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Comparative Analysis of Industry 4.0 Factors in Georgia and Slovakia: An Economic and Technological Perspective

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Abstract

The current paper presents a structured comparative analysis focusing on the adoption of Industry 4.0 in Slovakia and Georgia. Both countries, emerging from a shared history of socialism, have embarked on different paths toward integrating Industry 4.0 technologies. The research examines the economic and technological factors influencing the embrace of Industry 4.0, utilizing economic indicators and relevant metrics to assess the technological readiness of each nation. Key differences in GDP per capita, real GDP growth rate, unemployment rate, and active business entities underline their distinct economic scenarios. Using a Vector Autoregression (VAR) model, the study investigates the relationships between internet usage, R&D expenditure, and GDP in both countries. Results show that internet usage and R&D expenditure significantly drive GDP growth, with Georgia showing a larger immediate GDP response and Slovakia demonstrating more persistent GDP growth from R&D investments. This analysis offers a comprehensive understanding of the position and potential of Slovakia and Georgia in the global landscape of Industry 4.0, highlighting the varied impacts of digital transformation and innovation across distinct economic landscapes. Additionally, this study contributes to the scientific literature by providing empirical evidence on the critical role of digital transformation and R&D investment in economic growth within the context of Industry 4.0.

Introduction

World Economic Forum founder Klaus Schwab described the term "Fourth Industrial Revolution" (hereinafter: I4.0) as an era "that creates a world in which virtual and physical production systems work flexibly together globally."[1] He wrote that "like the revolutions that preceded it, the Fourth Industrial Revolution has the potential to raise global income levels and improve the quality of life of residents around the world."[2] Other authors describe the phenomenon as a "smart revolution" driven by transformative technologies such as artificial intelligence, big data and hyperconnectivity.[3]

The shift towards I4.0 marks a significant realignment of manufacturing and economic systems, underscored by the pervasive integration of digital technologies. Globally, nations are responding to this shift by launching initiatives to bolster the I4.0 framework, such as Germany's “Industrie 4.0,” China's “Made in China 2025,” India's “Made in India Initiative,” Italy's “Industria 4.0 Law,” and the “Smart Manufacturing Leadership Act” in the United States [4]. These actions illustrate a strategic recognition of the transformational potential that I4.0 presents, notwithstanding the varied levels of industrial maturity across different countries.

The adoption and evolution of I4.0 display marked contrasts between developed and developing nations. Developed countries, leveraging their established industrial infrastructure and information and communication technology (ICT), have primarily focused on marketing and social implications of I4.0, initiating this transition earlier. In contrast, developing countries are confronted with challenges including institutional voids and financial limitations, leading to a primary focus on economic goals within their I4.0 adoption strategies.[5] The disparity is rooted in the varying degrees of industrial maturity,

[1] SCHWAB, K. (2016): The Fourth Industrial Revolution, Penguin Random House UK, p. 12.
[2] Ibid.
[3] PYP, D., HWANG, J., YOON, Y. (2021). Tech Trends of the 4th Industrial Revolution. Germany: Mercury Learning and Information, p.3
[4] MARUCCI, A., RIALTI, R., & BALZANO, M. (2023). Exploring paths underlying Industry 4.0 implementation in manufacturing SMEs: a fuzzy-set qualitative comparative analysis. Management Decision.
[5] BOVOGIZ, A. V., OSIPOV, V. S., CHISTYAKOVA, M. K., & BORISOV, M. Y. (2019). Comparative analysis of formation of industry 4.0 in developed and developing countries. Industry 4.0: industrial revolution of the 21st century, 155-164.

where developing countries often lag in automation and ICT—critical components of the third industrial revolution that seamlessly transition into I4.0.[6]

Emerging economies, therefore, may exhibit a significant gap in adopting I4.0, evidenced by a slower uptake of foundational industrial stages.[7] This discrepancy highlights the need for a tailored analysis of I4.0 adoption determinants in these contexts. To this end, our research centers on understanding the economic, and technological factors that underpin the adoption of I4.0 in Slovakia and Georgia. By interrogating these determinants, this paper seeks to discern how each country's unique integration process is being shaped.

1. Slovak context

Slovakia, located in Central Europe, is actively implementing Industry 4.0 technologies to increase its industrial and economic competitiveness. Although Slovakia may not be as large or well-known as some other countries in this context, it has made significant progress in adopting digitization and advanced manufacturing.

Slovakia has a strong manufacturing heritage, especially in the automotive industry. The presence of large car manufacturers such as Volkswagen, Kia, Peugeot-Citroën and Jaguar Land Rover has led to the adoption of Industry 4.0 practices in the country.[8] These companies have implemented automation, IoT, and robotics in their manufacturing processes.

According to research conducted by Grenčíková, Kordoš and Berkovič, it is clear that only a small part, approximately one tenth, of industrial enterprises in Slovakia either do not know or are not actively engaged in the concepts of Industry 4.0. Most companies in the region are in the process of evaluating the feasibility of implementing elements of

[6] KAGERMANN, H., HELBIG, J., HELLINGER, A., & WAHLSTER, W. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Securing the future of German manufacturing industry; final report of the Industrie 4.0 Working Group. Forschungsunion.

[7] KRAWCZYŃSKI, M., CZYŻEWSKI, P., BOCIAN, K. (2016). Reindustrialization: A challenge to the economy in the first quarter of the twenty-first century. *Foundations of Management*, *8*(1), 107-122.

