors	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates all majors	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 graduates STEM F05-F07 both genders	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 both genders graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 both genders graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 both genders graduates STEM F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates STEM F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 both genders graduates all majors except F05-F06	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
Total ISCED 6-8 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 both genders graduates all majors except F05-07	% in relation to total population of each EU country that year	own calculations
ISCED 6 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 6 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 both genders graduates all majors except F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 7 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 7 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 both genders graduates all majors except F05-F06	% in relation to total population of each EU country that year	own calculations
ISCED 8 male graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
ISCED 8 female graduates all majors except F05-F07	% in relation to total population of each EU country that year	own calculations
Life expectancy at birth	years	Eurostat
School enrolment, primary	% gross	Eurostat
School enrolment, secondary	% gross	Eurostat
School enrolment, tertiary	% gross	Eurostat
Multidimensional poverty headcount ratio	% of total population	Eurostat
Suicide mortality rate	per 100,000 population	Eurostat
Taxes on income, profits and capital gains	% of revenue	Eurostat
Fertility rates by age	number of children per woman	Eurostat
Mean age of women at birth of first child	years	Eurostat

List of tables and figures

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List of author's publications

1. Petrenko, O. (2022) How universities determine economics development in 27 EU Member States. The ACC JOURNAL, 28(2), 106–121. https://doi.org/10.15240/tul/004/2022-2-009
2. Wróblewski, B., & Petrenko, O. (2022). Descriptive and inferential statistical analysis of expectations and needs of engineering students and graduates: a case study at the University of West Bohemia. Language Learning in Higher Education, 12(2), 477–494. https://doi.org/10.1515/cercles-2022-2057

3. **Accepted to publication:** Petrenko, O. & Cadil, J. (2023) Successful STEM students: can female graduates contribute to closing the gender pay gap in the EU? Accepted to the European Journal of Education, multi-journal special issue 'Gender Equality in Education' EJED-2023-0296.

4. Unpublished: Agasisti, T. & Petrenko, O. (2023) Higher education and economic development: a bibliometric analysis 1985-2022. Submitted to the Journal of European Education, Research, Development and Policy EJED-2023-0433.

5. Unpublished: Petrenko, O., Kwiatkowski, J., Błażejowski, M., & Cadil., J. (2023) Do more women majoring in STEM subjects help to bridge the gender pay gap in the EU? Submitted to Labour Economics LABECO-D-23-00437.