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DO ECONOMIC ACHIEVEMENTS AND ENVIRONMENTAL CONSEQUENCES COINCIDE? THE CASE OF CYCLICITY

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Abstract

The significance of green economic growth opens up a new space for studying cyclical development processes, raising the issue of coexistence between sustainable development and the cyclical features of economic growth. The purpose of this study is to identify statistically significant relationships between cyclical components (fluctuations) of economic growth and environmental consequences within national economic systems. The paper utilizes Hodrick–Prescott and Butterworth bandpass filters to detrend dynamic series of ecological and economic development, highlighting cyclical components (fluctuations) that are analyzed for the presence of correlation in the referenced and lag periods (to identify procyclical and lag dynamics). The analysis uses statistical data from the World Bank for Ukraine and Hungary for 1991–2022. The results prove that for Ukraine with an increase in the cyclical component of GDP per capita there is a cyclical increase in pollution indicators, according to the Butterworth filter for NOx emissions from industrial combustion (correlation coefficient 0.72), F-gases emissions from industrial processes (correlation coefficient 0.77), CO_2 emissions excluding LULUCF (correlation coefficient 0.70). The situation with Hungary is different, and the business cycle is not correlated with pollution fluctuations. The paper does not find a statistically significant relationship between the business cycle and fluctuations in methane (CH_4) emissions from waste (Mt CO_2e). Overall, most economic and environmental components are procyclical in nature, with the strongest correlation in the reference period for a developing industrial economy (Ukraine). In contrast, there is no such link within a more developed economy (Hungary).

Keywords economic cycles, pollution fluctuations, synchronization, energy efficiency

JEL Classification E32, Q53, F43, O13

INTRODUCTION

Business cycle analysis has created favorable conditions for the development of professional and scientific debates on economic growth. Macroeconomic cycles play an important role in shaping national economic policies. In particular, important research issues include the assessment of synchronization in amplitude and the duration of cycles between economic growth and the corresponding environmental consequences.

The theory of real business cycles posits that stochastic fluctuations in labor productivity are the primary source of fluctuations in economic activity. Hodrick and Prescott (1997) were the first to develop the procedure for detrending series of macroeconomic dynamics using the method that later became known as the Hodrick-Prescott filter (HP filter). Based on the detrended series, the indicators of standard deviations, correlations, and serial correlations of macroeconomic aggregates were calculated. Most economic variables are procyclical and exhibit a strong simultaneous correlation with GDP, while most macroeconomic variables are persistent, meaning that if GDP growth occurred in a certain period, it can be stated with a high degree of probability that a similar trend will continue in the future. Proponents of the concept of real business cycles believe that fluctuations are the response of the economic system to restore equilibrium disturbed by external technological changes in a competitive environment, where rational agents maximize their intertemporal choices. Being a follower of classical economic theory with Walrasian equilibrium, the theory of real business cycles emphasizes the effectiveness and necessity of fluctuations, and any government actions aimed at influencing market equilibrium are ineffective or even harmful, since they prevent the market from independently restoring its equilibrium.

Most scientific articles assess only the economic component of the business cycle, focusing on macroeconomic and financial indicators, such as GDP, financial markets, unemployment, and inflation. However, it is also important to study the coherence of economic and environmental cyclical components of development. Determining the procyclical or asynchronous dynamics of ecological indicators in relation to macroeconomic dynamics will allow for more informed decisions on ensuring environmental quality.

1. LITERATURE REVIEW AND HYPOTHESES

The usual set of factors explaining fluctuations in macroeconomic indicators is monetary, fiscal, oil price shocks, as well as technological shocks to labor productivity, which have been separated into a separate group and opened a new direction in economic theory – the theory of real business cycles. The theory of real business cycles originates from Kydland and Prescott (1982), who laid the foundations for combining the theory of economic growth with fluctuations in economic indicators and opened the way for better modeling of economic systems and calibration of economic parameters.

One of the most important features of a business cycle is the presence of clearly expressed signs of decline and growth, which recur with a certain periodicity, as evidenced by studies of short-term, medium-term, and long-term cycles (Dupraz et al., 2025; Hess & Iwata, 1997; Sarlan, 2001; Espinosa et al., 2023). In practice, one typically works with fluctuations that exhibit both increasing and decreasing properties; however, unlike cycles, they do not necessarily have to be harmonious or smooth (Filardo, 1994; Cashin & Ouliaris, 2004; Pagan, 1997). Fluctuations do not necessarily have cyclical development parameters. In particular, stages of decline can differ significantly in depth and time from stages of growth, and vice versa. Cyclical development is primarily characterized by the categories of depression and economic growth, while fluctuations, in addition to the above categories, are described by the categories of shock, stochastic volatility, and the absence of a development trend (Llosa et al., 2025; Benigno et al., 2025).

The theory of cycles is based on the argument that, in the process of development, economic systems sequentially go through several phases: growth, peak, decline, crisis, and stagnation. The peak and crisis phases are the extreme points of industrial growth and decline, respectively. The growth phase is characterized by a general expansion of economic activity, growth in production, expansion of credit operations, a decrease in the amount of money in financial institutions, a consistent increase in the interest rate and an increase in the cost of loans. Indeed, as stated by Zarnowitz (1992), there are no clearly expressed periodicities (cyclicality) of development, and the phases of economic growth differ from each other by almost ten times, with the longest growth duration of one hundred and six months and the shortest growth phase, which is twelve months. Since the average value in absolute measurement approaches the standard deviation, it is impossible to predict with sufficient probability the duration of the economic growth phase.

According to Malik et al. (2024), for the panel of 20 Asian economies using ARDL techniques and panel data for the 1990–2015 period, there is a positive and significant influence of external debt, FDI, and imports on business cycle fluctuations.

According to Falconio and Manganelli (2025), economic risk has a negative influence on business cycle fluctuations, increasing growth-at-risk, and has a limited influence on upward growth potential.

Analyzing business cycle fluctuations and environmental indicators in South Asia, Sarwar et al. (2021) found procyclical dynamics in CH4, NO, and GHG resource-intensive economies, with distinct dynamics across different economies. As for carbon dioxide emissions, they appeared to be similar across all of South Asia, demonstrating procyclical and volatile fluctuations. Moreover, using the Structural Vector Autocorrelation method, it was found that positive technological shocks for India and Bangladesh had a permanent impact on carbon dioxide emissions (affecting the trend component), while for Pakistan and Sri Lanka, positive technological shocks were temporary, affecting only the cyclical component of CO2 emissions.

Investigating CO2 cyclical dynamics in comparison with the corresponding business cycles for six large Asian and Middle Eastern economies (China, India, Japan, Iran, Saudi Arabia, and South Korea), Azami and Angazbani (2020) found that emissions of harmful substances are more volatile than GDP in the studied countries, except for Iran.

Investments have always been considered a cyclical component of economic growth with a positive impact on the trend and cyclical components (Makarenko et al., 2022). Vorontsova et al. (2022) found that for the panel of 31 European countries (26 EU Member States, 3 EFTA countries, and Ukraine), environmental investments do not have a statistically significant influence on SDG 6, SDG 13, and SDG 15. According to Alsmadi et al. (2022), an increase in oil prices enhances the value of the financial market in Saudi Arabia, while diversification of the investor portfolio improves the stability of the financial market.

Empirical studies have demonstrated the positive effects of economic instruments on economic volatility over the business cycle, focusing on the sources of fluctuations and how macroeconomic failures or market distortions interact with environmental policies (Annicchiarico et al., 2022; Melnyk & Kubatko, 2013). Kamanda et al. (2024), using Hodrick-Prescott bandpass filters and a Markov-switching approach for the South Africa post-apartheid era (covering the period 1990–2018), found that the amplitude of CO2 emissions varies over time, which was further confirmed using the Christiano-Fitzgerald, Baxter King, and the Butterworth bandpass filters. The procyclical dynamics were confirmed by Markov-switching analysis, which showed the synchrony of cyclical changes during recessions and expansions.

According to Skare et al. (2020), the examples of China and France have shown different directions of cyclical green growth, which was confirmed by the correlation of cycles, the coherence of cycles, and the duration of the cycle. Lintunen and Vilmi (2021) proved that carbon prices are associated with fluctuations in the marginal utility of consumption. The findings argue that climate policy should focus on setting a carbon price at an optimal growth level, giving fluctuations in carbon prices only a secondary role. One possible recommendation may be not to reduce CO2 emissions prices during periods of economic recession. A similar opinion is held by Ramezani et al. (2024), who state that under business subsidy policies, the dynamics of emissions of harmful substances will be procyclical, meaning emissions will increase when gross domestic product increases and vice versa. Using panel data for European Union countries from 2010 to 2020, Sineviciene and Miliauskaite (2025) find that environmental motives of companies are not statistically significant in the decision-making process to increase energy tax rates.

The COVID-19 pandemic introduced additional structural distortions that have hindered sustainable development trajectories and slowed the progress toward achieving environmental-related SDGs, with evidence from Ukraine confirming that only a minor share of planned sustainability targets was reached during the "new normal" period (Mishchuk et al., 2023).

Over time, both economic systems have begun to converge in terms of the cyclicality of development, as measured by green growth indicators, which suggests a link to globalization trends. The results of quantitative modelling support the idea that effective environmental policies lead to lower

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aggregate volatility in emissions of harmful substances, but are associated with higher welfare costs (Eydam, 2023). Empirical evidence also indicates that progress in the early sustainability goals related to poverty reduction and food security can stimulate broader economic empowerment. However, access to resources plays a critical mediating role in shaping these outcomes across different national economies (Nassar et al., 2023).

