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ECONOMIC DEVELOPMENT OF THE CZECH REPUBLIC IN TERMS OF INNOVATION AND R&D WITHIN THE SCOPE OF SOFTWARE DEVELOPMENT

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ABSTRACT

The purpose of this article is to investigate the influence of R&D and innovation investments on economic growth in the Czech Republic, which is a leader in software development in Europe. Annual data for the variables specified for the analyses were obtained from the World Bank and OECD databases for the period 1991-2020. To assess the series' stationarity, multiple regression, panel data analysis, Canonical co-Integrated Regression (CCR), Fully Enhanced Least Squares (FMOLS), Dynamic Least Squares (DOLS), and the ADF unit root test were used. The findings demonstrated that R&D and innovation have a considerable influence on GDP, which is the primary predictor of economic growth in the Czech Republic. Furthermore, FMOLS, DOLS, and CCR analyses conducted for the Czech Republic demonstrated a long-term association between R&D, innovation, and economic development between 1991 and 2020. Furthermore, the results of the Johansen cointegration, impulse-response, and variance decomposition tests agree with the results of the FMOLS, DOLS, and CCR studies. The following are the approaches that the Czech Republic should use in order to advance in terms of R&D, innovation, and software-based technological productivity: First, they should execute more reforms, beginning with universities, to boost research efficiency and make the developed human capital a contributing component to economic and technical progress. They must prioritize applied research for commercial goals while also altering the financing structure to increase university autonomy and competitiveness while also rewarding accomplishments. Universities could also improve collaboration between laboratories and industry.

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Introduction

Digitization has progressed from being largely connected with the industry in the early 1990s to being a general-purpose technology that pervades the whole economy. This compares digital technology to steam power and electricity, however unlike its forefathers, it influences the flow and usage of information rather than energy. This has ramifications for how new technology influences economic innovation. Innovation approaches that emphasize flexibility, efficiency, and speed have resulted in a paradigm change in software development. However, while innovation approaches have shown to be extremely effective, they are not the end-all-be-all of software development. "Innovation" is a catchphrase in today's knowledge-based economy. Knowledge generation and application have evolved into a competitive advantage for today's commercial companies. Furthermore, thanks to fast advances in information technology, worldwide competitiveness has increased. As a result of increased rivalry, multinational corporations, in particular, are investing heavily in novel goods, processes, and technologies in order to enhance their market share (Arachchi and Kuruppuarachchi, 2016).

Technological innovation is a critical engine of a country's long-term economic and social growth. Simultaneously, it has been convincingly established in a wide range of scholarly research that R&D investments contribute to long-term economic growth. This process is also a key stage for countries in transitioning from comprehensive to intense economic growth. Understanding the link between the three is especially crucial because R&D investment, technical innovation, and economic growth are all mutually impactful and interrelated. In economic terms, innovation refers to the invention and use of ideas and technology that improve goods and services or increase the efficiency of their production. The evolution of steam engine technology in the 18th century is a great example of innovation. In industries, steam engines were used, enabling mass manufacturing and changing railways and transportation. More recently, information technology has created new markets and business models, as well as altered how businesses manufacture and sell their goods and services. One of the most important functions of innovation is its contribution to economic progress. Innovation may lead to increased productivity, which is producing more output with the same input. As productivity rises, more products and services are produced, resulting in economic expansion (ECB, 2017).

It demonstrates that he is active and earns money. Innovation is defined as a continuous change in business processes, services, and products of companies under intense competitive pressure in order to gain a competitive advantage and increase business efficiency; in today's highly dynamic market conditions, this constant change is even more visible. As a result of the strong rivalry in worldwide markets, R&D advances continue to deliver this technology to additional markets. It is an irrefutable reality that the world's leading industrialized countries devote enormous resources to R& (Kalayci, 2020).

According to the OECD (2005) Oslo Manual (the Oslo Manual's subtitle is "recommended guidelines for the measurement of scientific and technological activity, collection and interpretation of data on technological innovation"), innovation is defined as a new or significantly improved product (good or service) or process, new technology, or new process. It is a marketing strategy or a new organizational approach in commercial operations, workplace organization, or external relations. According to European Union and OECD studies, the innovation process denotes the transformation of an idea into a marketable product or service, or improved production or distribution management, or a new social service management. More specifically, innovation is as follows (European Commission, 1996):

* Renewal and expansion of product, service and market range,

* Establishment of new production, supply and distribution methods,

* Management is the introduction of changes in work organization, working conditions and skills of the workforce.

It is critical to have a firm grasp of what innovation entails. This is due to the broad scope of inventions and the numerous repercussions they entail. Many scholars have defined and stressed innovation in slightly various ways over the years. According to Camisón-Zornoza et al. (2004), the term "innovation" is understood and examined in numerous ways. They also argued that because of the complicated production and spread process, innovation has a multifaceted aspect. Adoption of a new concept or habit for the organization that is implementing the innovation. They saw innovation absorption as a process that involved the production, development, and application of new ideas or behaviors.

Previous research on innovation distinguished between innovation and creativity. Hult et al. (2004) define innovation as "with the firm's potential to innovate; that is, the introduction of new processes, products or ideas in the organization. The term "capacity" refers to the potential for innovation in this context. Thus, innovation is defined as the ability to produce, accept, or apply new ideas. As a result, it presumes that highly inventive individuals or organizations would always innovate more. As a result, the concept of innovation involves openness to new ideas, and as Hult et al. (2004) pointed out, this phenomenon is also known as organizational culture.

