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The nexus between economic policy uncertainty and innovation performance in Visegrad group countries

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Abstract

Research background: Research and development (R&D) spending and innovation initiatives play a crucial role in promoting growth. However, economic policy uncertainty (EPU) is a reality that cannot be avoided when making business decisions. The Visegrad Group (V4), consisting of Poland, Hungary, the Czech Republic, and Slovakia, is considered a regional

alliance of four Central European countries with significant potential for innovation and economic development because these nations' economies are encountering the so-called 'middle-income trap'.
Purpose of the article: The paper's main objective is to examine the impact of economic policy uncertainty on innovation performance and R&D expenditures in the Visegrad Group countries.
Methods: The study used comparative panel models analysis (fixed effect, random effect, and system generalized method of moments [GMM]) between 2012 and 2021. The models include the lag periods for EPU to provide a better perspective on the short-term impact and even long-term consequences of EPU.
Findings & value added: The directions of innovation output and R&D expenditures are directly related to EPU. In V4 economies, businesses may reduce their spending on R&D and innovation activities when confronted with high EPU; however, over time, the volatility of economic uncertainties is adjusted for. Additionally, the political and economic control variables increase the number of dimensions used in the models, which will motivate additional EPU studies in the field. Although EPU studies are widely accepted, our investigation shows that the topic is still not properly developed for Visegrad Group countries in relation to how EPU affects innovation activity. Another unique feature of the current study is the diversity of variables used, including the EPU lag variables, variables representing essential economic and political issues, as well as control variables, thus incorporating complex panel models.

Introduction

Innovation plays a vital role in transforming new ideas into solutions. It acts as a social, economic and environmental problem solver and is essential for sustainable development (Fu & Shi, 2022). The four Visegrad (V4) nations — the Czech Republic, Hungary, Slovakia and Poland — have been members of the European Union since 2004. The initial circumstances, transitional options and subsequent economic advances of the V4 have varied significantly. Because of this, the V4 makes a great subject for comparative studies of how economic policies affect financial performance and economic innovation (Fidrmuc *et al*., 2002; Zybała, 2019). An actual illustration of how uncertainty can negatively impact the international economy can be found in the events that followed the COVID-19 pandemic. The economic policy uncertainty index (EPU) reveals that a high EPU is linked to negative effects on households, businesses and governments. The EPU was developed using policy-uncertainty-related newspaper stories taken from reputable publications. It measures the quantity of newspaper stories that contain the term 'economic uncertainty'. Under conditions of high uncertainty, people tend to delay financial decisions, which reduces consumption, the issuance of debt and investments, and increases unemploy-

ment (Al-Thaqeb *et al*., 2022). The EPU tends to have a favourable impact on state-owned businesses in China, businesses with weaker cash flows and businesses with few financial limitations (He *et al*., 2020).

A downturn in Central European economies could lengthen the process of catching up with more developed economies. External variables, such as international commerce, business innovation and financial flows, have an impact on growth in countries like the V4. However, to avoid stagnation and the so-called middle-income trap, V4 countries should focus on internal growth hurdles. The term 'middle-income trap' refers to the fact that middle-income nations are forced to choose between the rapidly advancing modern technology of wealthy nations and the low-wage-based final products of poor nations. It is a situation where countries struggle to attain high income status, while people cannot ensure high expenses due to their low wages (Imam & Temple, 2024). Convergence is not an appropriate vision either. Instead of a large jump, the V4 countries require a Schumpeterian 'disruption' in economic policy to help them turn their economies around and cease competing in terms of 'cheapness.' The V4 countries require additional resources to manage the transition to a knowledge-based economy focused on innovation and better human resources, which can only be achieved by increased investment in innovation and human capital (Csath, 2022; Zachová, 2023). According to Lu (2018), to avoid the middle-income trap, a country must prioritise investment in research-based education, financial regulations that harmonise public–private cooperation in the development of enterprises and proper capital allocation in various economic sectors that are monitored according to priorities, as well as bankruptcy policy control. Economic policy must ensure a healthy business climate that is appealing to entrepreneurs and innovators. Indeed, a sound economic policy favours creating new employment and consumer demand, as well as breeding new entrepreneurs and generating new skills (Fu & Shi, 2022). Therefore, it is critical to examine how the EPU has affected the performance of innovation in the V4 countries.

Particularly in Slovakia and the Czech Republic, the economies share traits in terms of their transformation from planned economies to market economies. The EPU values in these economies are influenced by fiscal policy uncertainty, stock market volatility, exchange rate changes and political uncertainty. However, the economy's capacity to quickly converge within the EU is significantly impacted by the priority given to rapid innovation and the emphasis placed on R&D development. Additionally, the

execution of structural reforms, the unpredictability of fiscal policy and stock market volatility complicate economic policy in Poland and Hungary (Oblath, 2016; Bod, 2019; Hołda, 2019; Ozcelebi & Izgi, 2023). No earlier research has empirically examined the effect of EPU on innovation in this specific and significant region of the V4 economies. Due to China's recent rapid economic expansion, researchers have concentrated on the effects of the EPU on Chinese innovation. Liu and Gao (2024) and Hao *et al*. (2022) examined the impact of the EPU on innovation in Chinese enterprises based on financial factors, such as equity, and the financing structure of firms. Li *et al*. (2023) also highlighted financial tools, for example, tightening financial flexibility and highlighting managerial qualities, in explaining the impact of the EPU on agribusiness technology innovation in China. Additionally, William and Fengrong (2022) investigated the effects of the EPU on patents as a proxy for innovation in cross-country data.

This paper examines the impact of economic policy uncertainty on innovation performance and R&D expenditures in the Visegrad Group countries. The economic policy uncertainty of the economy is measured by the EPU index, which has been used in the present study. Moreover, the lag periods for the EPU have been used to understand not only the short-term impact but also the long-term effects of EPU changes. Economic policy is greatly influenced by political and polling circumstances, in addition to economic and financial variables, as this study takes into account. We intend to test our hypotheses by using a fixed-effect technique and panel data for the V4 economies between 2012 and 2021. When panel data with country-specific effects are available, the comparative use of fixed effects, random effects, and System Generalized Method of Moments (GMM) models may represent an effective tool for analysing economic uncertainty in the V4 countries or any other situation.

The research project is divided into several sections. It includes an introduction, an intensive review of the literature, the methodology, the results, and the discussion. The final section of the study will offer conclusions and recommendations for future research.

Literature review

Uncertainty about government rules and policy frameworks is viewed as a factor in economic policy. Because of the market's unpredictability, this

phenomenon may lead businesses and individuals to delay purchases and investments. A high EPU increases the cost of financing as well, and it has a significant impact on corporate decisions and policies, such as leading to lower capital expenditures, fewer initial public offering (IPOs), less mergers and acquisitions (M&A) activity, more cautious payout policies and higher cash holdings (Al-Thaqeb & Algharabali, 2019). Bhattacharya *et al*. (2017) found that when uncertainty increases, fewer inventors file for patent applications, and political compromise fosters innovation. A number of investigations have been performed regarding how economic policy uncertainty affects innovation performance and the nature of R&D spending (He *et al*., 2020; Li *et al*., 2021; Xu *et al*., 2021; Tajaddini & Gholipour, 2021; William & Fengrong, 2022; Kyaw, 2022; Qi *et al*., 2022; Peng *et al*., 2023; Wang *et al*., 2024; Nguyen & Kim, 2023; Cui *et al*., 2023); however, very few such studies have been done regarding the V4 economies. Investigating this Central European region is therefore particularly interesting because the topic has unquestionably generated interest among researchers recently.