[8] Slovak investment and trade development agency (SARIO), (2021). Automative sector in Slovakia, Available at: sario-automotive-sector-in-slovakia-2021-02-05.pdf. Accessed [10.05.2024].

smart industry in their operations, or are already engaged in such implementations in various ways.[9]

In the context of small and medium-sized enterprises (SMEs) in Slovakia, the adoption of Industry 4.0 technologies presents a diverse picture. Some Slovak SMEs have demonstrated a relatively higher level of proactivity in using the advances of Industry 4.0. According to recent research, 61% of SMEs in Slovakia are familiar with the concept of Industry 4.0.[10] This positive level can be attributed to factors such as greater access to resources, availability of skilled labour and Slovakia's integration into the European supply chain. These advantages have put Slovak SMEs in a position to more easily integrate Industry 4.0 innovations into their operations.

The Slovak government has recognized the importance of Industry 4.0 and provides support through various initiatives and funding programmes. This includes financial incentives for research and development projects, as well as grants to companies investing in high technologies. Slovakia's Digital Transformation Strategy up to 2030 is a comprehensive government framework that outlines Slovakia's policies and priorities in the field of adaptation to the ongoing digital transformation of the economy and society. The strategy is closely linked to the digitisation initiatives of the European Union and global digital transformation trends.[11]

A positive factor for Slovakia is the trend of interest in the topic of Smart Industry, not only at the level of discussions, but also in the activities of companies.[12] Several Slovak manufacturing plants have transformed into smart factories by incorporating IoT sensors and data analysis into their production processes. Some scholars claim that Industry 4.0

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[9] GRENCÍKOVÁ, A., KORDOŠ, M., & BERKOVIČ, V. (2020). The impact of industry 4.0 on jobs creation within the small and medium-sized enterprises and family businesses in Slovakia. *Administrative sciences*, *10*(3), 71.

[10] TICK, A. (2023). Industry 4.0 Narratives through the Eyes of SMEs in V4 Countries, Serbia and Bulgaria. *Acta Polytechnica Hungarica*, *20*(2).

[11] JENČOVÁ, S., VAŠANIČOVÁ, P., & MIŠKUFOVÁ, M. (2023). Multidimensional Evaluation of EU and Slovakia in the Context of Digital Transformation. Central European Business Review, 12(1), 65.

[12] PAPULA, J., KOHNOVÁ, L., PAPULOVÁ, Z., & SUCHOBA, M. (2019). Industry 4.0: preparation of Slovak companies, the comparative study. *Smart Technology Trends in Industrial and Business Management*, 103-114.

wireless networks and cyber-physical intelligent production systems can be accelerators of the growth of added value of Slovak exports.[13]

However, there are some problems in Slovakia, especially at EU level. Slovakia has made huge strides in the development of digital technologies, especially at the level of core network infrastructure on an annual basis and faced a lack of relevant competencies and human resources.[14] In addition, Slovakia lags behind in the level of its digitization, like other V4 countries. This lag is evident in aspects such as broadband internet access and digital public services (EC 2019a). According to the DESI index, Slovakia's access to broadband internet and 4G is below the EU average, as is the digital skills of its population. It is noteworthy that Slovakia did not show any significant development in digitalisation according to the DESI index (EC 2020a).[15]

2. Georgian context

Although Georgia is making progress in adapting to Industry 4.0, it also faces challenges. These include insufficient infrastructure and funding, as well as the need for further training of the workforce. In Georgia, there is a noticeably low level of adoption among enterprises regarding key Industry 4.0 technologies such as ERP, Io.T, and AI, indicating significant challenges in readiness for this technological transformation.[16]

When considering the successful implementation of Industry 4.0 in Georgia, it is essential to emphasize the key role of solid digital infrastructure and innovative initiatives, as various scholars claim.[17] These elements form the foundation on which a thriving Industry 4.0 ecosystem can be built.

The Asian Development Bank's report “An emerging ecosystem for tech start-ups in Georgia” highlights a critical issue in the region. The report highlights that the potential

[13] VALASKOVA, K., NAGY, M., ZABOJNIK, S., LĂZĂROIU, G. (2022). Industry 4.0 wireless networks and cyber-physical smart manufacturing systems as accelerators of value-added growth in Slovak exports. *Mathematics*, *10*(14), 2452.
[14] GYIMESI, Á. (2021). National industry 4.0 platforms in the Visegrad 4 Countries–A comparison with the frontrunner digital economies in Europe. *Studia Universitatis Babes Bolyai-Oeconomica*, *66*(3), 21-39.
[15] Ibid.
[16] MTCHEDLIDZE, N., PAPULOVA, Z. (2024). Navigating Industry 4.0 in Georgia: Challenges and Opportunities on the Path to Technological Transformation. ResearchGate.
[17] TURMANIDZE R, DAŠIĆ P, POPKHADZE G. (2020): Digital infrastructure in Georgia as a condition for successful application. In*: Industry 4.0.* 2020, Vol. 5, N. 1, pp. 3-6

of digitalisation is still underexploited by businesses, especially small and medium-sized enterprises (SMEs) located outside the capital, Tbilisi. Furthermore, it draws attention to the significant gap in digital skills among the population, with these skills significantly lower in peripheral areas.[18]

In Georgia, SMEs have encountered significant challenges in adopting Industry 4.0. Barriers are likely to stem from constraints in areas such as limited resources, limited access to skilled labour and comparatively lower exposure to global markets. These factors may have hampered the rapid integration of Industry 4.0 technologies among SMEs in Georgia, indicating a difference in readiness and capacity of SMEs in both countries to take these transformative advances.