According to Drucker (1985), innovation is the process of providing new, enhanced capabilities or higher utility. He underlined that innovation is a value that can be judged by its environmental effect rather than a science or technology. Innovation may be described as the development and production of new or enhanced goods or services from a management standpoint. Changes such as new customer wants or innovative answers to current needs might indicate favorable conditions for innovation.

According to Wang and Ahmed (2004), process innovation "captures the introduction of new production techniques, new management approaches and new technology that may be utilized to improve production and management processes". This demonstrates how broad the reach may be when dealing with advancements. It also demonstrates how tough and complex innovation research is, as the substance of certain concepts might easily overlap. Wang and Ahmed (2004) underline that behavioral innovation can occur at the individual, team, or management levels and contributes to the development of a creative culture. They also highlight "synergy based on group dynamics". Thus, the relationship between organizational culture and the innovativeness of the organization becomes a very important factor. In fact, it can be said that culture and innovation mean the same thing in the innovation literature.

When it comes to the notion of R&D, the first question to ask is, "What is research and development?" To deepen the definition, an answer to the query and the history of R&D activities should be considered. It may be characterized in this sense as a research phrase used in scientific and technical operations to study and discover the unknown. "R&D is the transfer of individual and societal knowledge and involves creative activity based on a systematic foundation to support the translation of relevant information into new practices and practices," according to the R&D definition. R&D activities are characterized as "systematic and innovative investigations for the manufacture of new commodities and manufacturing processes in businesses" (Kavak, 2009).

R&D is the ongoing effort to gain new information or enhance current knowledge in order to advance science and technology. It also indicates that R&D is an organized set of investigations targeted at product or process innovation or scientific knowledge expansion. R&D incorporates systematic creative investigations to expand understanding of people, culture, and society and to apply this information to build new applications. Based on the principles above, a research and development activity should be methodical, done on a regular basis for the renewal of goods and processes, taxes should be collected, and analyses should be performed using appropriate methodologies (Zerenler et al., 2007).

All of the factors connected to the issue are explored in-depth and theoretically in the article's introduction. The second section included a complete literature review that took into account the pertinent factors. Both innovation and R&D activities are carried out in the third section using Multiple Regression Analysis of the relevant variables, Johansen Cointegration, impulse-response, variance decomposition, Fully Enhanced Least Squares (FMOLS), Dynamic Least Squares (DOLS), and Canonical Co-integrated Regression (CCR) methods. He looked at the impact of economic growth and whether there is a long-term link between the two. In the last part, which is the 4th chapter, in the light of empirical findings, some recommendations were made to the policy makers of the Czech Republic, which has developed in software, and various evaluations were made.

Literature Summary

Some research has been conducted to study the link between R&D spending and technological innovation. Initially, technical innovation was defined by scientific and technological achievements, particularly patents. The neoclassical growth model, established by Solow (1957) and one of the theoretical underpinnings of this thesis, has investigated economic growth variables by integrating qualitative and quantitative methodologies. Technology is viewed as a major role in economic growth under the model.

Endogenous technical advancement, rather than the accumulation of general means of production, is the most important source of economic growth, according to Romer's (1990) research. In this environment, scholars have begun to focus on the inherent drivers of economic growth that are based on innovation and technological progress. As a result, numerous scientists have contributed to the academic literature by doing studies on topics such as R&D investment, technological innovation, and economic growth.

Recent economic growth theories concentrate emphasis on internal technology development in order to explain global economic growth trends. According to Romer's (1986) endogenous growth theories, technological innovation is developed in research and development (R&D) industries by utilizing human capital and existing knowledge stock. Endogenous growth models are later applied in the manufacture of finished items, resulting in permanent increases in the output growth rate. At the heart of these models is the assumption that internally determined innovation triggers sustainable economic growth, given that there are continuous returns based on innovation in terms of human capital employed in R&D sectors. This thesis was written to investigate the following assumptions of R&D-based endogenous growth models for 4 countries that developed in software in the period 1991-2020 using various time series analysis: (1) R&D investment increases innovation and provides continuous returns. innovation; (2) It leads to permanent increases in GDP per capita.

The goal of empirical research for endogenous growth models is to assess the influence of R&D factors on TFP growth. Jones (1995), for example, tested the validity of R&D-based development models using time series graphs of TFP growth and the rate of increase in the number of scientists and engineers in France, Germany, Japan, and the United States. They discovered no evidence that these factors were associated in a beneficial way. Aghion and Howitt (1998) have made some explanations regarding the contradictory results of Jones (1995). First, the increasing complexity of technology makes it necessary to increase R&D over time to keep the rate of innovation constant for each product. Second, as the number of goods rises, each product's innovation influences a smaller section of the economy and so has a less proportional spillover effect on the entire stock of knowledge. They also claimed that the GDP share of R&D spending, rather than the number of scientists and engineers, should be utilized to account for the size of the economy. According to Scherer (1982), Griliches and Lichtenberg (1984), Aghion and Howitt (1998), and Zachariadis (2003), R&D investment in the US economy is positively associated to TFP growth.