Regarding the V4's function as a regional integration platform, Scott (2022) analyses the relevance and potential effects of illiberal political, economic, and social uncertainties. Illiberal regionalism is a reflection of how the V4 countries interact with one another within the EU in a reciprocal and interdependent way. Additionally, macroeconomic indicators show that Slovak, Czech, Polish, and Hungarian businesses have developed similarly, including in terms of gross domestic product (GDP), unemployment rate, inflation rate, average monthly gross wage, and the ease of doing business index (Valášková *et al*., 2020). A few studies related to economic policy uncertainty and innovation performance in Visegrad Group Countries can be identified, nevertheless, if we search for literature on each country. First, innovation and R&D investment will be impacted by economic policy uncertainty, as stock market volatility in the Czech Republic is an unavoidable contemporary factor (Das *et al*., 2019). Nestoroska (2020) found that the impact of the EPU on business performance is generally negative, that on interest rates is positive and that on inflation is only moderate when net profit margin is considered a proxy for firm performance. Julio and Yook (2012) and Békesová and Bohdalová (2022) found that political uncertainty causes investment cuts, which continue until the uncertainty is resolved. In particular, Czech policymakers allowed investment funds to participate in the privatisation process, despite the imperfect nature of

the legislation governing them. Additionally, the majority of people entrusted the funds on their own; however, it was a questionable decision, as investing on one's own creates uncertainty in the market (Soukup & Rozmainsky, 2018).

Secondly, the European Commission's in-depth study on Slovakia published in 2023 shows that while there have been growing vulnerabilities in terms of competitiveness, housing, household debt, and external balance, these issues, overall, seem to be contained and are anticipated to ease as economic conditions return to normal (European Commission, 2023). Jasova (2019) and Marcincin and Beblavy (2000) found that the common cause of contemporary EPU is the transformation of the economy from socialism (a planned economy) to capitalism (a market economy). In 2008 and 2009, Slovakia experienced a more moderate phase of the financial crisis, which was caused by insufficient restructuring and a distorted institutional framework, as well as low levels of research, technological development, and innovation (RTDI) development (Ministry of Finance of the Slovak Republic, retrieved in 2023). A study by the OECD (2024) demonstrates that the reason for contemporary fiscal policy uncertainty and the related challenges was high expenditures in the Slovak Republic in the health sector due to a rapidly aging population. In addition, Vondrová and Valach (2014) found out there is always a contradiction involved in determining economic policy priorities, which is an integral part of ensuring high-quality economic growth, along with a sufficient quantity of growth, for the sake of the nation.

Hungary is still recovering from the COVID-19 pandemic, and it is also dealing with increasing inflation and economic unpredictability because of Russia's war with Ukraine. Despite an expanding deficit, increasing energy costs, a persistent scarcity of skilled workers, and worries about corruption, the credit rating agencies, in 2021, maintained Hungary's public debt at a stable level (US Department of State, 2022). Different market contexts that achieve superior performance and outperform competitors may have different effects on how entrepreneurial orientation, as an organisational behaviour, affects the financial performance of businesses in Hungary (Kovacs *et al*., 2016). In a recent study, Katona *et al*. (2023) examined innovation performance by comparing Austria and Hungary, two neighbouring countries. The researchers identified significant discrepancies, at the macro- and micro levels, between the two nations in terms of digital maturity, with Hungarian businesses falling behind Austrian ones in terms of the adop-

tion of Industry 4.0 technologies. When implementing an Industry 4.0 strategy, Hungarian management was focused on increasing profits, whereas Austrian businesses were most concerned with strengthening their market positions. Additionally, Hungarian economic policy uncertainty is stimulated by other crucial factors. There is stock market volatility (Das *et al*., 2019); governmental fiscal support for IT is at its lowest (Mallinguh & Zeman, 2020); income convergence has been unequal and sluggish (Bod, 2019); there have been a flat income tax, unfair sectoral taxation and reliance on EU funding for budgetary support (Oblath, 2016) and the 2008–2009 global financial crisis led to vulnerability, which was worsening by large levels of domestic and foreign debt (Virág, 2018).

In Poland as compared to other three countries, there is more potential to invest in SMEs (Soliman, 2020). Additionally, prior collaboration with specialised local institutions has an impact on how innovatively local governments behave and how innovation networks' institutional pathologies can develop. The incremental ideas produced by properly operating innovation networks may contribute to resolving the current Polish problems (Godlewska *et al*., 2022). However, EPU prevails in Poland as in its counterparts: fiscal policy shocks impact the local economy as policy changes (Hołda, 2019; Bartha & Bontempi, 2022); stock market volatility exists because exchange rate fluctuations prevail (Hołda, 2019; Ozcelebi & Izgi, 2023) and private investments are negatively impacted by exchange rate volatility, inflation and growth uncertainty (Guney, 2019).

Overall, the transition from a planned to a market economy is a shared trait among the V4 economies. Political unpredictability, exchange rate fluctuations, stock market instability and fiscal policy uncertainty all increase the EPU in these economies. However, the economy's capacity to quickly converge with the EU is significantly impacted by the emphasis on R&D development and the priority placed on rapid innovation. The current study is distinctive, because it is the initial effort to assess the effects of EPU on innovation and R&D spending in Visegrad Group countries and uses the fixed effect, random effect and system GMM panel techniques to analyse these economic impacts methodologically.

Hypothesis of the study

Economic policy uncertainty and innovation possess a multifaceted and complex relationship that varies depending on the industry or nation.

There is a negative correlation between economic policy uncertainty and technical innovation. In nations with high levels of transparency, liberalised financial markets and strong property and patent rights protection, the negative effects of economic policy uncertainty on innovation are not severe, demonstrating the true effects of economic policy uncertainty shocks on the economy (William & Fengrong, 2022). Nevertheless, EPU has a significant influence on emerging and middle-income countries. Because these nations are neither affluent nor poor, there is a great need for continued development in the economy (Zachová, 2023; Imam & Temple, 2024). However, the results of Tajaddini and Gholipour (2021) demonstrate a favourable correlation between high levels of EPU and R&D spending per capita and innovation outputs (patent applications, patent grants and trademark applications). Additionally, family-owned business innovation was found to have a strong correlation with economic policy uncertainty in a study that investigated Chinese family firms from 2010 to 2018 (Qi *et al*., 2022). Enterprise innovation is significantly positively impacted by EPU. However, the influence of EPU on enterprise innovation varied between state-owned and non-state-owned businesses in China from 2000 to 2017 (He *et al*., 2020). Studies investigating how uncertainty in economic policy affects green innovation have gained attention in recent research, such as Li *et al*. (2021); Peng *et al*. (2023) and Cui *et al*. (2023). Cui *et al.* (2023) shows that EPU has a strong negative relationship with corporate green innovation. On the other hand, Li *et al*. (2021) indicate that environmental regulation and green innovation are positively correlated (Peng *et al*. 2023), whereas economic policy uncertainty and green innovation are negatively correlated.