Over the past decade, Georgia has made significant strides in establishing an institutional and policy framework to promote digitalization. The country adopted the "A Digital Georgia: e-Georgia Strategy and Action Plan 2014-2018," which encompassed 11 thematic pillars, emphasizing ICT utilization, e-government, and digital innovation. This strategy was integrated into the Public Administration Reform 2020, facilitating initiatives like the open data portal and unified e-services portal. Georgia is currently working on a second National Digital Governance Strategy and Action Plan. The business sector saw efforts to streamline transactions, enhance online payments, improve security, and expand broadband infrastructure, with the National Bank introducing regulations for transparency. Furthermore, Georgia has embraced the EU4Digital program, developing the National Broadband Development Strategy of Georgia (NBDS) to bridge the urban-rural digital divide.[19]

3. Comparative Analysis of Industry 4.0 Readiness in Georgia and Slovakia

This chapter provides a framework to analyze some important factors influencing the readiness and adoption of Industry 4.0 technologies in Georgia and Slovakia, highlighting demographic, economic, and innovation-related metrics before the main

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[18] NANITASHVILI, N. V., & VANDENBERG, P. (2023). GEORGIA'S EMERGING ECOSYSTEM FOR TECHNOLOGY STARTUPS. Asian Development Bank.

[19] OECD: Fostering Business Development and Digitalisation in Georgia. (2022). Available at: Fostering Business Development and Digitalisation in Georgia (oecd.org). Accessed [01.05.2024].

analysis. Understanding these contexts is crucial for assessing each country's capacity to integrate advanced technologies and drive economic growth.

Georgia has a population of 3,694,600 with a GDP per capita of $8,210.1 and a real GDP growth rate of 7.5%. Despite its rapid economic growth, Georgia faces a high unemployment rate of 16.4%, which could challenge the effective implementation of new technologies. The country has 205,684 active business entities, including 11,434 information and communication enterprises and 18,336 manufacturing entities. However, Georgia ranks 65th in both the Digital Quality of Life Index and the Global Innovation Index, and 99th in the Government AI Readiness Index, indicating areas for improvement in digital infrastructure and innovation.

In contrast, Slovakia, with a population of 5,424,687, boasts a higher GDP per capita of $24,462 but a slower real GDP growth rate of 1.6%. Its lower unemployment rate of 5.6% reflects a stable labor market conducive to adopting advanced technologies. Slovakia has 264,086 active business entities, with 17,252 information and communication enterprises and 32,232 manufacturing entities. Slovakia ranks significantly higher in the Digital Quality of Life Index (33rd), Global Innovation Index (45th), and Government AI Readiness Index (44th), indicating a stronger foundation for digital transformation and innovation.

Table 1. Comparative Factors Influencing Industry 4.0 Readiness in Georgia and Slovakia

Comparative Factors	**Georgia**[20]	**Slovakia**[21]
Population	3 694 600	5 424 687
GDP per Capita ($)	8 210.1	24 462
Real GDP Growth Rate (%)	7,5	1,60
Unemployment rate (%)	16,4	5.6
Active business entities 31.12.2023	205 684	264 086

[20] Data obtained from the National Statistics Office of Georgia. Available at: https://www.geostat.ge/en. Accessed [10.05.2024].
[21] Data obtained from the Statistical Office of the Slovak Republic. Available at: https://slovak.statistics.sk/. Accessed [12.05.2024].

Information and Communication enterprises (31.12.2023)	11 434	17 252
Manufacturing entities (31.12.2023)	18 336	32 232
Digital Quality of Life Index 2023[22]	65th place	33rd place
Global Innovation Index 2023[23]	65th place	45th place
Government AI Readiness Index 2023[24]	99th place	44th place

In summary, while Slovakia appears better positioned in terms of economic stability, digital infrastructure, and innovation readiness, Georgia shows promising growth potential but faces challenges in unemployment and digital skills.

4. Methodology

Our study adds to the existing literature by offering a comparative analysis of Industry 4.0 factors in Slovakia and Georgia, two countries with distinct economic and technological contexts. Papers focusing on specific drivers and barriers for Industry 4.0 adoption and its practical application remain scarce in the literature. [25]

We employ the Vector Autoregression (VAR) model to investigate the relationship between three key variables: internet usage (measured as the percentage of individuals using the internet), [26] research and development (R&D) expenditure (expressed as a percentage of GDP),[27] and economic performance (represented by GDP in constant 2015 US$).[28] Our objective is to forecast future values of these variables and visualize their interactions through Impulse Response Functions (IRFs).

The following hypotheses structure our investigation:

[22] Digital Quality of Life Index. Available at: https://surfshark.com/. Accessed [20.05.2024].
[23] Global innovation index 2023. Available at: https://www.wipo.int/global_innovation_index/en/2023/. Accessed [20.05.2024]
[24] Government AI Readiness Index. Available at: https://oxfordinsights.com/ai-readiness/ai-readiness-index/. Accessed [22.05.2024].
[25] Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., & Haug, A. (2021). Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers. Production Planning & Control, 32(10), 811-828.
[26] Individuals using the Internet (% of population). Available at: https://data.worldbank.org/indicator/IT.NET.USER.ZS. Accessed [31.05.2024]
[27] Research and development expenditure (% of GDP). Available at: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS. Accessed [31.05.2024]
[28] GDP (constant 2015 US$). Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.KD. Accessed [31.05.2024].

H1: Increased internet usage positively impacts GDP in both Slovakia and Georgia.

H2: Higher R&D expenditure positively impacts GDP in both Slovakia and Georgia.