In addition to environmental governance, institutional confidence plays a fundamental stabilizing role in the macroeconomic environment. Recent empirical evidence from EU countries suggests that higher public trust has a significantly stronger positive impact on macroeconomic stability than improvements in public sector transparency alone, indicating that trust-induced confidence channels can amplify GDP growth and currency stability during cyclical fluctuations (Vasylieva et al., 2023). Busu et al. (2024) prove an existing relationship between business cycles and the consumption of renewable energy by the population in the European Union (EU) during the first two decades of the twenty-first century. The paper proves the statistical significance of GDP growth indicators, government efficiency, and regulatory quality on REC per capita. Although previous studies have focused on macroeconomic fluctuations in developed countries, developing countries were discussed mainly with CO2 cyclical dynamics. Within this paper, more attention is paid to the estimation of broader set of environmental fluctuations for Ukraine and Hungary.

Considering the above, the purpose of this study is to identify statistically significant relationships between the cyclical components (fluctuations) of economic growth and the environmental consequences within national economic systems.

The hypotheses of the study are as follows:

H1: *With an increase in the cyclical component of GDP per capita (current USD), there is a cyclical increase in environmental pollution indicators (nitrous oxide emissions from industrial combustion; F-gases emissions from industrial processes; carbon dioxide emissions excluding LULUCF in resource-intensive economies).*

H2: *The cyclical component of GDP per capita (current USD) is the leading cyclical component, while energy efficiency is a lagging indicator of development.*

H3: *In an import-dependent economy, fluctuations in imports, GDP, and pollution indicators are strongly correlated.*

H4: *The cyclical component of GDP per capita (current USD) has no statistically significant relationship with the cyclical component of methane (CH4) emissions from waste (Mt CO2e).*

2. METHODS

To achieve the study's aim, two principal approaches were used. First, the bandpass filters detrend dynamic series of ecological and economic development, highlighting the cyclical component (fluctuations). Second, a correlation analysis identifies the close relationship between the cyclical components of national economic development.

When studying economic fluctuations with an upper limit on production capacity (Kose et al., 2003), the dynamic series of the economic indicator (y_t) is broken down into trend (τ_t) and transition components (c_t):

$$y_t = \tau_t + c_t, \tag{1}$$

In order to describe the development of the economy in the conditions of the existence of upper production capacities, it is necessary to set the parameters of the transitional component appropriately:

$$\begin{aligned} &c_t = \varphi_1 c_{t-1} + \varphi_2 c_{t-2} + u_t, \\ &u_t = \pi S_t + u_t, \quad \pi \neq 0, \;\; S_t = 0 \;\text{ or }\; 1, \end{aligned} \tag{2}$$

where πS_t is an asymmetric, discrete shock that depends on S_t the factor that is not observable until it manifests itself in the form of a normal situation or recession and an ordinary symmetric shock u_t The parameter u_t determines the nature of the shock in the economic system, and specifically, under normal conditions, it assumes a value of 0. In this case, the economic system is in conditions close to its potential or trend GDP. In the case of recessionary processes, the parameter S_t takes on a value equal to 1, and the economic system experiences a short-term shock, most likely a negative one.

Seasonal and random fluctuations are assumed to be insignificant and are included in the cyclical component (Hodrick & Prescott, 1997). Thus, as a result of applying this filter, a trend is determined that does not require additional smoothing.

$$\min_{\tau}\sum_{t=1}^{T}\left(y_t-\tau_t\right)^2 + \lambda\sum_{t=2}^{T-1}\left[\left(\tau_{t+1}-\tau_t\right)-\left(\tau_{t+1}-\tau_{t-1}\right)\right]^2 \quad (3)$$

Equation (3) represents the objective function to find the value for the trend component (τ) that minimizes the total variance (cyclic component) of the time series (Y_t), resulting in a smooth trend line (τ) with minimal fluctuations (c).

The parameter (λ) is an extrinsic value defined to adjust the behavior characteristic of the series. It determines the degree to which we want to include the effect of any sudden changes in the behavior of the time series in the filtering of our trend variable. If $\lambda = 0$, the solution degenerates to $\tau_t = y_t$, in which case the filter excludes all frequencies, i.e., $c_t = 0$. On the other hand, as $\lambda \to \infty$, the solution approaches the least squares line $\tau_t = \beta_0 + \beta_1$ (Hodrick & Prescott, 1997).

For a fixed λ, it can be shown that the cyclic component $c' = (c_1, c_2, ..., c_T)$ is calculated by:

$$c = (IT - M^{-1})y, \quad (4)$$

where y is the column vector $y' = (y_1, y_2, ..., y_T)$, IT is the identity matrix × T, and M is the $T \times T$ matrix.

On the other hand, the smoothing parameter λ plays a crucial role in balancing the fit and smoothness of the trend (e.g. smaller λ means smaller penalties on the smoothness condition). There are two approaches to choosing. One method, based on heuristic reasoning, is used to calculate default values for λ, in which a built-in factor sets λ to 1600 for quarterly data. The rescaled default values for λ are 6.25 for annual data (Ravn & Uhlig, 2002).

The second method of choosing λ uses recommendations of Pollock (2000), who used a filter gain function to determine the value. Thus, the HP filter can be used for time series of economic dynamics with different time parameters.

Pollock (2000) said that the generally accepted linear filters (for example, the Hodrick-Prescott filter) are not flexible enough. To resolve the aforementioned contradictions, it is proposed to use a rational wave filter (Butterworth filter), as the last is more accurate in defriending and extracting fluctuations.

Correlation analysis is used to analyze the relationship between the studied economic indicators and GDP per capita. The methods employed in this analysis enable the identification of the

$$M = \begin{pmatrix}
(1+\lambda) & -2\lambda & \lambda & 0 & 0 & 0 & \cdots & 0 \\
-2\lambda & (1+5\lambda) & -4\lambda & \lambda & 0 & 0 & \cdots & 0 \\
\lambda & -4\lambda & (1+6\lambda) & -4\lambda & \lambda & 0 & \cdots & 0 \\
0 & \lambda & -4\lambda & (1+6\lambda) & -4\lambda & \lambda & \cdots & 0 \\
\vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \cdots & \vdots \\
\vdots & 0 & \ddots & \ddots & \ddots & \ddots & \ddots & 0 \\
0 & \cdots & \lambda & -4\lambda & (1+6\lambda) & -4\lambda & \lambda & 0 \\
0 & \cdots & 0 & \lambda & -4\lambda & (1+6\lambda) & -4\lambda & \lambda \\
0 & \cdots & 0 & 0 & \lambda & -4\lambda & (1+5\lambda) & -2\lambda \\
0 & \cdots & 0 & 0 & 0 & \lambda & -2\lambda & (1+\lambda)
\end{pmatrix} \quad (5)$$

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most significant periodic dependencies and their corresponding lags (delays) within a single process. Correlation analysis enables the establishment of whether a connection exists between factors and the strength of this connection.

The presence of trends and cyclical fluctuations in the studied time series indicates the existence of connections between successive levels of the series; that is, the value of each subsequent level of the series depends on the previous ones. It is necessary to study the correlation dependence between successive levels of the time series. The degree of closeness of the connection can be determined using the linear correlation coefficient between the levels of a given time series and the levels of this time series shifted by several time steps. The magnitude of the shift lag is called the lag and means the delay in the influence of factors on the studied indicator. As the lag value increases, the number of pairs of values from which the correlation coefficient K_L (autocorrelation) is calculated decreases. It is assumed that the maximum lag should not exceed n/4.

Therefore, the coefficient K_L in this case characterizes the density of the connection between the primary series of dynamics and the same series shifted by lag periods. For the current research, a period (lag) of one year was determined.

Large values of K_L will indicate the presence of a close relationship between the indicators of the current and previous periods. If, when calculating the autocorrelation coefficients of higher orders (lag equal to 2, 4, 4…years), it turns out that the coefficient of order m takes the largest value, then we can conclude that there are cyclical fluctuations with a period m in the series.

The HP filter methodology is often used in conjunction with other econometric methods (e.g., correlation and regression analysis). The degree of closeness of the relationship can be determined using the linear correlation coefficient between the levels of a given time series and the levels of this time series shifted by several steps in time. The amount of shift lag is called lag. It means the delay in the impact of factors on the indicator under study.

The sequence of correlation coefficients of the first, second, and higher levels forms the autocorrelation function of the time series. Quantitative analysis of the autocorrelation function makes it possible to calculate the lag value at which the autocorrelation is highest. The value of this lag indicates the greatest closeness of the connection between the current and previous series. However, by the sign of the autocorrelation coefficient, one cannot conclude about the existence of an increasing or decreasing trend in the studied series.

The study will take into account a range of factors including: GDP per capita (current USD), nitrous oxide (N2O) emissions from industrial combustion, F-gases emissions from industrial processes, carbon dioxide (CO2) emissions (total) excluding LULUCF, methane (CH4) emissions from waste (Mt CO2e), electricity production from natural gas sources (% of total), electricity production from coal sources (% of total), merchandise imports (current USD), high-technology exports (current USD) and others for the economy of Ukraine and Hungary for the period 1991–2022.