For many years, academic researchers have undertaken several studies on the link between R&D activity and economic growth. Most studies have found that R&D expenditures contribute significantly to the growth of the country and the enterprise. Altn and Kaya (2009) discovered a substantial link between R&D spending and economic growth. The test demonstrated a long-term causation association between R&D spending and country economic development.

R&D efforts have their theoretical roots primarily in Schumpeter's conceptual framework. R&D and innovation, according to Schumpeter, were accelerators for economic expansion. Schumpeter was the first to address the relevance of technology in economic progress (Schumpeter, 1970). However, in the 1950s and 1960s, the theoretical majority of neoclassical methods did not accept Schumpeter's theories. At the time, the prevailing consensus was that Schumpeter's views were flawed. Technology, according to neoclassicists, is an external component for growth that is supposed to be consistent across countries (Özer and Çiftçi, 2009).

According to Tubbs (2007), many industry leaders raise their R&D spending during recessions in order to stay ahead of their competition. Some academic studies have also looked at the link between R&D investments, technological innovation, and economic growth. Many studies have found that the rise of the digital economy is linked to the creation, improvement, and expansion of a variety of markets directly tied to digital and mobile technology. The production of new knowledge has become a new economic power by harmonizing digital economic activity with traditional. The beneficial association between nations' own economic growth, R&D, and innovation has also been proven in research utilizing panel data analysis by academics such as Griffith et al. (2004) and Frantzen (2000). There is also substantial evidence that the diffusion of R&D

investments from developed to developing nations has a favorable influence on developing-country total factor productivity development.

According to Savvides and Zachariadis (2003), both local R&D and innovation boost local productivity and added value growth. They also evaluated the impact of R&D and innovation on overall manufacturing production and discovered that R&D had a considerably greater influence on economic growth than the manufacturing sector.

Hasan and Tucci (2010), on the other hand, evaluated the link between innovation and the economy and found that nations with a higher number of patents saw higher economic growth. Greenhalgh and Rogers (2010) describe innovation as "the application of new ideas to a firm's goods, processes, or other areas of its operations that result in greater value".

Similarly, Sohag et al. (2015) stated that innovation improves quality and stated that innovation is "providing social or economic development in order to increase the performance of products, services, production processes, business models, policies and such concepts or to achieve another desired effect.

Kim (2011) evaluated the contribution of R&D stock to economic growth in South Korea between 1976 and 2009 using the R&D-based Cobb-Douglas production function. He stated that R&D activities are one of the most efficient methods of increasing competitiveness in an economy that provides stable and continuous economic growth, and his study has shown that traditional factors of production - labor and capital - contribute approximately 65% to economic growth based on empirical results. It has been statistically proven that the contribution rate of the total R&D stock to economic growth is around 35%. The study also found that public and private R&D stocks contributed to economic growth of approximately 16% and 19%, respectively.

Gülmez and Yardimcioglu (2012) used 1990-2010 data to evaluate the link between R&D expenditures and economic growth in OECD nations, concluding that there is a long-term substantial interaction relationship between R&D expenditures and economic growth indicators in OECD countries.

According to Akinwale et al. (2012), both labor and capital are directly tied to economic growth, however although the former is vital, the latter is not. They stated in their research for Nigeria that the government should commit to supporting R&D and innovation, establishing strong institutions, increasing academia-industry connection, and adopting a credible science, technology, and innovation strategy to support and diversify the economy. They underlined that the government should also provide various financial incentives to various industrial firms to encourage them to participate in R&D and innovation activities through reverse engineering or inventing new ones, which will not only ensure economic growth but also have a very serious impact on Nigeria's global competitiveness. that they will contribute.

Horowitz (1967) examined the links between R&D development and regional economic growth for several states in the United States using data from 1920 to 1964, concluding that the growth equation, correlation measurement coefficients, and regional peoples' welfare are consistent with growth. has shown up. It has been discovered that there is a positive association between them, which is consistent with the rates of R&D activity increase.

Funke and Niebuhr (2000) examined the link between R&D spending and economic development in West Germany from 1976 to 1996. According to the results obtained, there is a long-term positive relationship between both variables. They also emphasized that the information technology and software sectors have significant effects on economic growth.

Segerstrom (2000) investigated the long-term impact of R&D incentives. According to the evidence, R&D incentives unexpectedly promote and stimulate long-term economic growth. A appropriate collection of parameter values is used to determine the growth trigger. This research also sheds fresh light on the subject of whether R&D incentives effect long-term economic development. Sadraoui et al. (2014) examined the relationship between software and R&D spending and economic development using data from 32 industrialized and developed nations from 1970 to 2012. The findings indicate a substantial relationship between economic development and software and R&D spending.

Genç and Atasoy (2010) used the 1997-2008 period data and the causality approach to evaluate the link between R&D expenditures and economic growth and discovered that there is a unilateral causality association between R&D expenditures and economic development. Taban and Engür (2014) used 1990-2012 period data and cointegration models in Turkey to analyze the link between R&D and economic growth and concluded that R&D expenditures positively impact economic growth in the long term.