We anticipate that a shock to either internet usage or R&D expenditure will lead to a positive response in GDP, highlighting the importance of these factors in driving economic performance in the context of Industry 4.0.

5. Data preprocessing and graphical analysis

For our research comparing Slovakia and Georgia using a VAR model estimation, we selected three key variables: the percentage of individuals using the Internet, Research and Development expenditure as a percentage of GDP, and GDP in constant 2015 US$. We used yearly data spanning from 1996 to 2021 from the World Bank database.

However, we encountered some missing data in the Research and Development expenditure (% of GDP) for Georgia during certain years. To address this, we used linear interpolation to estimate the missing values, ensuring a complete dataset for our analysis. This approach maintains the integrity of our data and allows us to proceed with the VAR model estimation, facilitating a robust comparison between the two countries.

We enhanced our VAR analysis by disaggregating annual data to monthly data using the Denton-Cholette method. This increased the number of observations and captured short-term dynamics. Monthly GDP values were summed, while internet usage and R&D expenditure percentages were averaged. Log transformations were applied to seasonally adjusted values to improve normality and stability, making the data suitable for VAR analysis and allowing for the interpretation of coefficients as elasticities.

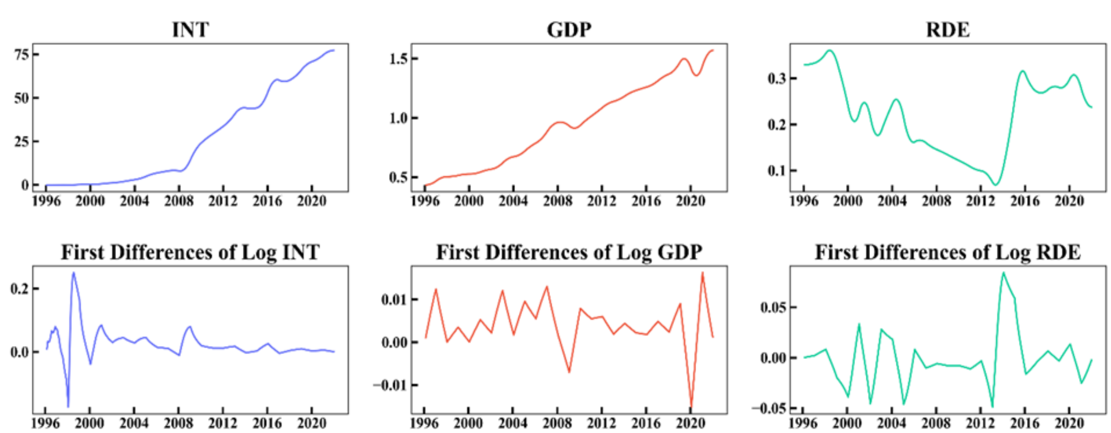


Figure 1. Time Series and First Differences of Log-Transformed Variables for Georgia

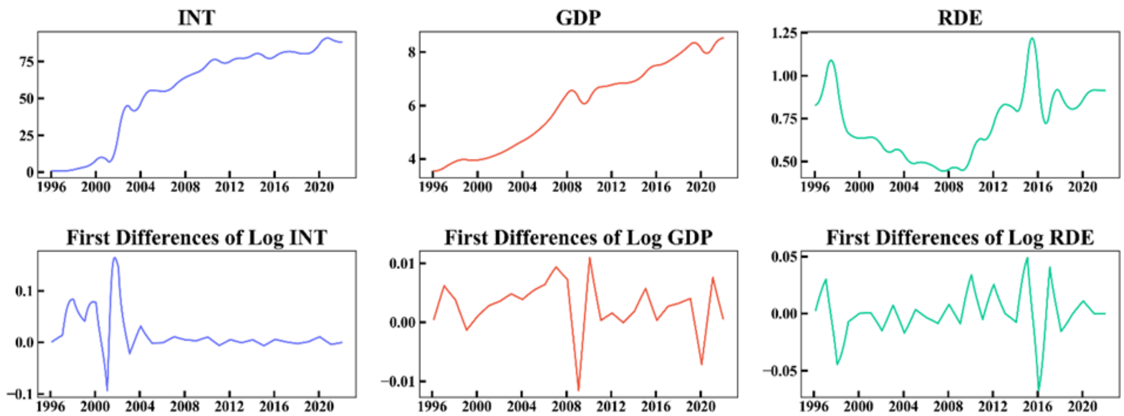


Figure 2. Time Series and First Differences of Log-Transformed Variables for Slovakia

Based on the time series plots and first differences of the log-transformed variables for Georgia and Slovakia, we observe several key findings. Firstly, the first differences of the log-transformed variables appear more stationary compared to the original time series for both countries, suggesting that the log-transformed variables are integrated of order one (I(1)). In terms of trends, GDP and internet usage (INT) exhibit clear upward trajectories in both countries, while R&D expenditure (RDE) demonstrates a more stable pattern with occasional fluctuations. Regarding volatility, the first differences of log GDP and log RDE are more volatile in Georgia compared to Slovakia, indicating higher variability in these variables for Georgia. Additionally, we identify critical points in the data: for instance, Georgia experiences a noticeable dip in GDP around 2008-2009, likely due to the global financial crisis, whereas Slovakia's GDP also shows a slowdown during this period, albeit to a lesser extent. Overall, the graphical analysis suggests that the log-transformed variables are more suitable for the VAR analysis due to their improved stationarity. The comparison highlights differences in the behavior of the variables between the two countries, which may lead to distinct outcomes in the VAR model.