It is interesting to note that the impact of EPU is not simply short term; it also has a considerable impact over time. For example, Xu *et al*. (2021) found that asymmetry has both long- and short-term effects on the relationship between economic growth and financial innovation, as well as between EPU and economic growth. However, short-term magnitudes were insignificant. The asymmetric effects of positive and negative shocks in financial innovation showed a positive relationship with economic growth, as well as a negative relationship between asymmetric shocks in EPU and economic growth in the long run. We use lags in the present study to capture the impact in both the short and long terms. After an event producing economic uncertainty occurs, firms may not immediately capture it, which may delay their responses the concurrent changes in in-

novation activities by altering strategies, resource reallocation and R&D investment plans.

Innovation is a very broad term. There are several proxies for innovation. For example, Liu (2009) used the number of patents filed, the sales percentage of innovative products and the degree of product novelty as indices of innovation. The justification for developing these our two hypotheses is that R&D is an input variable for innovation and innovation depends on a wide range of variables, along with R&D, such as firm performance, self-efficacy, confidence, autonomy, the anticipation of inventiveness on the part of a leader, the perception of a secure setting, objective clarity, diversity and innovation support (Hagelaar, 2018).

H1: *Innovation performance will be negatively impacted by the base and lag period of economic policy uncertainty.*

Research and development are essential for long-term economic growth, and nations develop economic plans that incorporate initiatives to foster innovation. However, economic policy uncertainty typically obscures economic results. Wang *et al*. (2024) confirmed consistent, long-term relationships between R&D, economic growth and trade openness, and economic policy uncertainty; as economic policy uncertainty increases, for example, R&D declines. That study concerned Asian countries from 2003 to 2018. Nguyen and Kim, (2023) investigated a strongly inverse relationship between EPU and R&D intensity and found that the EPU can influence the decision to invest in R&D. It is interesting to note that the detrimental effects of policy uncertainty have little impact on the R&D operations of businesses with growth prospects. In terms of R&D intensity, businesses in politically sensitive sectors exhibit stronger responses to EPU. Additionally, variables such as EPU and R&D spending per capita, United States Patent and Trademark Office(USPTO) patent grants and European Patent Office (EPO) patent grants all have significant long-term relationships (Tajaddini & Gholipour, 2021). Firms are encouraged to delay expenditures in environmental research and development (R&D) or postpone expensive environmental initiatives when economic policies and laws are uncertain. Kyaw (2022) demonstrates that a negative consequence of policy uncertainty — a decline in environmental innovation — occurs over a period of 5–6 years. Nevertheless, the harmful effect wears off after 6 years.

H2: *Research-and-development investment is negatively related to the base and lag period of economic policy uncertainty*.

The negative effects created by an uncertain economic policy on innovation are seldom discussed in V4 nations. Therefore, it is important to demonstrate the true effects of economic policy uncertainty shocks on these economies. When EPU occurs, the impact goes beyond the current level of innovation or R&D activities on the part of firms; it has long-term impacts as well. Therefore, in this study, we adopt a research methodology that examines the short- and long-term effects of EPU on innovation and R&D investment. It also includes important control variables, incorporating economic and political variables into the models.

Methods

Data source

The research project has been conducted using reputed secondary sources, such as EPU data collected from the Federal Reserve Economic Data source, which was developed by Baker *et al*. (2016). Based on the frequency of newspaper coverage, Baker *et al*. (2016) developed a new measure of EPU. Several sources of data suggest that the index serves as a good proxy for changes in policy-related economic uncertainty, including human readings of 12,000 newspaper items. For example, Brandt (2021) used an extension of Baker *et al*. (2016) EPU index to investigate how an unanticipated event can lead to uncertainty and impact individuals, markets and global economies. It is created by using news reports, tax code clauses, and other sources to determine the degree of economic policy uncertainty. The Federal Reserve Bank of St. Louis's Economic Research Division has gathered EPU data from the World Uncertainty Index. The EPU index is provided quarterly, and we take the moving average of four quarters in a year to prepare the annual EPU index. The EPU is the independent variable in this study, and we use two dependent variables, innovation output and R&D expenditures, for the V4 economies between 2012 to 2021. Eurostat data on the performance factors for SMEs are available on an annual basis. In the current study, the performance of SMEs was assessed by combining incre-

mental, radical and basic innovation. The Eurostat dataset was used for innovation output.

The World Development Indicators (WDI) database, which was maintained by from the World Bank between 2012 to 2021, provides data on research and development spending as a percentage of GDP. The present investigation derives the R&D expenditures from the GDP and the percentile fraction of GDP spent on R&D activities for the relevant nations in a given year. The Worldwide Governance Indicators (WGIs) database, which was created by World Bank, is used to collect government effectiveness and control of corruption data, while perceptions of the quality of public services, the standard of civil services, the degree of their independence from political constraints, the quality of policy formulation and implementation and the credibility of the government's commitment to such policies are all included in the category of government effectiveness. The estimate provides the aggregate indicator score for the nation in units of standard normal distribution (i.e., between about -2.5 and 2.5). On the other hand, Control of Corruption encompasses perceptions of how much public power is used for private gain, covering both small-scale and large-scale corruption, as well as the capture the state by elites and private interests. The estimate provides the aggregate indicator score for the nation in units of standard normal distribution (i.e., between about -2.5 and 2.5).

The International Monetary Fund, Balance of Payments Statistics, World Bank and OECD data are used for current account balances, and foreign direct investment (FDI) inflow data, World Bank national accounts data and OECD National Accounts data files are used to obtain trade information between 2012 and 2021. In order to calculate the current account balance (% of GDP), net exports of commodities and services, net primary income, and net secondary income are used. Trade (% of GDP) is the total of all goods, services, exports and imports expressed as a percentage of GDP. Foreign direct investment net inflows (% of GDP) are the net inflows of capital used to purchase a long-term management stake (10% or more of voting stock) in a company that operates in a different economy than the investor does. According to the balance of payments, FDI is the total of equity capital, the reinvestment of earnings, other long-term capital and short-term capital. These data, which are broken down based on GDP, display net inflows (new investment minus outflows) of foreign capital into the reporting economy. Additionally, the study includes certain control variables in the analysis, such as the total number of researchers, the GDP

growth rate, and the industry growth rate. The details regarding the variables and data sources and online links to data sources are described in Table 1 in the Annex.