Using data from 1998 to 2013, Bozkurt (2015) assessed the long-term link between R&D spending and economic development in Turkey using the Johansen cointegration test and vector error correction model. Furthermore, the empirical data obtained in conjunction with the causality test suggest that there is a causal relationship between economic development and R&D. He emphasized the importance of R&D in order to sustain actual economic activity and growth rates. He indicated that the R&D variable's long-term coefficients are statistically significant and have a positive value. When the R&D proportion of GDP grew by 1%, the GDP growth rate climbed by 0.2630%.

Liu and Xia (2018) assembled data from China from 1995 to 2016, creating an indicator system for research variables such as R&D spending, technological innovation, and economic development. They used the vector autoregression model and variance decomposition models to determine which independent variable influenced the dependent variable more than the other. The findings demonstrated that the variables had a long-term stable dynamic connection. Researchers that have demonstrated that R&D investment, technical innovation, and economic growth have stalled or even significantly diminished in recent years have demonstrated that economic development is not adequately maintained in the absence of these factors. They stated that the transmission mechanism between the three variables should be optimized. For example, they underlined that it should ensure stable economic growth by increasing the efficiency of R&D investments and funds, improving the incentive system for scientific and technological innovation, and promoting the effective use of innovation and integration of marketization.

Kaneva and Untura (2018) explored the links between R&D, innovation activity, and economic growth in Russian regions. They used econometric approaches to evaluate these correlations using fixed effects panel regression and the Arellano-Bond model using 2005-2013 data. When socioeconomic considerations are factored into the computations, the results reveal a clear association with potential labor competitiveness in the industry. The calculations also confirm the significant impact of expenditure on technological innovation and innovation, which is an indispensable variable for regional economic growth. It has also been demonstrated that information is more efficiently disseminated between regions with high absorptive capacity and regions with similar growth rates.

Cainelli et al. (2004) experimentally evaluated the association between firm-level research efforts and economic success. The empirical study is based on a unique longitudinal firm-level dataset that corresponds to the data from the Italian Community Innovation Survey (CIS II) (1993-1995) and a set of economic indicators given by the Italian Business Account System (1993–1998). An empirical investigation was conducted to determine if the presence of innovation and the number of resources committed to innovation impact the economic performance of service-sector firms. The results show that the productivity levels of the firms that invest in innovation contribute more to the economy than the firms that do not invest enough in innovation. Efficiency has also been found to be linked to the amount of innovation expenditure, particularly those devoted to the purchase and internal development of new software.

Griliches (1992) emphasized the importance of increasing returns and internalities in the structure of R&D. The empirical literature explores the magnitude of these effects. The endogenous growth theory emphasized two points;

(1) *It results from technological developments, conscious investments and decisions taken by different economic units.*

(2) *Without externalities and other sources of social incremental returns, sustained and stable economic growth cannot occur. The second point here examines the impact of externalities on growth and productivity growth.*

R&D investments, depending on their empirical size, can save the economy from diminishing returns. Griliches (1992) studied the impact of hybrid maize seed development in the research sector. Publicly supported and privately funded R&D can generate ideas and knowledge in a new product or product line. In this case, the social return on R&D is the sum of producer and consumer surplus. For example, the development of hybrid maize seeds can be given as an example in this regard.

Methodology and Data Analysis

The purpose of this essay is to demonstrate the influence of R&D and innovation investments on economic growth in the Czech Republic, which is a leader in software development in Europe. Annual data for the variables specified for the analyses were obtained from the World Bank (2022) and OECD (2022a, 2022b) databases for the 1991-2020 time periods.

Multiple regression, panel data analysis, Canonical Cointegrating Regression (CCR), Fully Modified Ordinary Least Squares (FMOLS), and Dynamic Ordinary Least Squares were used to determine the impact of innovation and R&D investments on economic growth in the Czech Republic, as well as the long-term relationship between related variables. (DOLS) techniques and the ADF unit root test were used to determine the series' stationarity.

The findings indicated whether or not innovation and R&D had a substantial influence on GDP per capita in the Czech Republic as a factor of economic growth. The methodology and data analysis section of this article discusses the Czech Republic, which is one of the most sophisticated countries in the software business and is heading toward dynamism in information technology. The country rankings determined by Daxx (2021), which was founded in Amsterdam, the Netherlands in 1999, were discussed as a consequence of the study undertaken in this area.

The independent variables, regional innovation level, and R&D spending, influenced the dependent variable, GNP, according to a multiple regression study conducted for the Czech Republic between 1991 and 2020. (Table 1. See). P-values revealed empirical findings of "0.0112" for R&D investments and "0.0204" for regional innovation level. Both independent variables are statistically inside the 5% confidence range.

Table 1. Multiple Regression Analysis Czech Republic

Dependent Variable: GSMH				
Method: Least Squares				
Sample: 1991 2020				
Included observations: 30				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
R&D INNOVATION	1.065217	0.391097	2.723661	0.0112
	0.253501	0.123806	2.047574	0.0204
C	24.67114	0.217329	113.5198	0.0000
R-squared	0.851297	Mean dependent var		25.48260
Adjusted R-squared	0.840282	S.D. dependent var		0.681748
S.E. of regression	0.272459	Akaike info criterion		0.331981
Sum squared resid	2.004312	Schwarz criterion		0.472100
Log likelihood	-1.979710	Hannan-Quinn criter.		0.376806
F-statistic	77.28494	Durbin-Watson stat		1.526044
AR(1)				
	0.0126	@trend		0.8746