5.1 Augmented Dickey and Fuller test

Each of these time series shows signs of non-stationarity due to their visible trends and variability over time. Non-stationary data in a VAR model can lead to spurious results, making it crucial to test for stationarity using unit root tests, such as the Augmented Dickey-Fuller (ADF) test.[29] The ADF test extends the Dickey-Fuller test by including higher-order autoregressive processes, enhancing its robustness for a wider range of time series.

Our analysis involved applying the ADF test to assess the stationarity of the variables—Research and Development expenditure (RDE), Internet Usage (INT), and GDP—for both Georgia and Slovakia. The test results indicate that the first differences of the log-transformed variables are more stationary compared to the original time series, suggesting that these variables are integrated of order one (I(1)). For detailed ADF test results, please refer to Appendix A.

The key findings are summarized as follows:

- **R&D Expenditure (RDE):** The first differences of log-transformed RDE are stationary in both Georgia and Slovakia.
- **Internet Usage (INT):** The first differences of log-transformed INT exhibit improved stationarity in both countries.
- **GDP:** The first differences of log-transformed GDP are stationary, confirming the presence of unit roots in the levels but not in the first differences.

These findings indicate that the log-transformed and differenced data are suitable for VAR analysis, ensuring robust and reliable results for our comparative study of Industry 4.0 factors in Georgia and Slovakia.

5.1.1 Selection of the lag order

In choosing the number of lags for our VAR model, we aim to balance capturing the dynamics of the system while avoiding overfitting. To automate this process, we used

[29] DICKEY, D. A., & FULLER, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American statistical association, 74(366a), 427-431.

criteria such as the Akaike Information Criterion (AIC),[30] the Hannan-Quinn Criterion (HQ), the Schwarz Criterion (SC), and the Final Prediction Error (FPE). The lag order associated with the lowest value of these information criteria was selected, with most criteria recommending a lag order of 2. Additionally, we used the Wald test to confirm the robustness of our results by assessing the significance of an additional lag.

5.1.2 Wald Test

The Wald test assesses the significance of multiple coefficients in VAR models by comparing a restricted model (where coefficients are set to zero) with an unrestricted model (where coefficients are freely estimated). The test statistic, which follows a chi-squared distribution, measures whether the inclusion of additional coefficients significantly improves the model fit. The Wald test results for Georgia indicated one significant test, while the results for Slovakia showed non-significant coefficients in all tests. Based on these mixed results, we decided to maintain a lag order of 2 for our VAR model, as it provided a more consistent and stable fit across both datasets (for a detailed analysis, please refer to Appendix B).

5.2 Estimation of the VAR Model

With the selected lag order of two, our theoretical VAR model involves estimating the relationships between the variables based on the two lagged observations. The models for Slovakia and Georgia are specified as follows:

Slovakia VAR Model (Equation 1)

$$\begin{pmatrix} RDE_{SK,t} \\ INT_{SK,t} \\ GDP_{SK,t} \end{pmatrix} = \begin{pmatrix} C_{11}^{SK} \\ C_{21}^{SK} \\ C_{31}^{SK} \end{pmatrix} + \begin{pmatrix} A_{11}^{SK} & A_{12}^{SK} & A_{13}^{SK} \\ A_{21}^{SK} & A_{22}^{SK} & A_{23}^{SK} \\ A_{31}^{SK} & A_{32}^{SK} & A_{33}^{SK} \end{pmatrix} \begin{pmatrix} RDE_{SK,t-1} \\ INT_{SK,t-1} \\ GDP_{SK,t-1} \end{pmatrix} + \begin{pmatrix} u_{1t}^{SK} \\ u_{2t}^{SK} \\ u_{3t}^{SK} \end{pmatrix}$$

Georgia VAR Model (Equation 2)

[30] AKAIKE, H. (1974). A new look at the statistical model identification. *IEEE transactions on automatic control*, *19*(6), 716-723.

$$\begin{pmatrix} RDE_{GE,t} \\ INT_{GE,t} \\ GDP_{GE,t} \end{pmatrix} = \begin{pmatrix} C_{11}^{GE} \\ C_{21}^{GE} \\ C_{31}^{GE} \end{pmatrix} + \begin{pmatrix} A_{11}^{GE} & A_{12}^{GE} & A_{13}^{GE} \\ A_{21}^{GE} & A_{22}^{GE} & A_{23}^{GE} \\ A_{31}^{GE} & A_{32}^{GE} & A_{33}^{GE} \end{pmatrix} \begin{pmatrix} RDE_{GE,t-1} \\ INT_{GE,t-1} \\ GDP_{GE,t-1} \end{pmatrix} + \begin{pmatrix} u_{1t}^{GE} \\ u_{2t}^{GE} \\ u_{3t}^{GE} \end{pmatrix}$$

5.2.1 Autocorrelation

The Breusch-Godfrey test, a statistical method used to detect autocorrelation in regression model residuals, is particularly useful for time series analysis where data points are serially correlated.[31] The next step was to conduct this test, and the results can be seen in Appendix C.

For both Georgia and Slovakia, the Breusch-Godfrey test results indicate significant serial correlation at higher lags (12 through 16). This suggests potential limitations in the VAR models, which could affect the reliability of our Impulse Response Functions (IRF) and forecasts.

5.2.2 Normality Test

The multivariate Jarque-Bera[32] test results for both Georgia and Slovakia show extremely high chi-squared values with p-values < 2e-16, indicating that the residuals of our VAR(2) models significantly deviate from normality.