Definition of the variables

To determine the influence of EPU on innovation and R&D spending in four nations (the Czech Republic, the Slovak Republic, Poland and Hungary) from 2012 to 2021, the present study used comparative panel models analysis (fixed effect, random effect and system generalised method of moments) for the years 2012 to 2021. The dependent variables in the following two models are innovation output and R&D investment. The innovation output is measured using the overall sales and business performance, and R&D investment is measured using R&D investment expenditures. On the other hand, the independent variables are EPU and EPU lags, and we also used control variables, such as economic factors proxied for by current account balance (% of GDP), trade (% of GDP), the net inflow of foreign direct investment (% of GDP) and political factors proxied for by government effectiveness and control of corruption. These variables consider the entire period of analysis of the study. See Table 1 for details.

Data analysis method

This study used a 10-year panel data span due to the availability of the data. The two models used for the fixed-effect method are as follows: the paper was intended to examine the impact of economic policy uncertainty on innovation performance levels, such as innovation output and R&D expenditures, in the V4 countries. The study not only emphasises current EPU data, but also attempts to estimate results based on previous years' (lag periods) EPU impact on the dependent variables, innovation and R&D expenditures. The rationale for using lag-based EPU models is that EPU's effect on innovation can vary from year to year and across contexts due to a variety of factors and dynamics, such as policy changes, adaptation by the government, yearly monetary and fiscal policy improvement through budgetary instruments and governing the money supply through central banks, industries being heavily regulated by government policies, the need to adapt new input-output strategies as economic policies and global economic conditions. As a result, several studies have considered both the

short- and long-term effects of EPU (Xu *et al.*, 2021; Tajaddini & Gholipour, 2021; Wang *et al*., 2024). The EPU variable should only be used up to lag 6 because the regression is affected by the perfect collinearity problem after that point. We estimate the fixed effect panel estimation using the regressor up until the lag 6 period to prevent this. Furthermore, the political and economic variables will produce informative findings because they are highly significant in terms of the implementation of economic policies.

Innovation and EPU model specification

$$\begin{gathered} Innovation = a + b1\,EPU\ +\ b2\,EPU\ Lag1\ +\ b3\,EPU\ Lag2\ + \\ +b4\,EPU\ Lag3\ +\ +\,b5\,EPU\ Lag4\ +\ b6\,EPU\ Lag5\ +\ b7\,EPU\ Lag6 + \\ +b8\,Political\ variables\ +\ b9\,Economic\ variables + \ e \end{gathered} \tag{1}$$

R&D expenditure and EPU model specification

$$\begin{gathered} R\&D\ expenditures = \ a\ +\ b1\,EPU\ +\ b2\,EPU\ Lag1\ + \\ +\ b3\,EPU\ Lag2\ +\ b4\,EPU\ Lag3\ +\ b5\,EPU\ Lag4\ + \\ +b6\,EPU\ Lag5\ +\ b7\,EPU\ Lag6\ + \\ +b8\,Political\ variables\ +\ b9\,Economic\ variables + \ e \end{gathered} \tag{2}$$

where Innovation = the total innovation output for the respective V4 economies, R&D expenditure = the total expenditure for R&D for the V4 economies, EPU = the economic policy uncertainty at the base or current level and EPU Lag_1 = the economic policy uncertainty value at the lag 1 period. The economic variable is one of the control variables, and it has, as proxies, the current account balance (% of GDP), trade (% of GDP) and the net inflow of foreign direct investment (% of GDP). Importantly, the political variable is another control variable used in the models that was proxied for by government effectiveness and control of corruption.

The panel data analysis is based on various studies related to EPU and innovation activities, such as fixed-effects models (Li *et al*., 2021; Tajaddini & Gholipour, 2021; William & Fengrong, 2022; Khojah *et al*., 2023). In particular, the system GMM, which is intended to handle endogeneity and unobserved heterogeneity in panel data models, is a useful dynamic panel data estimate technique. For example, Tabash *et al*. (2022) and Nguyen *et al.* (2021) employed two-step system GMM to investigate the impact of EPU on entrepreneurial decisions and total company financial decisions. Addi-

tionally, by utilising the system GMM method, Avom *et al*. (2020) showed how uncertainty in global economic policy affects FDI.

Results

Descriptive statistics

The EPU level for the V4 countries between 2012 and 2021 is plotted against time in Figure 1. The higher the value of the EPU index, more the economic policy uncertainty exists. The panel data concern 40 observations within the V4. Table 2 illustrates that the mean value for EPU is 0.167. Volatility is increased in Hungary and Poland, while the Czech Republic has an average rate of 0.160. Slovakia is quite stable, with a mean value of 0.050 during the study period. Additionally, in 2013, Hungary had the highest uncertainty value, and Poland had the highest value in 2015, at approximately 0.50 (see Figure 1).

Figure 2 illustrates that innovation performance is rapidly increasing throughout the V4 countries, except Slovakia, where innovation growth is sluggish. The average innovation output was 1,710.42 million euros from 2012 to 2021. The Polish economy has the highest innovation output, while Slovakia has the worst performance. Innovation performance in the Czech Republic has been quite stable and improving over the years as compared to Hungary and Slovakia.

Figure 3 demonstrates the R&D expenditures over the years for the V4 nations, of which Poland is the most dynamic nation in terms of investing money in R&D expenditures. Because the Polish economy is larger than those the other V4 nations, Poland spent only around 1.11% of its GDP on R&D activities from 2012 to 2021.

The R&D expenditures (% of GDP) in the Czech Republic were approximately 1.88% annually between 2012 and 2021, which represents a better position than those of Hungary and Slovakia. Though the R&D expenses increased slowly, the rate of R&D expenditure growth was positive in most cases during the study period. In 2016, the Czech Republic, Hungary, and Slovakia reduced R&D expenditures. However, this was brought on by an anticipated decline in foreign public resources, as well as the fact that the Czech economy expanded more quickly than overall R&D spending in 2015 and 2016 (Research, Development and Innovation Council, the Czech

Republic, 2020). On the other hand, the Slovak Republic had an identical amount of R&D investment, at around 1,000 million $US, throughout the study period.

The government effectiveness ranges between -2.5 to 2.5, where 0 is the average value. In the panel data, we have 0.711, which indicates more than average government effectiveness in the V4 nations. Simultaneously, the control of corruption is above average, with a mean value of 0.375. The current account balance is negative, at -0.304, which indicates that the trade balance has a deficit. Thus, the V4 nations' imports are greater than their exports on average. A high trade-to-GDP ratio is observed, at 102.007, which indicates that the V4 nations are highly integrated in terms of trade openness, as well as the global economy. Foreign direct investment inflows are 7.15% of GDP, which is also a good indicator for these economies.

Estimation of panel models

Table 3 shows the results of the fixed-effect panel regression analyses, in which R&D costs and innovation outputs were the dependent variables and EPU and EPU lag variables were independent variables in both models. The results of the regressions with EPU and lagged EPU are shown for each dependent variable. The results illustrate that the direction of both models (Model 1 is concentrated on innovation coefficients, with the dependent variable being innovation output, and Model 2 is concentrated on R&D expenditure coefficients, with the dependent variable being R&D expenditure) is identical. That means that the EPU and EPU lag period's coefficients related to innovation and R&D expenditure are in the same direction simultaneously within a specific period. For example, the correlation with EPU at the base level (the current period) is negative for both dependent variables. The lagged impacts on innovation and R&D expenditure in our sample countries were either positive or negative depending on the time period considered. For example, EPU Lag1, EPU Lag2, EPU Lag4, and EPU Lag5 have positive impacts on innovation and R&D expenditures, whereas EPU Lag3 and EPU Lag6 have negative impacts in the model.