3. RESULTS AND DISCUSSION

Calculations were performed using the Stata 18 software, version 2023, from StataCorp. The package is designed for statistical analysis and is widely used in economics, social sciences, biostatistics, and other fields. The code is presented in Appendix A.

When developing applied approaches to assessing the consistency of processes, phases, and communications between structural elements in the series of ecological and economic dynamics, it is necessary to use bandpass filters. Thus, the method of applying bandpass filters involves several consecutive stages that ensure the correct decomposition of time series into trend and cyclical components:

a) Import and data preparation. At the initial stage, the data are organized in the form of a time series, which allows the correct application of time structure analysis methods. This assumes the presence of a time variable and observations ordered according to it. In Stata, this is implemented through the tsset function, which sets the time structure for further analysis.

b) Establishing a time frame. Determining the time frame (monthly, quarterly, annual, etc.) is crucial for accurately interpreting the results. This allows Stata to recognize the type of series and ensures accurate filtering.

c) Turning the variable into the logarithms. For many macroeconomic indicators (e.g., GDP, price indices), logarithmic transformation is used. This allows differences to be interpreted as approximate growth rates, reducing variation and contributing to more stable data processing.

For practical assessment, World Bank data for Ukraine for 1991–2022 were taken. The results of the assessment of fluctuations in nitrous oxide (N2O) emissions from transport (energy) (Mt CO2e) and GDP per capita in Ukraine are shown in Figure 1. The programming of actions for applying the HP and Butterworth BW filters is shown in Appendix B.

Figure 1 shows the synchronous dynamic behavior of the indicators, with some time lag, the areas of decline, growth, and partly peak values (minimum and maximum) are synchronized. Direct correlation (without time lag) between the indicators is average according to the HP filter and high based on the Butterworth filter (0.72). It should be noted that the HP filter, to a lesser extent, highlights medium-term cycles, which are economic and environmental fluctuations, and to a greater extent, short-term economic fluctuations. However, the

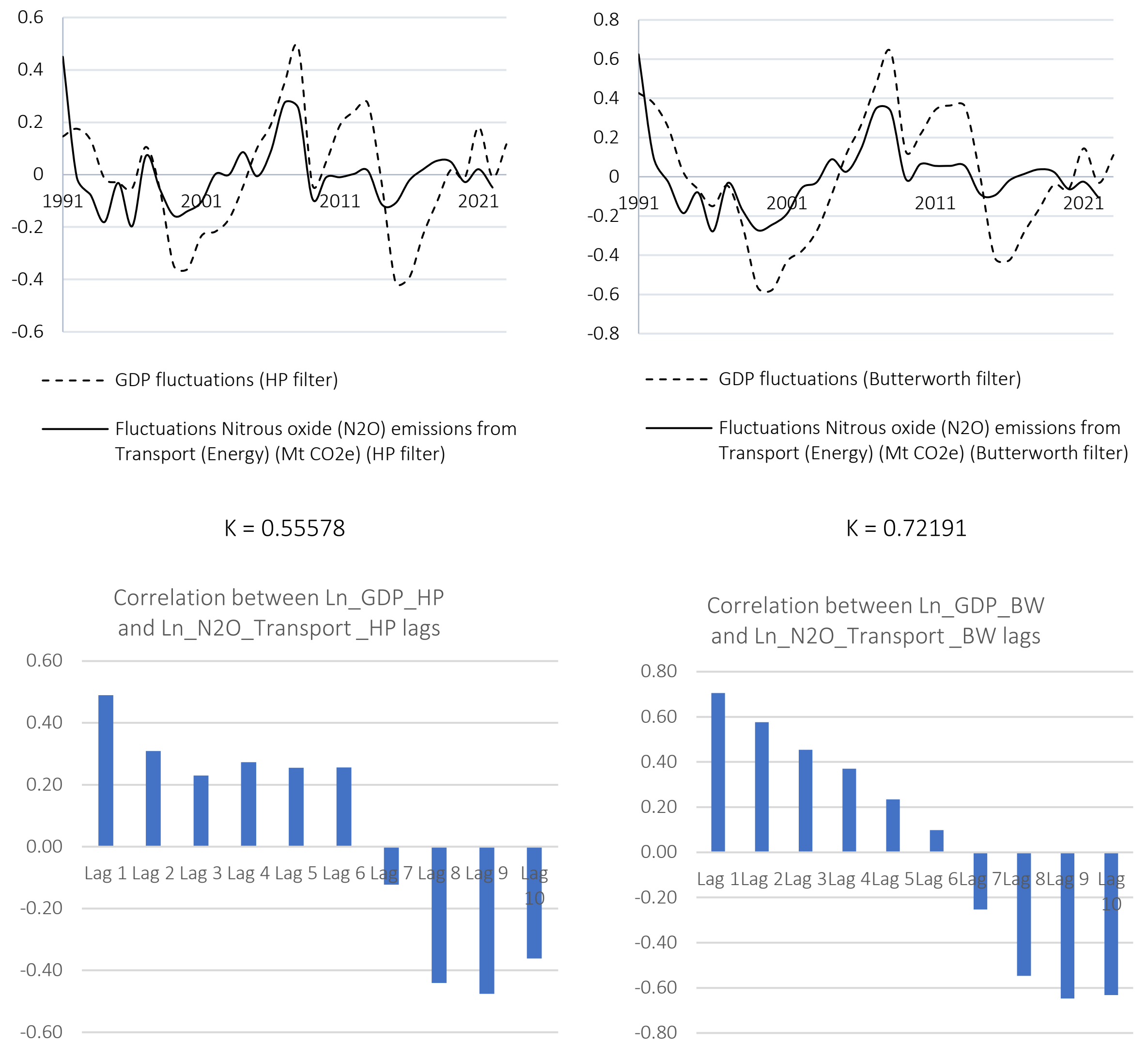

Figure 1. Medium-term fluctuations between nitrous oxide (N2O) emissions from transport (energy) (Mt CO2e) and GDP per capita (current USD) for Ukraine for 1991–2022

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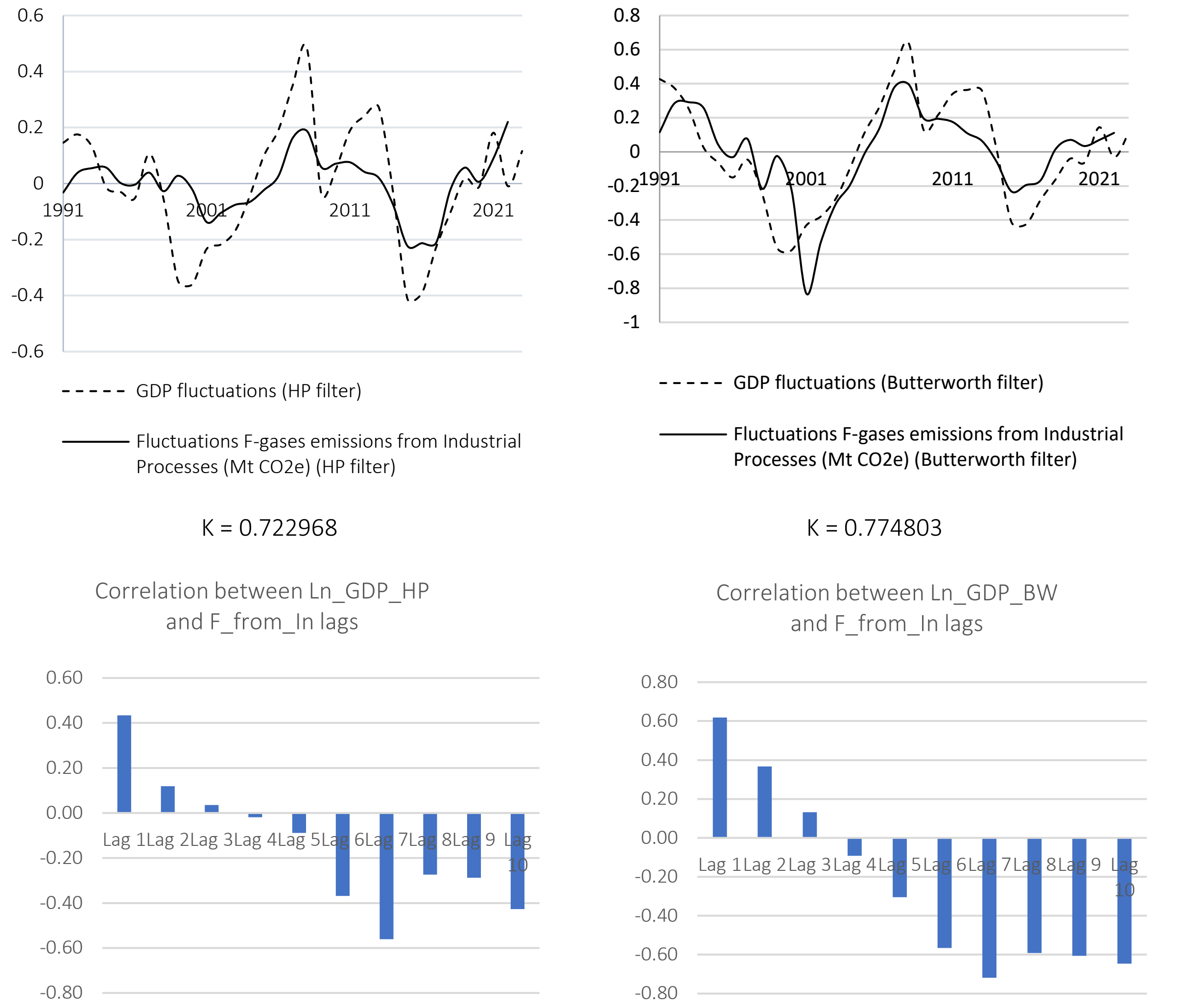
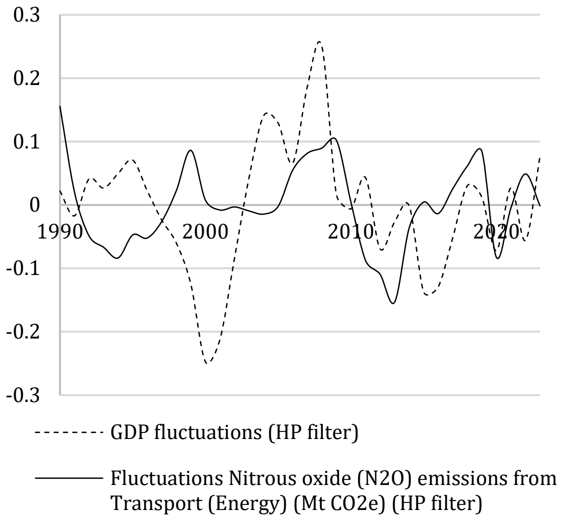