- Georgia:
    - JB-Test: Chi-squared = 255932, df = 6, p-value < 2e-16
    - Skewness: Chi-squared = 4531, df = 3, p-value < 2e-16
    - Kurtosis: Chi-squared = 251401, df = 3, p-value < 2e-16
- Slovakia:
    - JB-Test: Chi-squared = 255489, df = 6, p-value < 2e-16
    - Skewness: Chi-squared = 4244, df = 3, p-value < 2e-16
    - Kurtosis: Chi-squared = 251246, df = 3, p-value < 2e-16

[31] BREUSCH, T. S. (1978). Testing for Autocorrelation in Dynamic Linear Models. Australian Economic Papers, 17(31), 334-355

[32] JARQUE, C. M., BERA, A. K. (1980). Efficient Tests for Normality, Homoscedasticity and Serial Independence of Regression Residuals. Economics Letters, 6(3), 255-259

These results suggest potential limitations in our model's ability to capture the underlying data distribution.

5.2.3 Heteroskedasticity Test

The multivariate ARCH test results show no significant heteroskedasticity in the residuals of our VAR(2) models.[33]

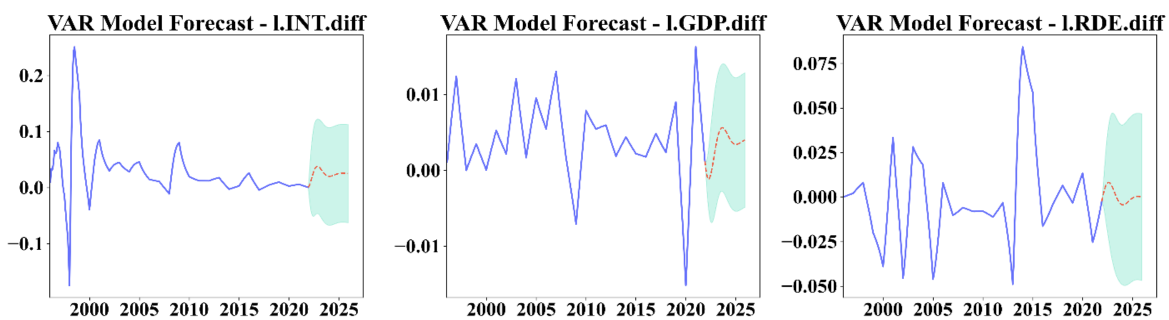
- Georgia: Chi-squared = 59.9, df = 180, p-value = 1
- Slovakia**:** Chi-squared = 20.7, df = 180, p-value = 1

5.3 Forecasting Analysis

5.3.1 VAR Model Forecast Interpretation for Georgia

The VAR model forecasts for Georgia indicate the following trends:

- Internet Usage (INT): An increasing trend over the next few years, signaling continued growth in internet penetration.
- GDP: Expected to grow, but at a slower pace compared to internet usage.
- R&D Expenditure (RDE): Projected to remain relatively stable with minor fluctuations around the current level.

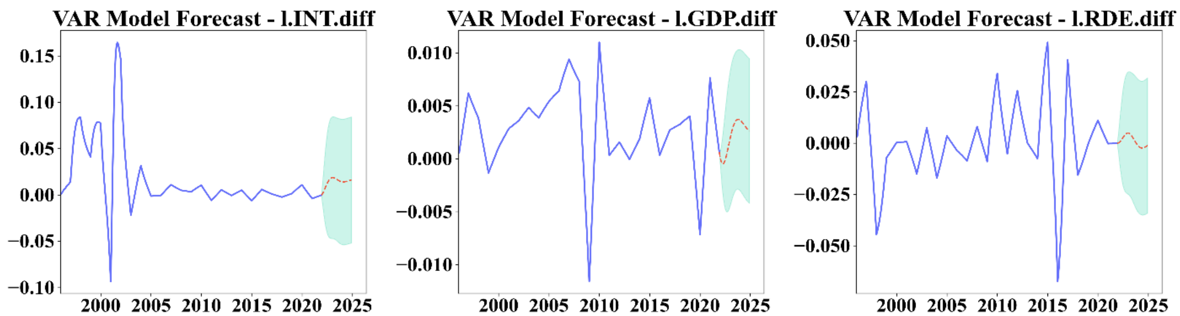


5.3.2 VAR Model Forecast Interpretation for **Slovakia**

The VAR model forecasts for Slovakia reveal:

[33] ENGLE, R. F., KRONER, K. F. (1995). Multivariate Simultaneous Generalized ARCH. Econometric Theory, 11(1), 122-150.

- **Internet Usage (INT):** A steady increase in the coming years, suggesting further expansion of internet access.
- **GDP:** Positive growth is expected, but it will be more moderate compared to Georgia.
- **R&D Expenditure (RDE):** Forecasted to experience a slight decline in the short term before stabilizing around the current level.



5.3.3 Comparison of Forecasts

Both countries are expected to see continued growth in internet usage, highlighting the ongoing digital transformation. However, the growth in internet usage is more pronounced in Georgia compared to Slovakia. GDP growth is projected to be positive in both countries, with Georgia showing a slightly higher growth rate. R&D expenditure is forecasted to remain relatively stable in both countries, with Slovakia experiencing a minor decline in the short term.

Overall, the VAR model forecasts suggest that:

- Both countries will continue to experience growth in internet usage and GDP.
- R&D Expenditure: Expected to remain relatively stable in both countries.

These projections can assist economists, researchers, and industry leaders in both countries to make informed decisions and plan for the future in the context of Industry 4.0 development.