The reasons for the negative and positive values for EPU Lag0 to EPU Lag6 vary, but they are primarily related to the unpredictability and volatility of governmental policies. Over the long term, policies can be altered by business expansion, cyclical effects, investor confidence, government support and other factors. For example, Tajaddini and Gholipour (2021)

found that not all businesses can delay their R&D investments due to the significant opportunity costs of such delays. This typically applies to knowledge-intensive services and high-tech, forward-thinking industries, which heavily rely on the results of R&D expenditures. As a result, an industry may decrease its R&D spending because of EPU, which would have a detrimental effect on innovation. Our sample countries are Central European countries that have experienced several transitions and economic reforms throughout their histories and now host a mixture of developed and middle-income groups. Therefore, once high economic policy uncertainty occurs, these nations will reduce their R&D expenditures, and innovation will be hindered. However, their economies are learning to adapt to EPU and, in the long term, will continue to contribute to innovation via R&D activities. Additionally, a downturn in the Central European economies could lengthen the process of catching up with more developed economies. External variables, such as international commerce, business innovation and financial flows, have an impact on growth in countries such as the V4. However, to avoid stagnation and the middle-income trap, the V4 countries should focus on internal growth hurdles.

To justify our models, we would like to estimate random effect models for both innovation coefficients and R&D expenditure coefficients and run the Hausman test to determine reliable estimations. The Hausman test was performed because there are not many significant coefficient values for either random effects model. The Hausman test, which is a form of statistical analysis used to determine whether a fixed effects (FE) model or a random effects (RE) model is better suited to a particular dataset, is used to estimate and check our results (Khojah *et al*., 2023). If the Hausman test fails to reject the null hypothesis (H0), the random effects model is appropriate, rather than the fixed effects model. If the p-value is greater than the significance level (e.g., 0.05), this indicates that the random effects model is more reliable and effective and should thus be used. For Model 1, (Prob > chi2 = 0.8637), which indicates that the random effects model is appropriate for the innovation coefficients. However, Model 2 implies the opposite result as compared to Model 1. We obtain a Hausman test probability of Prob > chi2 = 0.0000, indicating that the fixed effects model is effective and reliable for R&D expenditure coefficients.

More specifically, when the Hausman test result has a probability value less than the critical value of 0.05, this indicates that there is no systematic difference between the fixed effects and random effects models. Thus, we

can use both models equivalently, because they are valid in terms of explaining the data and do not differ in any systematic way. On the other hand, if the probability value is less than 0.05, we reject the null hypothesis, and there is a systematic difference for the coefficients between the fixed effects and random effects model. Therefore, one of the models is more appropriate than the other.

Table 5, the GMM estimation demonstrates that EPU has a significant negative impact on innovation and R&D expenditures at the base level, but that EPU has strong positive correlations with the dependent variables at the lag-2 and lag-5 levels. This indicates that EPU has a negative impact on an economy's innovation activities, including R&D spending. The relationship between policy uncertainty and economic outcomes, however, can also be influenced by shifts in the global economy, geopolitical situations or technological developments.

Table 6 shows that countries can stimulate innovation by investing in it, lowering its risk, working together to develop it and utilising rules or regulations to do it. The political control variables of government effectiveness and corruption control have been estimated at this level. In the case of EPU at the base level, the innovation coefficient is negative, but it is highly significant when we include EPU Lags. However, the impact of EPU on R&D expenditure is not as strong as that of the innovation coefficients, as we can see that without EPU Lag, R&D expenditure is only 10% significantly and negatively correlated with EPU, as shown in Table 5. The effect of EPU on innovation (-522.8295) without the EPU Lag model implies that a 1-unit increase in EPU will lead to a reduction of 522.8295 innovation unit at a 10% significant level in the short term. It also leads to a 2828.085-unit reduction in innovation after we combine the lag values of EPU with a high and significant rate. Additionally, after the 1 unit of corruption is controlled for, such an increase will stimulate 519.9961 units of innovation activity in the short term at the 5% level of significance.

Comparing two political variables, in Table 5, corruption control is only positively significant without EPU Lags for innovation coefficients. Likewise, as show in Model 3 in Table 4, EPU Lag 2 and EPU Lag 5 are positively related to the innovation coefficients. Additionally, the R&D coefficients have, in most cases, the same directions as the innovation coefficient; however, a significant magnitude is absent in the case of R&D coefficients.

In Table 7, we can see that EPU, as is customary, has a negative relationship with innovation and R&D expenditures when we include economic

variables such as the current account balance, the trade balance and foreign direct investment inflow. However, this relationship is only highly significant when we consider EPU's lag values in relation to the innovation coefficients. Additionally, the models show a negative relationship between the current account balance and FDI inflows among the three economic variables, whereas trade balance has a positive relationship in this regard. Research-and-development coefficients are relevant to the current account balance in both the lag-free and lag-filled scenarios. However, innovation coefficients are highly significant in situations with and without lag.

We obtain several interesting findings if we consider the control factors, such as the overall researcher population, annual GDP growth and annual industry growth. The number of researchers in a country has a favourable impact on research and innovation activities, and it is positively and significantly related to the innovation and R&D coefficients. Gross domestic product growth is also positively related to innovation and R&D, as the higher GDP allows national development, which stimulates national expenditure on R&D activities and encourages invention. On the other hand, annual industry growth is negatively related to innovation, as well as R&D expenditures, in these V4 economies because these economies are often suffering from negative annual industrial growth; however, these coefficients are insignificant, as shown in Table 8.

To illustrate long-term impacts, in Table 5, the GMM estimation without controls shows that EPU Lag2 and EPU Lag5 are highly significant at the 1% level and have positive relationships with innovation output. Additionally, the R&D expenditure is positively influenced by EPU Lag2 at the 5% significance level. This remains true after we include the pollical control variables (Table 6). In addition, considering the economic controls, EPU Lag2 has a significant (5%) and positive relationship with the innovation coefficients (Table 7). If the model includes political factors (e.g., government effectiveness and control of corruption), this reveals the positive influence of EPU on innovation output. Overall sales and business performance is not drastically affected by uncertainty and political factors. As time goes by, firms know how to tackle uncertainties. As the results at the 1% significance level show, the policy environment plays a vital role in the long term when political controls are considered. Importantly, the inclusion of economic control variables (e.g., current account balance, trade balance, and FDI inflows) lead to positive directions as compared to EPU Lag2. However, the significance level drops to 5%. This suggests that firms delay

innovation investment to become innovative and competitive in the long term. According to the study of Van Vo and Le (2017), firms invest more in R&D when faced with higher levels of uncertainty, as these firms wish to become more competitive in their industries, as do firms with products that have little market power.