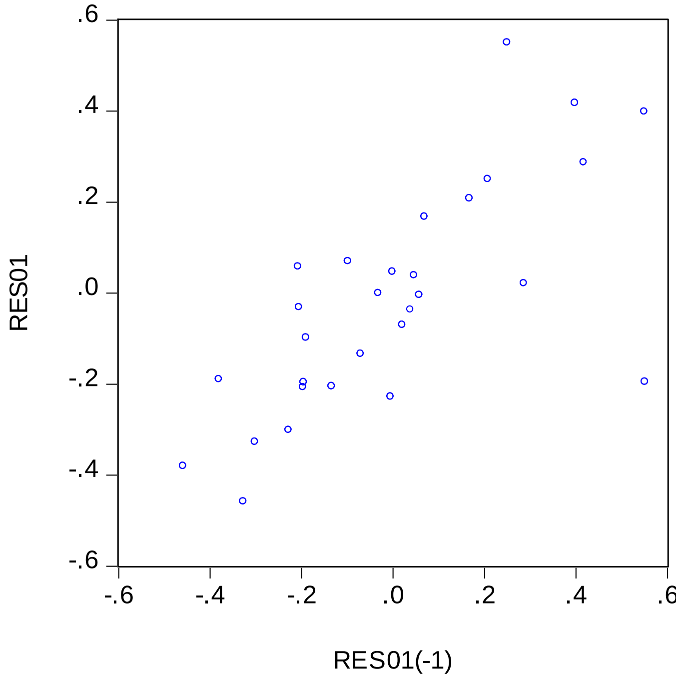

Figure 1. Autocerealtion Scheme for Czech Republic

Figure 1 randomly distributes the main indicators indicating that there is no autocorrelation problem in the study performed in Table 1. Entropy is introduced into the residue graph. Another indicator that there is no autocorrelation problem in the Czech Republic's multiple regression analysis is that the Durbin-Watson statistics are close to 2 when Table 1 is used. One of the other important characteristics indicating that there is no autocorrelation in the model is that the result is close to 2. Furthermore, AR(1) findings in both tables are less than 0.05, indicating that there is no autocorrelation. Finally, @trend was calculated as 0.8746 in Table 1 to demonstrate that there is no inter-variable spurious regression issue.

For the Czech Republic, tests at the I(0) level (undifferentiated series) were applied. For the Czech Republic, it has been determined that all series are not stationary in Table 2. Empirical findings of all relevant series showed that the P-value was well above 0.05, showing that the series were not stationary for all relevant countries.

Table 2. ADF Unit Root Test at Level I(0) for Czech Republic

(R&D Investments) Null Hypothesis: R&D has a unit root			
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=7)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.954786	0.7556
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	
*MacKinnon (1996) one-sided p-values.			

(GNP) Null Hypothesis: GSMH has a unit root			
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=7)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.691322	0.8336
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	
*MacKinnon (1996) one-sided p-values.			
Null Hypothesis: INOVASYON has a unit root			
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=7)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-0.379495	0.9002
Test critical values:	1% level	-3.679322	
	5% level	-2.967767	
	10% level	-2.622989	
*MacKinnon (1996) one-sided p-values.			

In the ADF unit root test for the Czech Republic, the P-value for R&D investments between 1991 and 2020 was computed as 0.0051 and the t-statistic as -3.9715 (taking the absolute values of the figures into consideration), raising the percentage by more than -3.6891. It was discovered with a confidence interval of 1. As a result, the appropriate values were acquired, and the series' stationarity was established using the optimal values. Besides, the P-value for GNP was obtained as 0.0020, and the first-order difference was found to be stationary, with a confidence interval of 1 percent. Finally, after taking the first-order difference of the innovation series in Table 7, both t-statistics and probability values were determined at optimal values like the previous two series and obtained as stationary.

Table 3. ADF Unit Root Test at Level I(1) for Czech Republic

(R&D Investments) Null Hypothesis: R&D1 has a unit root			
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=6)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-3.971569	0.0051
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	
*MacKinnon (1996) one-sided p-values.			
(GNP) Null Hypothesis: GSMH1 has a unit root			
Exogenous: Constant			
Lag Length: 0 (Automatic - based on SIC, maxlag=6)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.350515	0.0020
Test critical values:	1% level	-3.689194	
	5% level	-2.971853	
	10% level	-2.625121	
*MacKinnon (1996) one-sided p-values.			
(İnovasyon) Null Hypothesis: INOVASYON1 has a unit root			
Exogenous: Constant			
Lag Length: 2 (Automatic - based on SIC, maxlag=6)			
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-5.824275	0.0001
Test critical values:	1% level	-3.711457	
	5% level	-2.981038	
	10% level	-2.629906	
*MacKinnon (1996) one-sided p-values.			