5.4 Impulse Response Function Analysis

5.4.1 Impulse Response Function Results for Georgia

Based on the impulse response function (IRF) results for Georgia, we observe the following:

- Shock to Internet Usage (l.INT.diff): Leads to an initial positive response in GDP, which then declines over time. This supports the hypothesis that increased internet usage positively impacts GDP.
- Shock to R&D Expenditure (l.RDE.diff): GDP responds positively, with the effect peaking after a few time steps and then gradually decreasing. This aligns with the hypothesis that higher R&D spending boosts GDP.
- Shock to GDP (l.GDP.diff): GDP responds strongly and positively to its own shock before the effect tapers off.
- Response to GDP Shock: Both internet usage and R&D expenditure respond positively, indicating a bidirectional relationship between these variables and economic performance.

5.4.2 Impulse Response Function Results for Slovakia

For Slovakia, the IRF results show:

- Shock to Internet Usage (l.INT.diff): Similar to Georgia, a shock to internet usage leads to an initial positive response in GDP, which then declines over time, supporting the hypothesis.
- Shock to R&D Expenditure (l.RDE.diff): GDP responds positively, with the effect peaking after a few time steps and then gradually decreasing, in line with the hypothesis.
- Shock to GDP (l.GDP.diff): Strong and positive response of GDP to its own shock before tapering off.
- Response to GDP Shock: Internet usage and R&D expenditure positively respond to a GDP shock, suggesting a bidirectional relationship.

5.4.3 Comparison of IRF Results

When comparing the IRF results for Georgia and Slovakia, several differences and similarities emerge. The response of GDP to internet and R&D shocks is larger in Georgia compared to Slovakia, while in Slovakia, the GDP response to an R&D shock is more persistent over time relative to Georgia. The IRF results support the hypothesis that internet usage and R&D expenditure are significant drivers of GDP growth in the Industry 4.0 era for both countries. However, there are differences in the magnitude and persistence of these effects. Georgia exhibits a larger magnitude of GDP response to internet and R&D shocks, whereas Slovakia shows a more persistent GDP response to R&D shocks. These findings suggest that while both internet usage and R&D expenditure are crucial for economic performance, their impacts vary between countries, which may influence policy decisions (For detailed graphical analysis, please refer to Appendix D).

Discussion and Conclusion

In our research, we conducted a comparative analysis of Industry 4.0 factors in Slovakia and Georgia using the Vector Autoregression (VAR) model. We investigated the relationship between internet usage, research and development (R&D) expenditure, and economic performance (GDP), hypothesizing that increased internet usage and higher R&D expenditure positively impact GDP in both countries.

The impulse response functions (IRFs) supported our hypothesis, showing that shocks to internet usage and R&D expenditure led to positive responses in GDP for both Georgia and Slovakia. This aligns with economic theory, which suggests that technological advancements and innovation drive economic growth in the Industry 4.0 era.

Our methodology included data preprocessing, graphical analysis, unit root testing, and VAR model estimation with appropriate lag selection. The stability of our VAR models was confirmed, although the Breusch-Godfrey test indicated serial correlation at higher lags, and the Jarque-Bera test revealed deviations from normality, which could impact the reliability of our forecasts.

Despite these limitations, our study highlights the importance of digital transformation and innovation in driving economic development. The VAR model forecasts suggest continued growth in internet usage and GDP for both Georgia and Slovakia. This research provides empirical evidence that internet usage and R&D expenditure are significant determinants of GDP growth in the context of Industry 4.0, adding valuable insights to the scientific literature comparing developing and developed countries.

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Appendix A: Detailed Augmented Dickey-Fuller Test Results

Augmented Dickey-Fuller Test Results for R&D Expenditure (RDE) – Georgia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.RDE.tau3	-3.98	-3.42	-3.13	-1.5894
l.RDE.phi2	6.15	4.71	4.05	1.3161
l.RDE.phi3	8.34	6.3	5.36	1.9481
d.l.RDE.tau3	-3.98	-3.42	-3.13	-6.1373
d.l.RDE.phi2	6.15	4.71	4.05	12.5631
d.l.RDE.phi3	8.34	6.3	5.36	18.8436

Augmented Dickey-Fuller Test Results for R&D Expenditure (RDE) - Slovakia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.RDE.tau3	-3.98	-3.42	-3.13	-2.7855
l.RDE.phi2	6.15	4.71	4.05	3.8346
l.RDE.phi3	8.34	6.3	5.36	5.7279
d.l.RDE.tau3	-3.98	-3.42	-3.13	-7.7247
d.l.RDE.phi2	6.15	4.71	4.05	19.9409
d.l.RDE.phi3	8.34	6.3	5.36	29.8933

Augmented Dickey-Fuller Test Results for Internet Usage (INT) - Georgia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.INT.tau3	-3.98	-3.42	-3.13	-1.2777
l.INT.phi2	6.15	4.71	4.05	6.3661
l.INT.phi3	8.34	6.3	5.36	4.6082
d.l.INT.tau3	-3.98	-3.42	-3.13	-6.7243
d.l.INT.phi2	6.15	4.71	4.05	15.0770
d.l.INT.phi3	8.34	6.3	5.36	22.6081

Augmented Dickey-Fuller Test Results for Internet Usage (INT) - Slovakia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.INT.tau3	-3.98	-3.42	-3.13	-3.5446
l.INT.phi2	6.15	4.71	4.05	11.9925
l.INT.phi3	8.34	6.3	5.36	14.2493
d.l.INT.tau3	-3.98	-3.42	-3.13	-7.6550
d.l.INT.phi2	6.15	4.71	4.05	19.5342
d.l.INT.phi3	8.34	6.3	5.36	29.3003