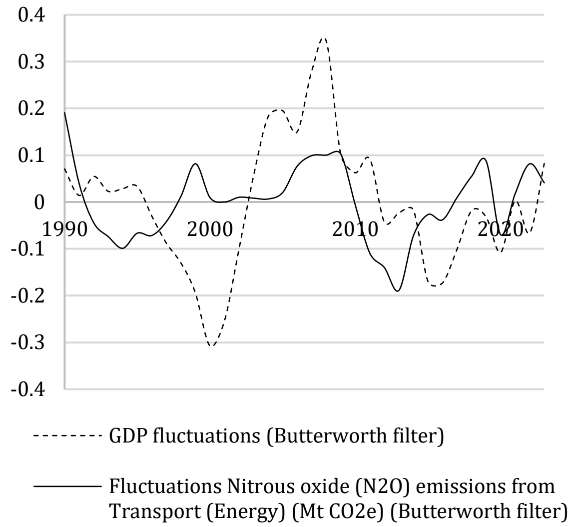
Figure 2. Medium-term fluctuations between F-gases emissions from industrial processes (Mt CO2e) and GDP per capita (current USD) for Ukraine for 1991–2022

Butterworth filter eliminates the shortcomings of the HP filter. When working with medium-term fluctuations, a clear procyclical dependence is visible between nitrous oxide (N2O) emissions from transport (energy) (Mt CO2e) and GDP per capita. Similar dynamics are observed for fluctuations in F-gases emissions from industrial processes (Mt CO2e) (Figure 2).

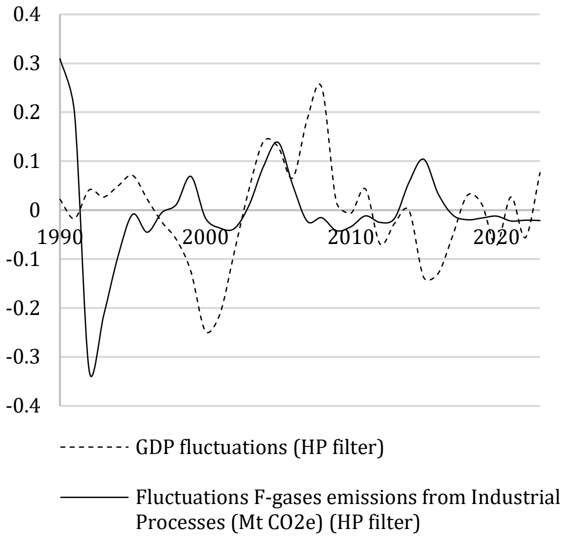
Figure 2 demonstrates the synchronous dynamic behavior of F-gas emissions from industrial processes (Mt CO2e) and GDP per capita (current USD) for Ukraine from 1991 to 2022. The peak values (minimum and maximum) coincide in the same manner. The direct correlation between the indicators is high, specifically 0.72 for the HP filter and 0.77 for the Butterworth filter. In general, Figures 1 and 2 and proper correlations clearly state that, therefore the H1 hypothesis is confirmed for Ukraine for 1991–2022.Appendix C presents the results of the separation of the cyclical component based on the Hodrick-Prescott and Butterworth filters in Stata 18 for the merchandise imports (current USD), methane (CH4) emissions from waste (Mt CO2e), and GDP per unit of energy use (constant 2021 PPP D per kg of oil equivalent). In an import-dependent economy, fluctuations in imports, GDP, and pollution indicators are strongly correlated, as shown in Appendix C. In particular, there is a significant closeness of the relationship between the cyclical indicators of GDP per capita (current USD) for Ukraine for 1991–2022 and merchandise imports (current USD), in particular, the correlation coefficient between the two cyclical components for the HP



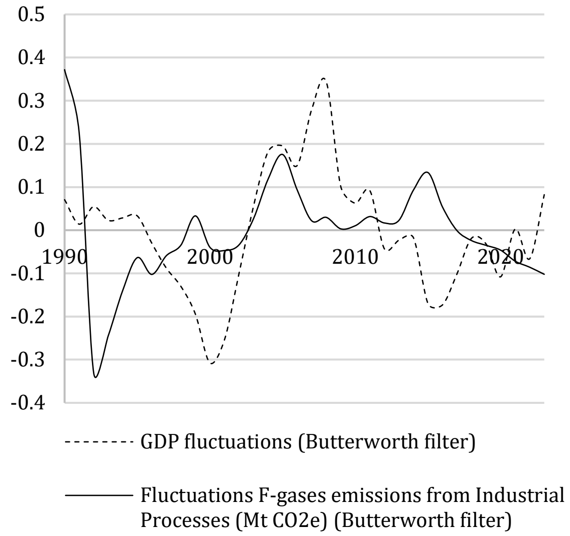
K = 0.1469



K = 0.2488



K= –0.022



K = 0.1615

Figure 3. Medium-term fluctuations between nitrous oxide (N2O) emissions from transport (energy) (Mt CO2e), F-gases emissions from industrial processes (Mt CO2e), and GDP per capita (current USD) for Hungary for 1991–2022

filter is 0.83, and for the Butterworth filter, it is 0.83 and as a result the H3 hypothesis is confirmed for Ukraine (Figure B1).

It is expected that methane (CH4) emissions from waste (Mt CO2e) and GDP per capita (current USD) for Ukraine from 1991 to 2022 are not correlated, which is confirmed by the lack of coincidences in the corresponding phases and amplitudes of the cycles. Thus, Hypothesis 4 is confirmed, as methane (CH4) emissions from waste in the current period do not depend on the level of economic activity (Figure B2). Regarding the cyclical component of GDP per unit of energy use (constant 2021 PPP D per kg of oil equivalent) and the cyclical component of GDP, the average and high correlation for the HP filter is 0.56. For the Butterworth filter, it is 0.76, therefor the Hypothesis 2 is rejected.

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As seen from Figure 3, the situation with Hungary is different, and the business cycle is not correlated with fluctuations in environmental consequences, therefore the H1 hypothesis is not confirmted for the Hungary. One explanation is that Hungary has a relatively robust economy and is less dependent on industrial production as a percentage of GDP.

The results of this study are consistent with Sarwar et al. (2021), showing evidence that procyclicality for CO2 emissions is not only in the US but also in South Asian economies. The current study is consistent with the evidence for six large Asian and the Middle Eastern economies (China, India, Japan, Iran, Saudi Arabia, and South Korea), as Azami and Angazbani (2020) established the procyclical behavior of emissions in all studied countries except for India, but the amplitude of fluctuations in pollution indicators depends on domestic policies. In the general case, the price for environmental pollution is procyclical, that is, prices should be lower during recessions and, accordingly, higher during economic growth.

The asymmetric fluctuations in business cycles have also been noted by Morley and Piger (2012) and Acemoglu and Scott (1997), who observed that recessions have a steeper decline slope than subsequent expansions. Moreover, Kim and Nelson (1998) argued that there is a positive time dependence in the duration of a recession, meaning that the longer the recession lasts, the more likely it is that it is already over. At the same time, none of the scientists found a time dependence in the growth phases; if it has already started, it will persist indefinitely. An important result was found by Beaudry and Koop (1993), where the effect of duration (temporal persistence) was studied, and it was proven that negative shocks were less persistent than positive ones. Perhaps, as a working hypothesis, the idea can be expressed that when a negative shock occurs, the actions of the government or people responsible for economic policy will be at minimizing the effect of the negative factor as soon as possible. When a positive shock occurs, on the contrary, all government actions are at maintaining the positive dynamics of stimulating factors as long as possible. Another type of asymmetry in business fluctuations was observed during the development of Keynesian economic theory, immediately after the Great Depression, when the recessionary trend was replaced with a growing one almost instantly. Developing countries such as Angola, Argentina, and Benin are facing financial instability caused by FDI flows, trade fluctuations, high inflation, and currency volatility, highlighting that globalization differently influences countries' national economies and regulatory systems (Saad & Sági, 2025).