Augmented Dickey Fuller (ADF) unit root test (calculated according to the AIC Akaike Information Criteria) was applied to series containing Innovation, GNP, and R&D investments to test for stationarity. According to Serena and Perron's (2001) suggestion, the maximum lag length was chosen as 2. A parametric correction is provided for high coefficient correlation, assuming the ADF test follows an AR(k) process and adds the lagged difference terms of the dependent variable to the right side of the series.

$$\Delta y_{\mathrm{t}} = c + \alpha y_{t-1} + \sum_{j=1}^{k} d_{\mathrm{j}}\, \Delta y_{\mathrm{t-j}} + \varepsilon_{t} \qquad (1)$$

$$\Delta y_{\mathrm{t}} = c + \alpha y_{t-1} + \beta t \sum_{j=1}^{k} d_{\mathrm{j}}\, \Delta y_{\mathrm{t-j}} + \varepsilon_{t} \qquad (2)$$

Equation (1) examines the null hypothesis against the mean stationary alternative unit root in yt of the studied time series y. Equation (2) examines the unit root of the null hypothesis against the trend-stationary alternative. The term Δ_{yt_j} represents the first difference in the error term that provides the serial correlation. A constant and linear time trend can be included in the ADF test regression, as shown in the equations above.

The search constraints in the time series and the existence of significant volatile breaks occur thanks to a unit root test mechanism that gives accurate results. Granger (2010) states that interval constraints (boundaries) are frequently observed in time series data. These constraints can make the integrated series seem stationary. Therefore, standard unit root tests are ineffective in detecting the difference between stationarity and nonstationarity. In this context, Cavaliere (2005) and Yazıcı (2022) analyzed the nonstationarity behavior in limited time series.

Table 4. Johansen Cointegration Test for Czech Republic

Sample (adjusted): 1994 2020
Included observations: 27 after adjustments
Trend assumption: Linear deterministic trend
Series: AR_GE1 GSMH1 INOVASYON1
Lags interval (in first differences): 1 to 1

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized		Trace	0.05 Critical	
No. of CE(s)	Eigenvalue	Statistic	Value	Prob.**
None *	0.564570	50.72599	29.79707	0.0001
At most 1 *	0.484504	28.27761	15.49471	0.0004
At most 2 *	0.319341	10.38673	3.841466	0.0013

Trace test indicates 3 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Johansen cointegration test was performed to show whether there is a long-term relationship between the variables after determining their stationarity as a result of the results obtained in the unit root tests for all the series with first degree differences in Czech Republic. The results obtained for the Czech Republic, which has shown significant development in software in Europe in Table 4 above, indicate that there is a long-term relationship between R&D investments, innovation and economic growth.

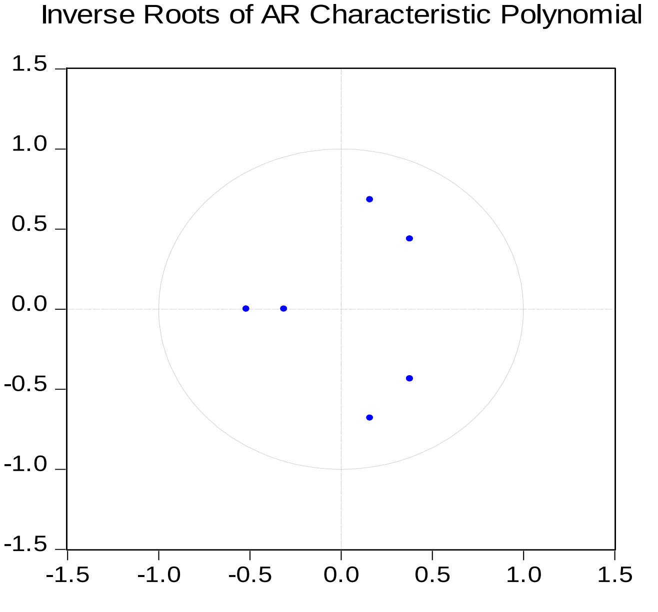

Figure 2. VDR Analysis for the Czech Republic

Table 5. Variance Degradation Analysis for the Czech Republic

Period	S.E.	AR_GE1	GSMH1	INOVASYON1
1	1.63E+10	4.910736	95.08926	0.000000
2	1.74E+10	4.543823	86.12474	9.331435
3	1.84E+10	12.35568	78.73436	8.909958
4	1.87E+10	12.23242	79.04186	8.725717
5	1.89E+10	12.36108	78.75807	8.880853
6	1.90E+10	13.24413	77.90224	8.853623
7	1.90E+10	13.23734	77.78517	8.977494
8	1.91E+10	13.26682	77.68378	9.049405
9	1.91E+10	13.30796	77.64738	9.044660
10	1.91E+10	**13.30160**	**77.62935**	**9.069057**

Regarding the Johansen cointegration test in Table 4 above, the long-term link between the variables was identified and proven to be relevant empirical results because the p-values for all variables in the Czech Republic were less than 0.01. The model's stationarity was then assessed using VDR analysis in the next step (see Figure 2.). In this thesis, the VDR model was used to analyze the trend of three variables in detail. R&D, innovation and GNP were considered as internal variables, and the lag range for VDR was determined as 2. Also, all the points of the inverse roots of the characteristic polynomial remained in the circle. This proves that the VDR model is stationary.