Augmented Dickey-Fuller Test Results for GDP - Georgia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.GDP.tau3	-3.98	-3.42	-3.13	-1.0564
l.GDP.phi2	6.15	4.71	4.05	7.1699
l.GDP.phi3	8.34	6.3	5.36	1.0504
d.l.GDP.tau3	-3.98	-3.42	-3.13	-7.0200
d.l.GDP.phi2	6.15	4.71	4.05	16.4936
d.l.GDP.phi3	8.34	6.3	5.36	24.6443

Augmented Dickey-Fuller Test Results for GDP - Slovakia

	1% Critical Value	5% Critical Value	10% Critical Value	Statistic
l.GDP.tau3	-3.98	-3.42	-3.13	-0.9013
l.GDP.phi2	6.15	4.71	4.05	5.4970
l.GDP.phi3	8.34	6.3	5.36	1.0602
d.l.GDP.tau3	-3.98	-3.42	-3.13	-6.4299
d.l.GDP.phi2	6.15	4.71	4.05	13.8126
d.l.GDP.phi3	8.34	6.3	5.36	20.6719

Appendix B: Additional Data and Analysis

Selection of the Lag Order for VAR Model

Criterion	*Georgia*	*Slovakia*
AIC	*3*	*2*
HQ	*2*	*2*
SC	*2*	*2*
FPE	*3*	*2*

Wald Test Results

Test	*Georgia (Chi-squared, df, P-value)*	*Slovakia (Chi-squared, df, P-value)*
Test 1	*0.38, 3, 0.95*	*3.4, 3, 0.34*
Test 2	*13.7, 3, 0.0033*	*2.0, 3, 0.58*
Test 3	*1.7, 3, 0.63*	*1.1, 3, 0.77*

Appendix C: Breusch–Godfrey test results

Georgia

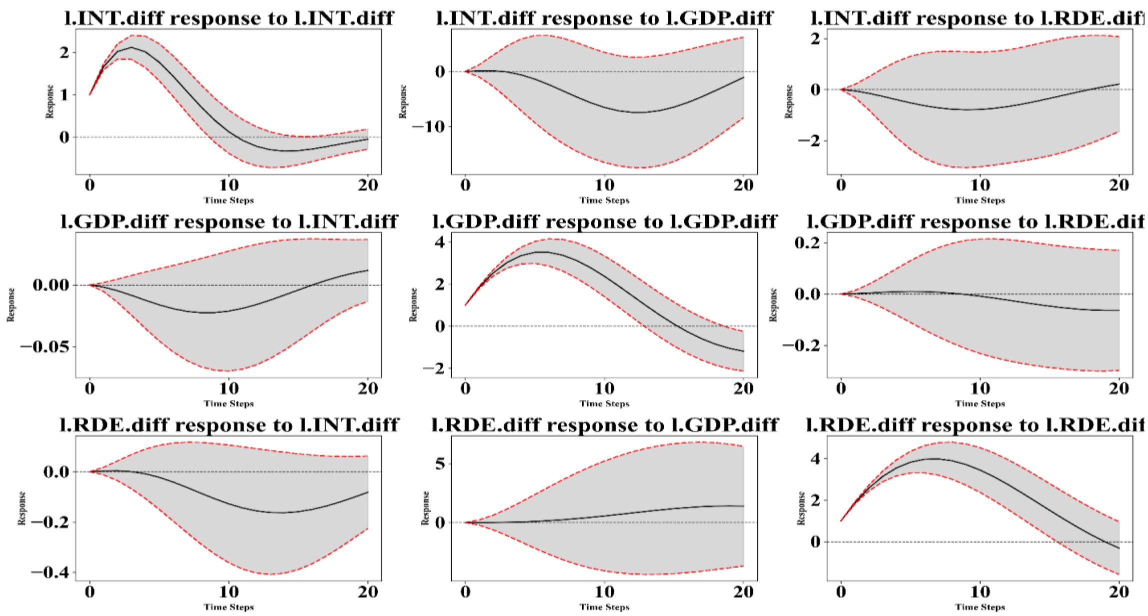
Lag	Statistic	df	p.value
1	14.096	9	0.11894
2	15.555	18	0.62359
3	16.251	27	0.94799
4	18.078	36	0.99445
5	18.499	45	0.99984
6	23.256	54	0.99992
7	25.893	63	0.99999
8	30.997	72	0.99999
9	41.724	81	0.99991
10	65.862	90	0.97382
11	103.305	99	0.36361
12	325.673	108	0.00000
13	337.718	117	0.00000
14	341.521	126	0.00000
15	343.330	135	0.00000
16	346.235	144	0.00000

Slovakia

Lag	Statistic	df	p.value
1	4.1482	9	0.90139
2	7.0589	18	0.98962
3	9.3705	27	0.99934
4	10.9825	36	0.99998
5	12.1657	45	1.00000
6	13.3304	54	1.00000
7	15.2173	63	1.00000
8	20.6205	72	1.00000
9	33.9418	81	1.00000
10	65.7573	90	0.97440
11	119.9555	99	0.07464
12	417.0341	108	0.00000
13	428.6297	117	0.00000
14	433.4876	126	0.00000
15	434.6797	135	0.00000
16	435.6519	144	0.00000

Appendix D: Detailed Impulse Response Function Graphs

Georgia



Slovakia