In the transition from the recessionary stage to the stage of economic growth, technological shocks play a crucial role, complemented by Schumpeter's theory of creative destruction (Schumpeter, 1976). Innovative achievements and shifts in production up to the middle of the twentieth century were not considered key factors in the dynamics of economic cycles. The Schumpeter's theory of innovations also could be used as an explanation of economic and pollution dynamics, but as for Ukraine, it is the way of restructuring from command economy to market economy is more dominant in explaining cyclicity. Following Melnyk et al. (2024), more research has to be done on linking digital innovations and economic fluctuations.

In contrast to Kim and Nelson (1999), who developed and estimated an empirical "threshold" (potential, natural level of GDP) model of economic fluctuations, this paper has not found the "threshold" for the GDP level. Permanent technological shocks spread their effects throughout the entire economic system until the economic system rebuilds its homeostatic level to a new, higher level. Transitive shocks also spread their effects throughout the entire economic system, but the influence of the latter fades over time, and the economic system returns to its homeostatic level. Regarding the causal relationships between shocks and fluctuations in economic indicators, most of the variability is explained by transitory shocks. Technological shocks spread at a slower pace than transitive ones, and the economic system has enough time to rebuild its homeostasis. Moreover, it can be hypothesized that permanent technological shocks become a source of one-time shocks or permanent unidirectional fluctuations in the behavior and expectations of economic agents. Thus, a technological shock causes a transitory shock, which is reflected in the economic system in the form of positive expectations of future technological changes of a fundamental nature.

Economic agents often lack sufficiently well-founded information and may therefore suffer from asymmetric or incomplete information. Sultanuzzaman et al. (2024) argue that green financing plays a significant role in promoting energy development, supporting energy access and stability, especially during economic recessions (the cyclical component of the business cycle), periods of low income, and limited technological shifts. If the information regarding the upcoming technological shock turns out to be false, but only "noise", then economic agents (Dées & Zimic, 2019) will adjust their behavior accordingly. Given reliable information, the economic system will gradually rebuild its level of homeostasis in a direction consistent with technological changes. Therefore, changes in expectations, both positive and negative, become a source of economic fluctuations in the short and long term.

CONCLUSION

The purpose of this study is to identify statistically significant relationships between cyclical components (fluctuations) of economic growth and environmental consequences within national economic systems.

We used Hodrick-Prescott and Butterworth bandpass filters for Stata 18 on the example of Ukraine for 1991–2022. It was found that with an increase in the cyclical component of GDP per capita (current USD), there is a cyclical increase in environmental pollution indicators (nitrous oxide emissions from industrial combustion, F-gases emissions from industrial processes, carbon dioxide emissions excluding LULUCF). However, there is no corresponding correlation between the business cycle and methane emissions from waste. The situation with Hungary is different, and the business cycle is not correlated with fluctuations in environmental consequences.

The hypothesis that the cyclical component of GDP per capita (current USD) is the leading cyclical component, while energy efficiency is a lagged indicator of development, was not confirmed, since the strongest connection was in the lag-free real period. In an import-dependent economy (Ukraine), fluctuations in imports, GDP, and pollution indicators are strongly correlated; using both filters (Hodrick-Prescott and Butterworth in Stata 18), the correlation coefficients of the cyclical components are 0.83.

Thus, most of the economic and environmental components of development are procyclical in nature for a developing economy with a relatively industrialized sector (Ukraine), with the greatest closeness of correlation precisely in the referenced period without lag. Moreover, there is no correlation in the business cycle and emission for a more developed economy (Hungary). However, using Hungary data is not enough to make conclusion about the absence of pollution and business cycle links in more developed economics and more research on this topic has to be done.

For the state's economic policy, based on Ukrainian data, the periods of economic growth will be immediately accompanied by a proportional increase in environmental pollution. Due to significant damage to the industrial complex during Russia's aggression against Ukraine, industrial growth is not well understood, and therefore, in real-world conditions, it cannot be extrapolated into the future without specifying the appropriate conditions.

AUTHOR CONTRIBUTIONS

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Supervision: Oleksandr Kubatko.
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REFERENCES

1. Acemoglu, D., & Scott, A. (1997). Asymmetric business cycles: Theory and time-series evidence. *Journal of Monetary Economics, 40*(3), 501-533. https://doi.org/10.1016/S0304-3932(97)00049-4
2. Alsmadi, A. A., Alrawashdeh, N., Anwar, A.-G., Alhwamdeh, L. N., & Al_hazimeh, A. M. (2022). Do oil prices and oil production capacity influence decision making and uncertainty in the financial market? Evidence from Saudi Arabia. *Investment Management and Financial Innovations, 19*(3), 335-345. http://dx.doi.org/10.21511/imfi.19(3).2022.28
3. Annicchiarico, B., Carattini, S., Fischer, C., & Heutel, G. (2022). Business cycles and environmental policy: A primer. *Environmental and Energy Policy and the Economy, 3,* 221-253. https://doi.org/10.1086/717222
4. Azami, S., & Angazbani, F. (2020). CO2 response to business cycles: New evidence of the largest CO2-Emitting countries in Asia and the Middle East. *Journal of Cleaner Production, 252,* Article 119743. https://doi.org/10.1016/j.jclepro.2019.119743
5. Beaudry, P., & Koop, G. (1993). Do recessions permanently change output? *Journal of Monetary Economics, 31*(2), 149-163. https://doi.org/10.1016/0304-3932(93)90042-E
6. Benigno, G., Foerster, A., Otrok, C., & Rebucci, A. (2025). Estimating macroeconomic models of financial crises: An endogenous regime-switching approach. *Quantitative Economics, 16*(1), 1-47. https://doi.org/10.3982/QE2038
7. Busu, M., Staicu, G., Gheorghe, M., Prinz, E., & Fonseca, L. M. (2024). Analysing the effects of the business cycle on renewable energy consumption and sustainable development: Evidence from EU countries. *Amfiteatru Economic, 26*(18), 1048-1064. https://doi.org/10.24818/EA/2024/S18/1048
8. Cashin, P., & Ouliaris, S. (2004). Key features of Australian business cycles. *Australian Economic Papers, 43*(1), 39-58. https://doi.org/10.1111/j.1467-8454.2004.00215.x
9. Dées, S., & Zimic, S. (2019). Animal spirits, fundamental factors and business cycle fluctuations. *Journal of Macroeconomics, 61,* Article 103123. https://doi.org/10.1016/j.jmacro.2019.103123
10. Dupraz, S., Nakamura, E., & Steinsson, J. (2025). A plucking model of business cycles. *Journal of Monetary Economics, 152,* Article 103766. https://doi.org/10.1016/j.jmoneco.2025.103766
11. Espinosa, V. I., Alonso-Neira, M. A., & Huerta de Soto, J. (2023). The central banking system paradox. *Economics & Sociology, 16*(4), 56-72. https://doi.org/10.14254/2071-789X.2023/16-4/3
12. Eydam, U. (2023). Climate policies and business cycles: The effects of a dynamic cap. *National Institute Economic Review, 264,* 75-90. https://doi.org/10.1017/nie.2023.12
13. Falconio, A., & Manganelli, S. (2025). Financial conditions, business cycle fluctuations and growth-at-risk. *Journal of Economic Dynamics and Control, 176,* Article 105109. https://doi.org/10.1016/j.jedc.2025.105109
14. Filardo, A. J. (1994). Business-cycle phases and their transitional dynamics. *Journal of Business & Economic Statistics, 12*(3), 299-308. https://doi.org/10.1080/07350015.1994.10524545
15. Hess, G. D., & Iwata, S. (1997). Measuring and comparing business-cycle features. *Journal of Business & Economic Statistics, 15*(4), 432-444. https://doi.org/10.1080/07350015.1997.10524721

16. Hodrick, R. J., & Prescott, E. C. (1997). Postwar US business cycles: An empirical investigation. *Journal of Money, Credit, and Banking, 29*(1), 1-16. https://doi.org/10.2307/2953682

17. Kamanda, E. D., Regret, S., Biyase, M., Frank, B., & Simioni, M. (2024). Analysing the response of CO2 emissions to business cycle in a developing economy: Evidence for South Africa post-apartheid era. *Frontiers in Environmental Science, 11*. https://doi.org/10.3389/fenvs.2023.1321335

18. Kim, C.-J., & Nelson, C. R. (1998). Business cycle turning points, a new coincident index, and tests of duration dependence based on a dynamic factor model with regime switching. *The Review of Economics and Statistics, 80*(2), 188-201. https://doi.org/10.1162/003465398557447

19. Kim, C.-J., & Nelson, C. R. (1999). Friedman's plucking model of business fluctuations: Tests and estimates of permanent and transitory components. *Journal of Money, Credit and Banking, 31*(3), 317-334. https://doi.org/10.2307/2601114

20. Kose, M. A., Otrok, C., & Whiteman, C. H. (2003). International business cycles: World, region, and country-specific factors. *American Economic Review, 93*(4), 1216-1239. https://doi.org/10.1257/000282803769206278

21. Kydland, F. E., & Prescott, E. C. (1982). Time to build and aggregate fluctuations. *Econometrica, 50*(6), 1345-1370. https://doi.org/10.2307/1913386