Robustness check for the system GMM models

Regarding performing robustness checks, the Sargan test of overidentifying restrictions is a crucial technique for determining the validity of a GMM model. Because overidentification can occur when we have more instruments used in the GMM estimation than endogenous variables in the model, the Sargan test should not reject the null hypothesis if the moment conditions are correctly specified and the GMM model is correctly identified. The test verifies that the GMM is offering useful data for estimating the model, which is sensitive to the inclusion of specific moment conditions or instruments. The Sargan test also helps confirm the efficacy of these instruments in addressing endogeneity issues in the form of unobserved heterogeneity or omitted variable bias (Sargan, 1958; Bobba & Coviello, 2007; Roodman, 2009). The associated Chi-squared statistic and probability values for the Sargan test do not reject the null of each system GMM model's validity.

Discussion

This study provided a spectrum of findings indicating that the effect of uncertain economic policy on innovation and R&D investment may exist in either a positive or negative direction. This direction depends on a variety of factors, contexts and settings. The GMM illustrated at the current level of EPU was always negative, whether it considered EPU lag variables or not. After EPU lag was included in the model, EPU had a greater influence on firm innovation activity as compared to the model that did not include EPU lags. It is statistically significantly (1%) and negatively related to firm performance and innovation. William and Fengrong (2022) revealed that economic policy uncertainty causes a substantial decrease in innovation productivity. The coefficients for the number of patents, patenting firms, and patent citations are all negative and significant (1%). Additionally,

Kyaw (2022), Cui *et al*. (2023) and Nguyen and Kim (2023) found a negative relationship between uncertainty and innovation and R&D expenditures.

This project's empirical conclusions have confirmed the previous research of Ali *et al*. (2022) and Wen *et al*. (2021), which illustrated that government efficiency positively and significantly affects national technological innovation. Our research on the V4 countries shows identical positive relationships in this regard; however, the results are statistically insignificant. Additionally, Sena *et al.* (2018) and Lee *et al*. (2020) contradict the present study's results, as they revealed that corruption has a significant negative impact on innovation and R&D spending. In our analysis, we found that the control of corruption increased innovation and R&D activities significantly.

This research project illustrated positive correlations between EPU and innovation and R&D expenditures, and it is important that the economic policy of developed economies does not halt their innovation activities during volatile economic conditions, as high-tech products require continuous development activities, as well as innovation for the sake of market competition. This study's results also confirmed the empirical results of Tajaddini and Gholipour (2021); Qi *et al*. (2022) and He *et al.* (2020). As a result, the strategic growth option theory, which holds that investment leads to a higher potential to take advantage of future development possibilities in markets with strategic competition, typically justifies the positive correlation between EPU and innovation. Thus, Kulatilaka and Perotti (1998) is also confirmed.

Current account balance is negatively correlated with innovation and R&D spending, which suggests that net primary income, net secondary income and net exports of goods and services are unattractive when innovation activities must be budgeted for. The net flow of products, services, income and current transfers between a country and the remainder of the world is measured by the current account balance. It includes net revenue from overseas investments, the trade balance (exports minus imports) and net transfers (remittances and foreign aid). The innovation and R&D activities of these selected nations are negatively influenced by the combination of these features. Additionally, FDI inflows have a negative and considerable influence on innovation, which means that these countries' internal innovation is not attracted to the portion of foreign wealth received through investment, remittances, grants or aids. The export-import trade balance has a favourable effect on innovation and R&D spending. There is

still room for more research exploring how each aspect of the balance of payment affects innovation in the V4 economies.

Finally, the EPU impacts not only the short term but also the long term regarding a firm's decisions about R&D investment and innovation activities, as in the long term, firms have the opportunity to adjust their external business phenomenon and undertake internal strategies to adapt to the volatility in the market and the economy (Long term: Xu *et al*., 2021; Wang *et al*., 2024).

Conclusions

Undoubtedly, R&D expenditure and innovation activities are integral parts of fostering growth. Economic policy uncertainty is a phenomenon that cannot be avoided. Therefore, the managers and business administration are required to make their investment and innovation decisions while considering the EPU consequences. The Visegrad Group (V4) needs significant potential innovation and economic development to have an upward move from its status as middle-income countries. Using fixed-effects panel models for the years 2012 to 2021, this paper's primary goal was to investigate the effects of economic policy uncertainty on innovation performance and R&D spending in the V4. The results show that the direction of innovation output and R&D expenditures are identically correlated with EPU. Some levels are significantly positive, and some levels are significantly negative, as both models include the lag periods for EPU to reveal not only the short-term impact but even the long-term ones. Businesses in the V4 economies may reduce R&D and innovation spending when faced with high EPU; however, over time, the volatility of economic uncertainty is adjusted for.

Since this is a macro-level study of the V4 economies, future research can look forward to examining the impact of EPU on innovation and R&D spending in particular sectors, such as knowledge-intensive businesses; pharmaceutical firms or high-tech businesses, including those in the automotive, computer and software industries of the region. The political and economic control variables also represent the models with large numbers of research dimensions, which encourages further EPU studies to explore these subjects. Importantly, sales and business performance increased over time as firms learn how to tackle uncertainty and political crises in the long term. Furthermore, the research indicates that companies withhold innova-

tion investment to ultimately become inventive and competitive in their respective industries.

There is no doubt that the European Union has a significant influence on Central-Eastern European democracy, public policy decisions, budg*et al*location and other factors. because the V4 countries are heavily influenced by EU policy and there have been relatively few studies on this region, the present study contributes new perspectives to the study of the V4 countries regarding how EPU affects innovation and R&D expenditures. Importantly, our research included diverse factors, such as EPU lag variables and crucial economic and political factors as the control variables in the analysis via the complex panel models.

The study was carried out based on the currently insufficient state of the literature because it lacked adequate support from earlier research conducted in the V4. As a result, the researchers discovered that conducting the background study was initially challenging. Furthermore, most of the current literature is derived from reports and news articles. In addition, there is limited data availability. Therefore, this research project has analysed data over a span of 10 years.

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Compliance with ethical standards

This article does not contain any studies with human participants or animals performed by the authors. Extracting and inspecting publicly accessible files (scholarly sources) as evidence, before the research began no institutional ethics approval was required.

Data availability statement

All data generated or analyzed are included in the published article. The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation. The raw anonymized data can be provided by emailing the primary author.