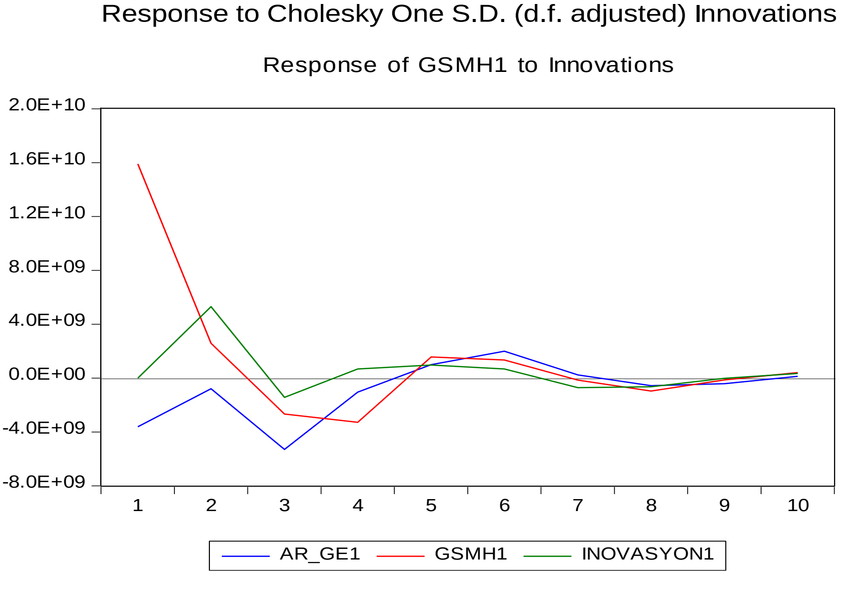

Figure 3. Impulse-Response Scheme for Czech Republic

According to the results obtained, the VDR model was found to be stationary since all 6 points of interest remained in the circle. The VAR analysis (using the Akaike Information Criterion [AIC]) was applied to the variables of R&D, innovation, and GNP to test stability. According to the suggestion of Serena and Perron (2001) the maximum lag length was determined as 2.

Impulse-response analysis (see Figure 3) was applied for the Czech Republic, one of the most important countries in Europe in terms of software, between 1991 and 2020, a shock was applied to the dependent variable, GNP, and as a result, R&D investments relatively increased economic growth according to innovation. more triggered. In Table 5 above, similar results were found in the variance decomposition analysis for the Czech Republic, and it was observed that R&D investments triggered economic growth more than innovation. Fully Enhanced Least Squares (FMOLS), Dynamic Least Squares (DOLS), Canonical Co-integrated Regression (CCR) methods for the Czech Republic in Table 6., Table 7., and Table 8. It was used to determine whether the independent variables affect the dependent variables.

Table 6. FMOLS (Fully Corrected Least Squares) Analysis for the Czech Republic

Dependent Variable: GSMH1
Method: Fully Modified Least Squares (FMOLS)
Sample (adjusted): 1993 2020
Included observations: 28 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AR_GE1	-5.47E+10	3.66E+10	-1.492480	0.0481
INOVASYON1	3.26E+09	1.68E+09	1.932746	0.0347
C	7.16E+09	3.55E+09	2.017477	0.0545
R-squared	0.106529	Mean dependent var		7.52E+09
Adjusted R-squared	0.035051	S.D. dependent var		1.66E+10

S.E. of regression	1.63E+10	Sum squared resid	6.65E+21
Long-run variance	2.47E+20		

Table 7. DOLS (Dynamic Least Squares) Analysis for the Czech Republic

Dependent Variable: GSMH1
Method: Dynamic Least Squares (DOLS)
Sample (adjusted): 1994 2019
Included observations: 26 after adjustments
Cointegrating equation deterministics: C
Fixed leads and lags specification (lead=1, lag=1)
Long-run variance estimate (Bartlett kernel, Newey-West fixed bandwidth = 3.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AR_GE1	-1.03E+11	5.89E+10	-1.751519	0.0279
INOVASYON1	7.14E+09	4.75E+09	1.503225	0.0411
C	6.10E+09	5.83E+09	1.045540	0.0104

R-squared	0.513745	Mean dependent var	8.14E+09
Adjusted R-squared	0.284919	S.D. dependent var	1.70E+10
S.E. of regression	1.44E+10	Sum squared resid	3.51E+21
Long-run variance	1.73E+20		

Since the p-values for each variable were below 0.05 in all 3 analyzes (Table 6., Table 7., and Table 8.), innovation and R&D investments, which are independent variables, affected economic growth, as well as long periods among all 3 variables. It is understood that there is a long-term relationship.

Table 8. CCR (Canonical Cointegration Regression) Analysis for the Czech Republic

Dependent Variable: GSMH1
Method: Canonical Cointegrating Regression (CCR)
Sample (adjusted): 1993 2020
Included observations: 28 after adjustments
Cointegrating equation deterministics: C
Long-run covariance estimate (Bartlett kernel, Newey-West fixed bandwidth= 4.0000)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AR_GE1	-6.02E+10	4.24E+10	-1.418496	0.0684
INOVASYON1	3.62E+09	2.54E+09	1.425278	0.0664
C	7.10E+09	3.91E+09	1.819175	0.0809
R-squared	0.100096	Mean dependent var		7.52E+09
Adjusted R-squared	0.028103	S.D. dependent var		1.66E+10
S.E. of regression	1.64E+10	Sum squared resid		6.70E+21
Long-run variance	2.47E+20			

The findings of the Fully Designed Least Squares (FMOLS), Dynamic Least Squares (DOLS), Canonical Co-integrated Regression (CCR) techniques developed for the Czech Republic, one of Europe's most developed software countries, and the previously performed Johansen cointegration test. The empirical findings are well supported by multiple regression, impulse-response, and variance decomposition analysis.