22. Lintunen, J., & Vilmi, L. (2021). Optimal emission prices over the business cycles. *Environmental & Resource Economics, 80*(1), 135-167. https://doi.org/10.1007/s10640-021-00581-x

23. Llosa, L. G., Pérez-Forero, F. J., & Tuesta, V. (2025). Uncertainty shocks and financial conditions in Latin-American countries. *Emerging Markets Review, 68*, Article 101327. https://doi.org/10.1016/j.ememar.2025.101327

24. Makarenko, I., Plastun, A., Kozmenko, S., Kozmenko, O., & Rudychenko, A. (2022). Corporate transparency, sustainable development, and SDGs 2 and 12 in agriculture: The case of Ukraine. *AGRIS on-line Papers in Economics and Informatics, 14*(3), 57-70. https://doi.org/10.7160/aol.2022.140305

25. Malik, S., Abbas, A., Shabbir, M. S., & Ramos-Meza, C. S. (2024). Business cycle fluctuations, foreign direct investment, and real effective exchange rate nexus among Asian countries. *Journal of the Knowledge Economy, 15*, 5466-5479. https://doi.org/10.1007/s13132-023-01316-7

26. Melnyk, L., & Kubatko, O. (2013). The EU experience in economic systems adaptation to resource fluctuations through stimulation of green innovations. *Actual Problems of Economics, 150*, 36-42. Retrieved from https://essuir.sumdu.edu.ua/server/api/core/bitstreams/56cafbaf-2838-4e10-872f-036811b27851/content

27. Melnyk, L., Kalinichenko, L., Rozghon, Y., Derykolenko, O., Kovtun, O., & Tulyakov, O. (2024). Prospects of business process management based on chatbots. *Problems and Perspectives in Management, 22*(2), 197-212. https://doi.org/10.21511/ppm.22(2).2024.16

28. Mishchuk, H., Czarkowski, J. J., Neverkovets, A., & Lukács, E. (2023). Ensuring sustainable development in light of pandemic "New Normal" Influence. *Sustainability, 15*(18), Article 13979. https://doi.org/10.3390/su151813979

29. Morley, J., & Piger, J. (2012). The asymmetric business cycle. *The Review of Economics and Statistics, 94*(1), 208-221. https://doi.org/10.1162/REST_a_00169

30. Nassar, S., Tóth, Z. N., & Vasa, L. (2023). Economic empowerment as a result of achieving SDGs with resource access: A comparative research between Gaza Strip and Hungary. *Journal of International Studies, 16*(2). https://doi.org/10.14254/2071-8330.2023/16-2/1

31. Pagan, A. (1997). Towards an understanding of some business cycle characteristics. *Australian Economic Review, 30*(1), 1-15. https://doi.org/10.1111/1467-8462.00001

32. Pollock, D. S. G. (2000). Trend estimation and detrending via rational square-wave filters. *Journal of Econometrics, 99*(2), 317-334. https://doi.org/10.1016/S0304-4076(00)00028-2

33. Ramezani, F., Arjomandi, A., & Harvie, C. (2024). The economic and environmental effects of an optimal emission reduction subsidy policy in the presence of business cycles. *Studies in Economics and Finance, 41*(2), 224-240. https://doi.org/10.1108/SEF-02-2022-0118

34. Ravn, M. O., & Uhlig, H. (2002). On adjusting the Hodrick-Prescott filter for the frequency of observations. *Review of Economics and Statistics, 84*(2), 371-376. https://doi.org/10.1162/003465302317411604

35. Saad, R. A., & Sági, J. T. (2025). Assessing the impact of globalisation on financial stability: Evidence from selected developed and developing countries. *Investment Management and Financial Innovations, 22*(2), 397-410. https://doi.org/10.21511/imfi.22(2).2025.31

36. Sarlan, H. (2001). Cyclical aspects of business cycle turning points. *International Journal of Forecasting, 17*(3), 369-382. https://doi.org/10.1016/S0169-2070(01)00095-4

37. Sarwar, M. N., Ali, S., & Hussain, H. (2021). Business cycle fluctuations and emissions: Evidence from South Asia. *Journal of Cleaner Production, 298*, Article 126774. https://doi.org/10.1016/j.jclepro.2021.126774

38. Schumpeter, J. A. (1976). *Capitalism, socialism and democracy* (1st ed.). London: Routledge. https://doi.org/10.4324/9780203202050

39. Sineviciene, L., & Miliauskaite, L. (2025). What determines energy tax rates in European Union countries? *Problems and Perspectives in Management, 23*(3), 715-727. https://doi.org/10.21511/ppm.23(3).2025.51

http://dx.doi.org/10.21511/ee.16(4).2025.09

40. Skare, M., Tomic, D., & Stjepanović, S. (2020). Green business cycle: An analysis on China and France. *Acta Montanistica Slovaca, 25,* 563-576. https://doi.org/10.46544/AMS.v25i4.10

41. Sultanuzzaman, R., Yahya, F., & Lee, C.-C. (2024). Exploring the complex interplay of green finance, business cycles, and energy development. *Energy, 306,* Article 132479. https://doi.org/10.1016/j.energy.2024.132479

42. Vasylieva, T., Kasperowicz, R., Tiutiunyk, I., & Lukács, E. (2023). Transparency and trust in the public sector: Targets and benchmarks to ensure macroeconomic stability. *Journal of International Studies, 16*(4). https://doi.org/10.14254/2071-8330.2023/16-4/8

43. Vorontsova, A., Rieznyk, O., Treus, A., Oleksich, Z., & Ovcharova, N. (2022). Do environmental protection investments contribute to environmentally-oriented SDGS? *Environmental Economics, 13*(1), 141-154. https://doi.org/10.21511/ee.13(1).2022.12

44. Zarnowitz, V. (1992). *Business cycles: Theory, history, indicators and forecasting.* University of Chicago Press: National Bureau of Economic Research, Inc. Retrieved from https://EconPapers.repec.org/RePEc:nbr:nberbk:zarn92-1

APPENDIX A

Applying the Hodrick–Prescott filter in Stata 18

tsset Year (sets the time data structure)
tsfilter hp Ln_GDP_trend = Ln_GDP, smooth(100)
tsfilter hp Applies the HP filter (Hodrick–Prescott filter) to extract the cyclical component from a time series.
Ln_GDP_trend = Ln_GDP Creates a new variable Ln_GDP_trend, which will contain the cyclical component of the original variable Ln_GDP.
smooth(100) Specifies a smoothing parameter of λ = 100. This is a typical value for annual data. The larger the value, the smoother the trend will be.
tsfilter hp Ln_GDP_trend = Ln_GDP, smooth(100)
tsfilter hp Ln_GDPpercapitacurrentUS_trend = Ln_GDPpercapitacurrentUS, smooth(100)
tsfilter hp Ln_ICT_trend = Ln_ICT, smooth(100)
tsfilter hp Ln_Trade_trend = Ln_Trade, smooth(100)
tsfilter hp Ln_N2O_Transport_trend = N2O_Transport, smooth(100)
tsfilter hp Ln_N2O_Industrial_Comb_trend = Ln_N2O_Industrial_Comb, smooth(100)
tsfilter hp Ln_F_from_In_trend = Ln_F_from_In, smooth(100)
tsfilter hp Ln_Carbon_of_GDP_trend = Ln_Carbon_of_GDP, smooth(100)
tsfilter hp Ln_CO2_trend = Ln_CO2, smooth(100)
tsfilter hp Ln_fromEnergy_CO2_trend = Ln_fromEnergy_CO2, smooth(100)
tsfilter hp Ln_CH4_trend = Ln_CH4, smooth(100)
tsfilter hp Ln_Comp_exp_trend = Ln_Comp_exp, smooth(100)
tsfilter hp Ln_GDP_per_unit_trend = Ln_GDP_per_unit, smooth(100)
tsfilter hp Ln_Electricity_trend = Ln_Electricity, smooth(100)
tsfilter hp Ln_Electricity_gas_trend = Ln_Electricity_gas, smooth(100)
tsfilter hp Ln_Electricity_coal_trend = Ln_Electricity_coal, smooth(100)
tsfilter hp Ln_HT_exp_trend = Ln_HT_exp, smooth(100)
tsfilter hp Ln_Comp_exp_trend = Ln_Comp_exp, smooth(100)
tsfilter hp Ln_Internet_trend = Ln_Internet, smooth(100)
tsfilter hp Ln_Secure_trend = Ln_Secure, smooth(100)
tsfilter hp Ln_Renewable_trend = Ln_Renewable, smooth(100)
tsfilter hp Ln_Level_trend = Ln_Level, smooth(100)
tsfilter hp Ln_Water_trend = Ln_Water, smooth(100)
tsfilter hp Ln_GDP_energy_trend = Ln_GDP_energy, smooth(100)
tsfilter hp Ln_Renewable_electricity_trend = Ln_Renewable_electricity, smooth(100)
tsfilter hp Ln_Research_trend = Ln_Research, smooth(100)
tsfilter hp Ln_Employment_trend = Ln_Employment, smooth(100)
tsfilter hp Ln_EmploymentP_trend = Ln_EmploymentP, smooth(100)
tsfilter hp Ln_Agriculturallandofland_trend = Ln_Agriculturallandofland, smooth(100)
tsfilter hp Ln_Forestareaoflandarea_trend = Ln_Forestareaoflandarea, smooth(100)
tsfilter hp Ln_Tradeinservices_trend = Ln_Tradeinservices, smooth(100)
tsfilter hp Ln_Alternative_trend = Ln_Alternative, smooth(100)
tsfilter hp Ln_Merchandiseimports_trend = Ln_Merchandiseimports, smooth(100)
tsfilter hp ICTgoodsexports_trend = ICTgoodsexports, smooth(100)
tsfilter hp Ln_Hightechnologyexports_trend = Ln_Hightechnologyexports, smooth(100)
The calculations extract the cyclical component of the logarithm of GDP using an HP filter with a smoothing parameter of 100, which is suitable for annual data. This allows for the analysis of long-term dynamics of the economy.