Author contributions

All listed authors have made a substantial, direct and intellectual contribution to the work, and approved it for publication. The authors take full responsibility for the accuracy and the integrity of the source analysis.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Annex

Table 1. Description of variables and data sources

Notation	Variable	Definition	Source
EPU	Economic policy uncertainty	World Uncertainty Index for the Czech Republic, Poland, Hungary and Slovakia.	Federal Reserve Economic Data, Federal Reserve Bank of St. Louis, US. Link: https://fred.stlouisfed.org/series/GEPUCURRENT
Inoov	Innovation output	As a proxy indicator measured by the overall sales and business performance.	Eurostat data set, European Union. Link: https://ec.europa.eu/eurostat/data/database
R&D	Research and development expenditure	Total R&D expenditure is calculated as R&D as a percentage of GDP multiplied by GDP.	World Development Indicators database (WDI), WorldBank. Link: https://databank.worldbank.org/source/world-development-indicators
Govt_Effect	Government effectiveness	The standard of public services, their independence from political pressures and the quality and effectiveness of policy implementation and commitments, with a scale from -2.5 to 2.5.	Worldwide Governance Indicators (WGI) database, World Bank. Link: https://databank.worldbank.org/source/world-development-indicators
Corrup_Cont	Control of corruption	Control of corruption examines perceptions of the degree to which public power is used for personal gain, with a scale from -2.5 to 2.5.	Worldwide Governance Indicators (WGI) database, World Bank. Link: https://databank.worldbank.org/source/world-development-indicators
C_Act_balance	Current account balance (% of GDP)	Net primary income, net secondary income and net exports of goods and services are summed to generate the current account balance, which is expressed as a percentage of GDP.	International Monetary Fund, Balance of Payments Statistics, World Bank and OECD. Link: https://databank.worldbank.org/source/world-development-indicators
Trade_balance	Trade (% of GDP)	Trade is the total goods and services exports and imports expressed as a percentage of GDP.	World Bank national accounts data, and OECD National Accounts data files. Link: https://databank.worldbank.org/source/world-development-indicators
FDI_Inflow	Foreign direct investment, net inflows (% of GDP)	The net inflows of capital from overseas investors are measured as foreign direct investment and divided by GDP.	International Monetary Fund, Balance of Payments Statistics, World Bank and OECD. Link: https://databank.worldbank.org/source/world-development-indicators
Researchers	Researcher (male and female)	Total number of male and female researchers in a specific country.	Eurostat data set, European Union. Link: https://ec.europa.eu/eurostat/data/database
GDP_growth	Gross domestic product (GDP) growth rate (%)	Percentage growth of GDP for a specific country.	World Development Indicators database (WDI), WorldBank. Link: https://databank.worldbank.org/source/world-development-indicators
Ind_growth	Industry growth rate (%)	Percentage growth of the industrial sector for a specific country.	World Development Indicators database (WDI), WorldBank. Link: https://databank.worldbank.org/source/world-development-indicators

Table 2. Descriptive statistics

Variable	Obs.	Mean	Std.	Max value	Min value
EPU	40	0.1672	0.1323	0.4948	0.021884
Innovation	40	1710.42	1259.86	5206.576	241.979
R&D expenditures	40	3011.35	2093.75	8615.563	646.1823
Government effectiveness	40	0.71093299	0.2051	1.11026	0.29277676
Control of Corruption	40	0.37508186	0.24539	0.79195	0.0356078
Current account balance (% of GDP)	40	-0.3040889	2.0633	4.55246	-4.1079854
Trade (% of GDP)	40	102.007683	65.1594419	168.3945	-3.3411774
Foreign direct investment, net inflows (% of GDP)	40	7.15262833	21.675689	106.5942	-40.086346
Researcher (male and female)	40	21322.2	17614.8893	72092	2436
Gross domestic product (GDP) growth rate (%)	40	2.58461614	2.91647588	7.2000	5.5029
Industry growth rate (%)	40	2.005138339	5.391521169	13.5437	-12.5581

Table 3. Fixed effect (FE) regression estimation

EPU base and Lag periods	Model 1	Model 2
	Innov. Coefficients	R&D coefficients
EPU	-2792.352 **	-2560.357
EPU Lag1	1177.146	1702.326
EPU Lag2	5527.603**	2455.721
EPU Lag3	-2819.07***	-4262.901**
EPU Lag4	1140.024	2064.33
EPU Lag5	4761.205**	3228.614
EPU Lag6	-1210.822*	-1086.05
Cons	1654.898***	3554.341
Prob > F	0.0000***	0.0000***
Rsq within	0.9682	0.9393
Rsq between	0.7976	0.6849
Rsq overall	0.7734	0.2829

Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The fixed effect group variables are V4 countries and years, and the independent variable is EPU.

Table 4. Random effect (RE) regression estimation

EPU base and Lag periods	Model 1	Model 2
	Innov. Coefficients	R&D coefficients
EPU	5360.727	5473.876
EPU Lag1	2516.306	4352.068
EPU Lag2	-952.2504	-1168.639
EPU Lag3	3618.17	5825.849
EPU Lag4	3582.029	7110.969
EPU Lag5	-409.5619	1193.102
EPU Lag6	3201.516*	3728.312
Cons	-337.5261	-399.0919
Prob > F	0.0000***	0.0000***
Rsq within	0.4479	0.3032
Rsq between	0.9641	0.9452
Rsq overall	0.9304	0.9149

Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The fixed effect group variable is V4 countries and years, and the independent variable is EPU.

Table 5. System Generalized Method of Moments (GMM) Estimation

EPU base and Lag periods	Model 3	Model 4
	Innov. Coefficients	R&D coefficients
DV_Lag1	0.9588522***	1.152199***
EPU	-1881.568***	-3864.63***
EPU Lag1	-1050.353	-1264.258
EPU Lag2	4476.53***	4615.625**
EPU Lag3	-425.4009	-635.7004
EPU Lag4	-1224.722	-1294.516
EPU Lag5	2165.955**	1519.789
EPU Lag6	-135.0874	-652.4043
Cons	172.8203	175.5786
Prob > Chi2	0.0000	0.0000
Wald chi2	3146.18	4159.42
Sargan test chi2	5.830741	5.529177
Sargan test Prob > chi2	0.6662	0.6998

Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. DV_Lag1 is the lag 1 for dependent variables.

Table 6. System Generalized Method of Moments (GMM) Estimation for EPU, EPU Lags and Political Control Variables

EPU base, Lag and political controls	**Model 5**		**Model 6**	
	Inov. Coefficients		**R&D coefficients**	
DV_Lag1	1.07452***	0.9013762***	1.138525***	1.15746***
EPU	-522.8295*	-2828.085***	-883.3732*	-3128.051
Govt_Effect	98.16861	596.3896	142.451	-738.8727
Corrup_Cont	519.9961**	61.33188	3.976005	250.0536
EPU Lag1		-949.5582		-1106.083
EPU Lag2		5583.205***		3537.046
EPU Lag3		-986.1925*		-316.7903
EPU Lag4		-1134.498		-1149.568
EPU Lag5		3615.248***		97.94789
EPU Lag6		-449.2936		-488.9074
Cons	-113.4182	-194.1107	-169.0813	624.5274
Prob > Chi2	0.0000	0.0000	0.0000	0.0000
Wald chi2	1685.75	3321.63	1156.65	2374.28
Sargan test chi2	38.84091	3.134313	40.40377	2.346037
Sargan test Prob > chi2	0.2232	0.7918	0.1758	0.8853

Note: ***, ** and * indicate statistical significant at the 1%, 5% and 10% levels, respectively. DV_Lag1 is the lag 1 for dependent variables.