Result

Given the Czech Republic's location, around 25 to 35% of the invention has come a long way, with approximately 25 to 35% of innovation being exploited, carefully observed, reproduced the finest technologies, and clearly fitted to skilled intellectual capital. However, taking into account all of the programs in which firms carry out innovation and software development while the state just facilitates and encourages, there have been considerable advancements in knowledge generating centers in the Czech Republic. University advancement has also been impressive, and state-funded R&D spending have stayed near to EU norms.

In terms of R&D and innovation, the following are the techniques that the Czech Republic should use in order to advance in software-based technological productivity: First, they should execute more reforms, beginning with universities, to boost research efficiency and make the developed human capital a contributing component to economic and technical progress. They must prioritize applied research for commercial goals, as well as change the financing structure to increase university autonomy and competitiveness, and to reward outcomes (performance in market results). Universities could also improve collaboration between laboratories and industry.

The second suggestion is to restructure laboratories and combine them with universities and industry. Privatizing universities and changing them into Private-Public Partnerships, as seen in the UK reforms, are examples of key changes that may be undertaken. Furthermore, markets should be fostered to assist countries' industrial competitiveness strategies, particularly for software businesses.

Third, it could use the Ministries of Science and Technology's various programs, such as regional universities and polytechnics, to decentralize some laboratories and establish a network of Design and Technology Centers dedicated to core industry and service sectors and integrated into regional clusters. Thus, the technological advancement of the business structure can be achieved. Conducive environments and systems can then be created to launch new ventures involving new technologies. Finally, by implementing policies to increase innovation and R&D investments at the enterprise level, strategies focused on attracting multinational companies to the country should be developed.

It is no coincidence that developed and high-income countries devote greater money to R&D. Many studies in the literature show a considerable association between technical advancements, innovation, and R&D efforts and economic growth. Although the knowledge economy and high-tech industries are critical to economic development, it is clear that development and progress would be difficult to achieve without R&D.

Technological progress is critical for productivity growth and competitiveness, and R&D is required for technological development. As a result, R&D efforts should be prioritized, and economic reliance may be avoided by reaching a point when innovations can be manufactured. It is critical in this process to raise and spread R&D awareness. Human capital investments should be encouraged, universities and industry cooperation should be developed, incentive opportunities provided to companies and organizations that will make R&D investments should be reviewed and maintained. The state should increase its R&D expenditures and allocate more resources to R&D activities; In this context, the rate of per capita GDP should be increased.

Financial investments are the most significant element influencing productivity change. As financial investments grow, so does the proportion of funds committed to R&D research. Furthermore, market concentration has a favorable effect on productivity change. Low-tech sectors that need a lot of labor limit exports to more competitive, high-tech manufacturing countries. In industries with a high degree of technology, R&D studies are necessary, and intangible expenditures such as computer software are spent on patent rights, capital is used more effectively, and the link between human capital and labor productivity is positive. However, financial investments in these sectors are lower. Therefore, as a policy recommendation, the Czech Republic should further increase investments in these sectors in order to catch up with leading technologies in the future.

International marketplaces are characterized by intense competition. Every country, especially emerging ones, is fighting for a piece of the international trade pie, and the rivalry is growing stronger by the day. This is particularly true for nations with large trade deficits because the majority of their exports rely on imported intermediate products. Many studies have been conducted on the link between economic growth, technology, R&D, and export performance. In the literature, Schumpeter (1911) highlighted the power of technology in economic expansion in the first half of the twentieth century. The neo-classicals, on the other hand, disputed Schumpeter's theories. In contrast, Neoclassical ideas considered technology as an external component that is expected to be consistent across countries. Another key neoclassical idea is the convergence of economies, which claims that emerging countries have stronger growth rates than industrialized countries. Many other ideas, such as Romer's (1986) research, have excluded convergence theories and technology as an external element. With these advancements, neoclassical theorists have come to embrace the premise that technology is an internal component in economic growth. These models support the three pillars of the critical R&D industry, intermediate products, and final goods. From an empirical perspective, the impact of software, technology or R&D activities on economic performance is studied by many scientists. These studies showed that there is strong empirical support that software and technology are positively associated with economic growth performance. The findings are consistent with the findings, since R&D activities are critical for economic growth in various businesses, not only R&D-intensive industries. Another finding from the empirical research is that the size of the domestic market is essential for those industries that rely substantially on R&D. Furthermore, in addition to direct R&D operations, spillover effects from other enterprises or nations, known as indirect R&D activities, are significant.

Although there is a significant and positive association between the variables, whether R&D operations result in productivity and returns as innovation is dependent on a number of other factors. The variation in spending composition across nations should be considered when discussing and comparing R&D expenditures. Increased R&D spending in industries such as software, IT, and electronics promotes greater innovation than in sectors such as agriculture or tourism. Furthermore, the impact of research and development activities changes depending on whether they are publicly or privately sponsored. Publicly funded research tends to be basic research, while privately funded research tends to be conducted for a specific purpose. As a result, privately supported research and development activities have a better potential for innovation. Another factor to consider is the time lag associated with the effects of R&D on innovation. Creating information and seeing it reflected in freshly developed apps necessitates not just experienced researchers and developers, but also skilled employees in industries.

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