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Using the Butterworth BW filter in Stata 18

tsfilter bw Ln_GDP_BW = Ln_GDP
tsfilter bw Applies a BW filter (Butterworth filter) to extract the cyclical component from a time series.
Ln_GDP_BW = Ln_GDP Creates a new variable Ln_GDP_BW that will contain the cyclical component of the original variable Ln_GDP.

```
.tsfilter bw Ln_GDP_BW = Ln_GDP
.tsfilter bw Ln_ICT_BW = Ln_ICT
.tsfilter bw Ln_Trade_BW = Ln_Trade
.tsfilter bw Ln_N2O_Transport_BW = Ln_N2O_Transport
. tsfilter bw Ln_N2O_Industrial_Comb_BW = Ln_N2O_Industrial_Comb
. tsfilter bw F_from_In_BW = F_from_In
. tsfilter bw LN_Carbon_of_GDP_BW = LN_Carbon_of_GDP
. tsfilter bw Ln_CO2_BW = Ln_CO2
. tsfilter bw Ln_fromEnergy_CO2_BW = Ln_fromEnergy_CO2
. tsfilter bw Ln_Comp_exp_BW = Ln_Comp_exp
. tsfilter bw Ln_GDP_per_unit_BW = Ln_GDP_per_unit
. tsfilter bw Ln_Electricity_BW = Ln_Electricity
. tsfilter bw Ln_Electricity_coal_BW = Ln_Electricity_coal
. tsfilter bw Ln_Internet_BW = Ln_Internet
. tsfilter bw Ln_HT_exp_BW = Ln_HT_exp
. tsfilter bw Ln_Secure_BW = Ln_Secure
. tsfilter bw Ln_Electricity_gas_BW = Ln_Electricity_gas
. tsfilter bw Ln_Comp_BW = Ln_Comp
. tsfilter bw Ln_GDP_energy_BW = Ln_GDP_energy
. tsfilter bw Ln_Research_BW = Ln_Research
. tsfilter bw Ln_Renewable_electricity_BW = Ln_Renewable_electricity
. tsfilter bw Ln_Employment_BW = Ln_Employment
. tsfilter bw Ln_EmploymentP_BW = Ln_EmploymentP
. tsfilter bw Ln_Tradeinservices_BW = Ln_Tradeinservices
. tsfilter bw Ln_Alternative_BW = Ln_Alternative
. tsfilter bw LN_Government_BW = LN_Government
```

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APPENDIX B

Extraction of the cyclical component based on the Hodrick-Prescott and Butterworth filter in Stata 18 for the indicators *Merchandise imports (current USD), Methane (CH4) emissions from Waste (Mt CO2e), GDP per unit of energy use (constant 2021 PPP D per kg of oil equivalent) (Ukraine, 1991–2022)*

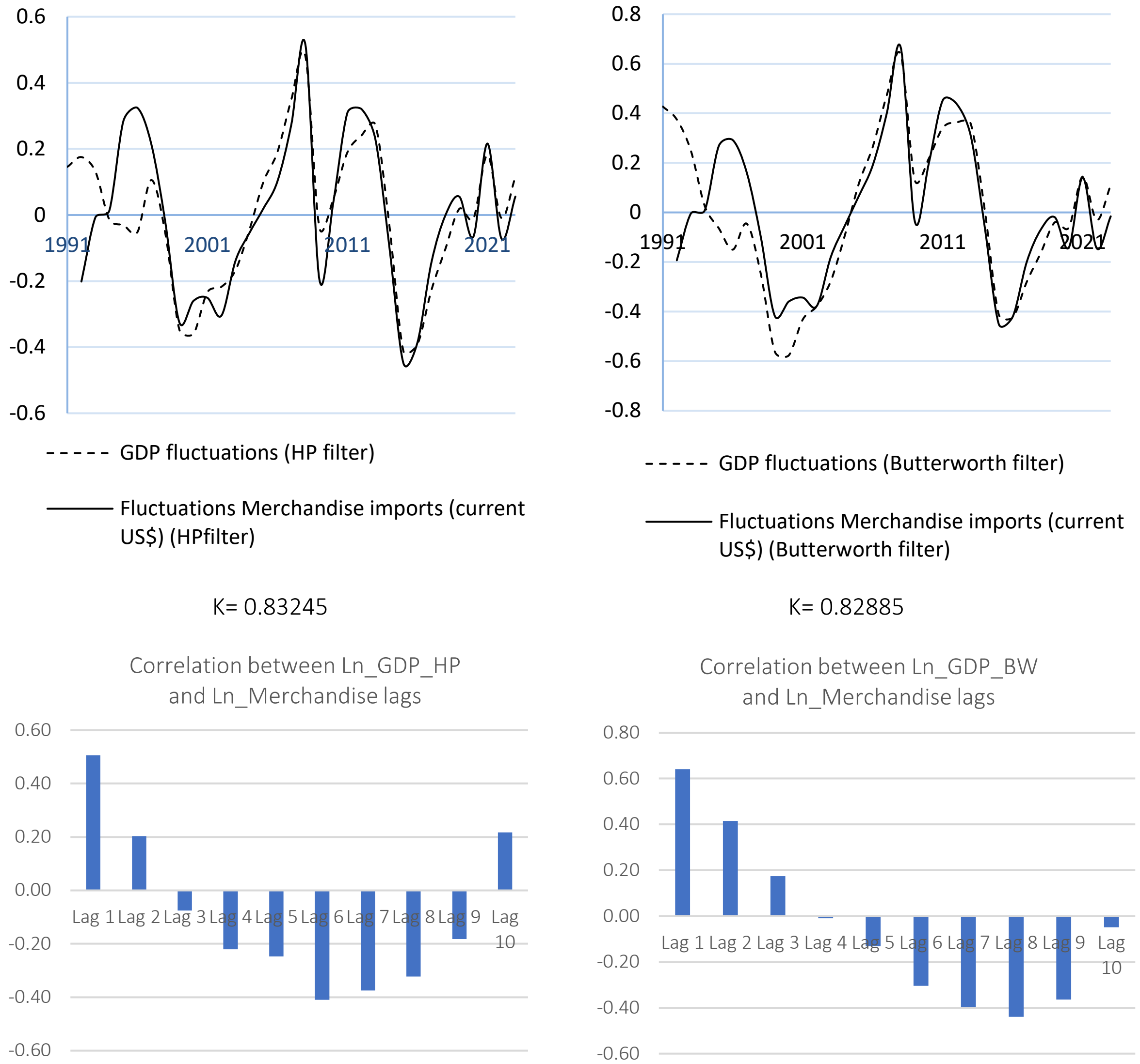

Figure B1. Medium-term fluctuations between merchandize imports (current USD) and GDP per capita (current USD) for Ukraine, 1991–2022