Table 7. System Generalized Method of Moments (GMM) Estimation for EPU, EPU Lags and Economic Control Variables

EPU base, Lag and economic controls	**Model 7**		**Model 8**	
	Inov. Coefficients		**R&D coefficients**	
DV_Lag1	1.060995 ***	1.013166***	1.105781***	1.097118***
EPU	-103.4194	-810.6756***	-515.6914	-277.1124
C_Act_balance	-47.62956***	-45.53105***	-49.34118*	-80.19736**
Trade_balance	4.877922***	7.750122***	6.69602**	4.958363
FDI_Inflow	-2.37319**	-2.185551*	-3.386185	-2.405173
EPU Lag1		835.336**		-1716.952**
EPU Lag2		292.3934		1329.186*
EPU Lag3		-167.0266		549.3962
Cons	-385.9436**	-614.3563***	-702.9099**	-544.8182
Prob > Chi2	0.0000	0.0000	0.0000	0.0000
Wald chi2	2558.70	1851.91	1363.48	1264.54
Sargan test chi2	42.38318	15.83899	37.55921	19.15479
Sargan test Prob > chi2	0.1269	0.8621	0.2681	0.6922

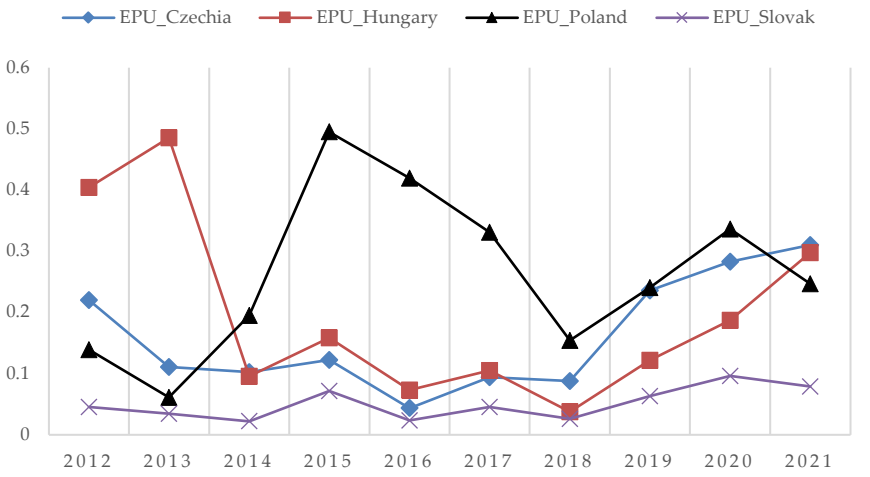
Note: ***, ** and * are statistically significant at the 1%, 5% and 10% levels, respectively. DV_Lag1 is the lag 1 for dependent variables.

Table 8. System Generalized Method of Moments (GMM) Estimation for EPU, EPU Lags and Other Control Variables

EPU base, Lag and controls	Model 9 Inov. Coefficients		Model 10 R&D coefficients	
DV_Lag1	0.8300253***	0.9172178***	0.8717021***	0.5593747***
EPU	-87.91214	-522.6307	-349.0395	1443.497**
Researchers	0.0166658***	0.0091743	0.0247211**	0.0567091***
GDP_growth	31.33262**	30.65077	30.873	43.40136
Ind_growth	-7.002551	-4.960749	4.154218	-9.030701
EPU Lag1		827.9157		-2321.015***
EPU Lag2		-114.4275		-236.0676
EPU Lag3		223.8632		1061.052**
Cons	28.27679	-13.31991	-30.96473	51.50223
Prob > Chi2	0.0000	0.0000	0.0000	0.0000
Wald chi2	2745.41	1551.06	1725.15	1829.03
Sargan test chi2	32.74362	19.87921	37.1368	19.63177
Sargan test Prob > chi2	0.4798	0.6492	0.2841	0.6640

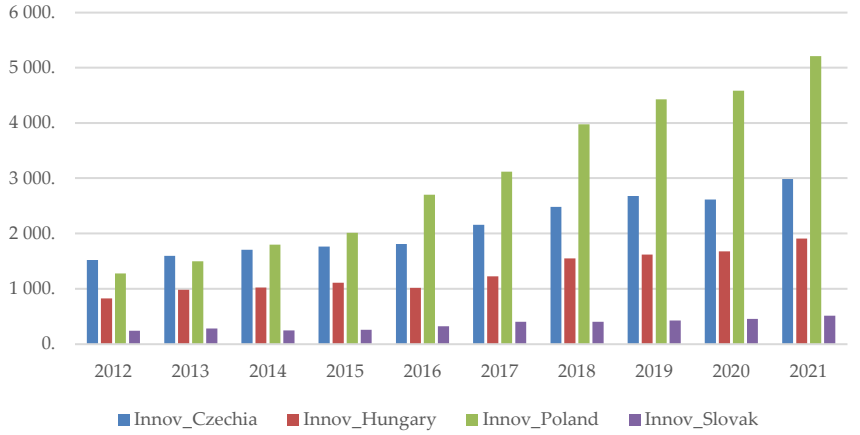
Note: ***, ** and * indicate statistical significance at the 1%, 5% and 10% levels, respectively. DV_Lag1 is the lag 1 for dependent variables.

Figure 1. EPU in the V4 economies from 2012 to 2021



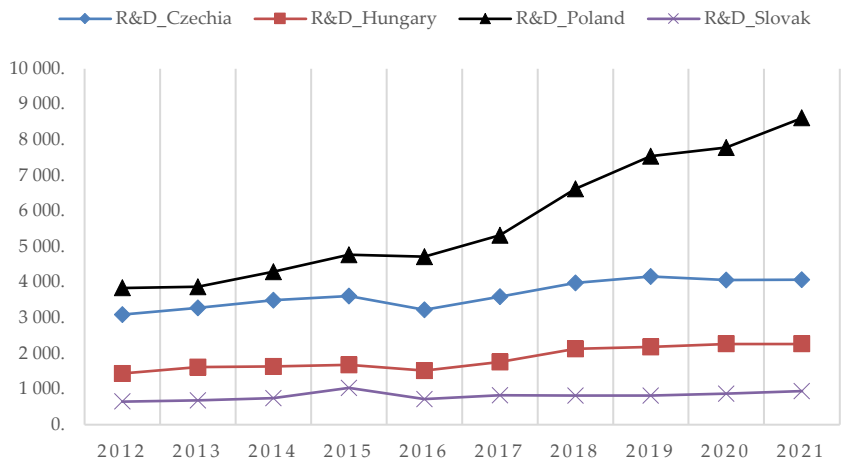
Source: Own calculation based on Federal Reserve Economic Data developed by Baker *et al.* (2016).

Figure 2. Innovation output for V4 nations from 2012 to 2021



Source: Own calculation based on Eurostat data set, European Union (2023).

Figure 3. R&D expenditures in the V4 economies from 2012 to 2021



Source: Own calculation based on World Development Indicators database (WDI), World Bank (2023).