http://dx.doi.org/10.21511/ee.16(4).2025.09

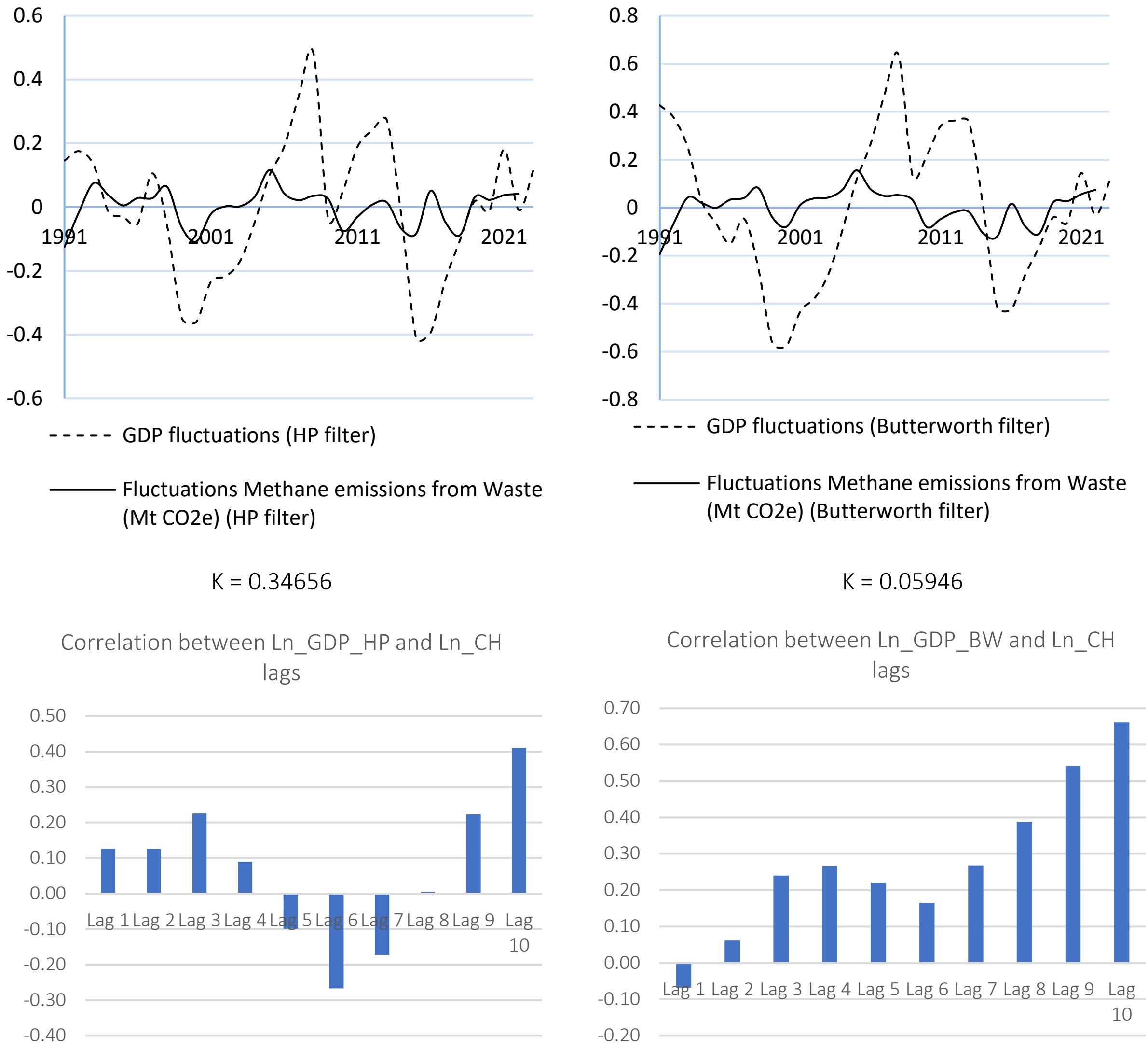

Figure B2. Medium-term fluctuations between methane (CH4) emissions from waste (Mt CO2e) and GDP per capita (current USD) for Ukraine, 1991–2022

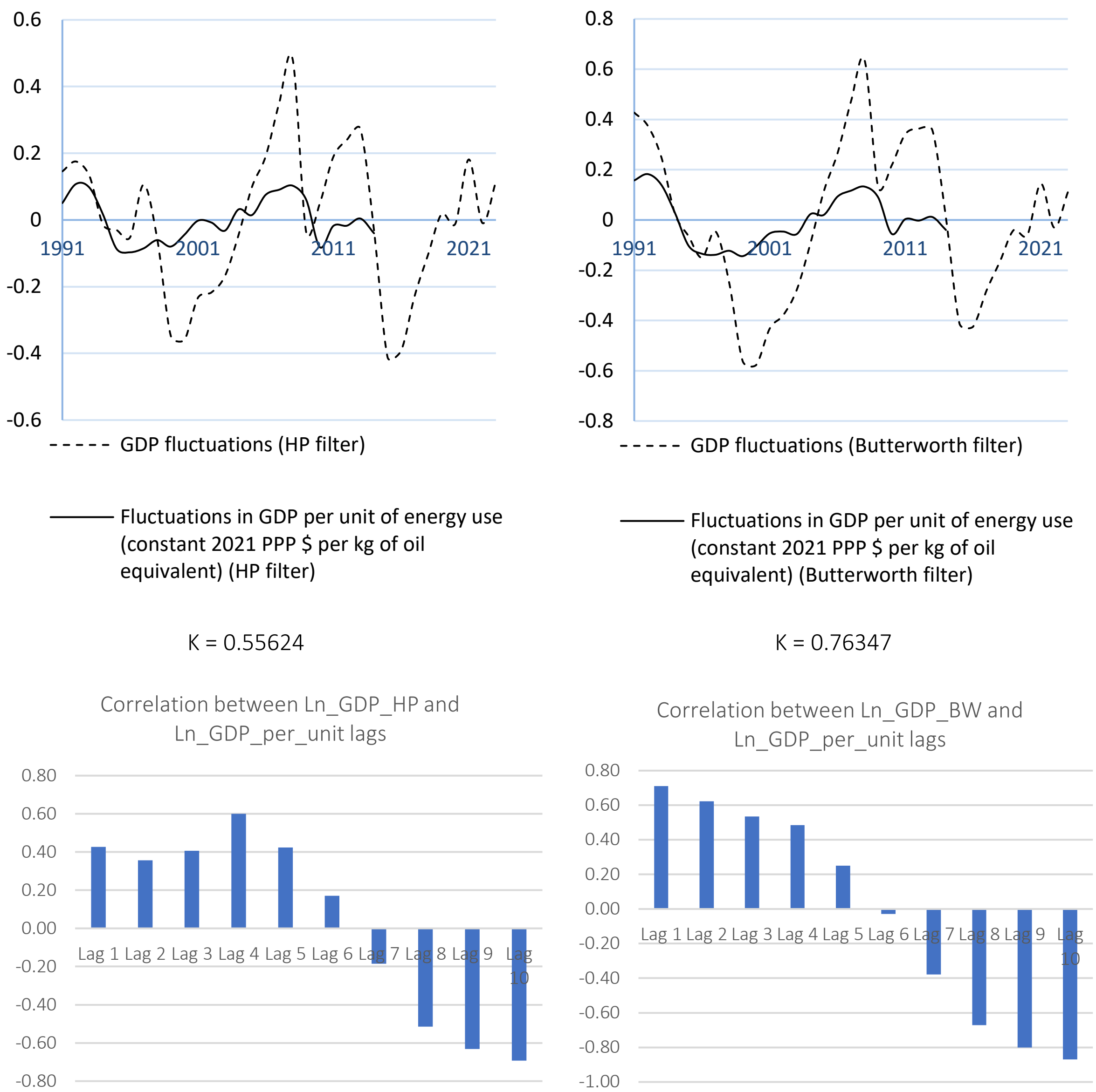

Figure B3. Medium-term fluctuations between GDP per unit of energy use (constant 2021 PPP D per kg of oil equivalent) and GDP per capita (current USD) for Ukraine, 1991–2022

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APPENDIX C

Table C1. Summary table of values of correlation coefficients K (excluding lags) between a set of economic and environmental indicators and GDP per capita (current USD) for Ukraine, 1991–2022

Cyclical component of economic and environmental indicators	HP	BW	CF
ICT goods imports (% total goods imports)	–0.22132931	–0.4055085	–0.4613633
Trade (% of GDP)	–0.51007287	–0.6713209	–0.7000609
Nitrous oxide (N2O) emissions from transport (energy) (Mt CO2e)	0.555775908	0.72190771	0.72301698
Nitrous oxide (N2O) emissions from industrial combustion (energy) (Mt CO2e)	0.396801634	0.57252348	0.57726785
F-gases emissions from industrial processes (Mt CO2e)	0.722967813	0.77480284	0.73424644
Carbon intensity of GDP (kg CO2e per 2021 PPP D of GDP)	–0.40789515	–0.6810005	–0.6212641
Carbon dioxide (CO2) emissions (total) excluding LULUCF	0.551911806	0.7008872	0.67900333
Carbon dioxide (CO2) emissions from fugitive emissions (energy) (Mt CO2e)	0.256692381	0.22849525	0.34163065
Methane (CH4) emissions from waste (Mt CO2e)	0.346559559	0.05945658	0.11179763
Computer, communications and other services (% of commercial service exports)	–0.36029377	–0.3920454	–0.332624
GDP per unit of energy use (constant 2021 PPP D per kg of oil equivalent)	0.556235099	0.76347411	0.83782516
Electricity production from renewable sources, excluding hydroelectric (kWh)	0.267646131	0.213556	0.43757556
Electricity production from natural gas sources (% of total)	–0.08333514	–0.3492894	–0.2601308
Electricity production from coal sources (% of total)	0.377271469	0.57683889	0.55426432
High-technology exports (% of manufactured exports)	–0.48904039	–0.4806926	–0.2092724
Computer, communications and other services (% of commercial service imports)	–0.16320141	–0.3316704	–0.4251256
Individuals using the Internet (% of population)	–0.2101842	–0.2775391	–0.4410665
Secure Internet servers	–0.28711426	–0.4416494	–0.6407965
GDP per unit of energy use (PPP D per kg of oil equivalent)	0.544464279	0.75509661	0.78793777
Renewable electricity output (% of total electricity output)	–0.02637319	–0.2166365	–0.1594906
Research and development expenditure (% of GDP)	0.286091011	0.46699268	0.48745222
Employment to population ratio, ages 15-24, total (%) (modeled ILO estimate)	0.353414276	0.55313395	0.52365079
Employment to population ratio, 15+, total (%) (national estimate)	0.06254549	0.08840845	0.13775794
Trade in services (% of GDP)	–0.62969789	–0.5983058	–0.6154264
Alternative and nuclear energy (% of total energy use)	–0.14889484	–0.5115123	–0.4699598
Government expenditure on education, total (% of GDP)	0.450277561	0.63162749	0.76377598
Merchandize imports (current USD)	0.83245037	0.82884684	0.82003858
ICT goods exports (% of total goods exports)	–0.05265809	0.00550155	0.13247862
High-technology exports (current USD)	0.58300695	0.55178348	0.65297689