Tudorache, Maria-Daniela; Jianu, Ionut

Conference Paper — Published Version

The Nexus Between Technology and Economic Development in the European Union

The Nexus Between Technology and Economic Development in the European Union

Maria-Daniela Tudorache[1] and Ionuț Jianu[2]
[1)2)] *Bucharest University of Economic Studies, Bucharest, Romania.*
E-mail: daniela.tudorache@economie.ase.ro; E-mail: ionut.jianu@economie.ase.ro

Please cite this paper as:
Tudorache, M.D., & Jianu, I. (2026). The Nexus Between Technology and Economic Development in the European Union. In C. Vasiliu, D.-C. Dabija, A. Tziner, D. Pleșea, & V. Dinu (Eds.), *Proceedings of BASIQ International Conference on New Trends in Sustainable Business and Consumption, 12th Edition* (pp. 24-31). Editura ASE.
DOI **10.24818/BASIQ/2026/12/029**

Abstract

Over the last two decades, technological progress has significantly transformed economic and social structures, making innovation and digitalization essential drivers of competitiveness and sustainable growth. However, EU still lags behind the US in terms of innovation, research and development expenditure. This paper examines the relationship between technological factors and economic development in European Union Member States. The analysis is based on panel data covering 2010-2024, with an effective estimation sample of 2012-2024 due to lag structure and first difference transformations to improve the model accuracy. The analysis applies the Panel Estimated Generalized Least Squares (EGLS) method, using Period SUR as GLS weights option and as a coefficient covariance method. The results identify positive and significant associations between the research and development expenditure / employment in technology and knowledge intensive sectors and GDP per capita. In contrast, unemployment shows a negative relationship with economic performance. These findings highlight the important role of innovation and knowledge-based sectors in supporting economic growth and competitiveness within the European Union. The results suggest that research and development activities are associated with higher levels of economic development across the European Union. This finding is particularly relevant in the current context, given that the European Union has consistently failed to meet its R&D expenditure targets throughout the 2010–2024 period, with the share of R&D expenditure in GDP increasing by only 0.25 percentage points over the last 15 years. We also calculated the impact of greenhouse gas emissions per capita on GDP per capita, which was found to be positive, indicating the short-run cost of the green transition, as well as the negative effect of the major COVID-19 restriction on GDP per capita.

Keywords:

Technology, economic development, Panel, research and development

DOI: 10.24818/BASIQ/2026/12/029

Introduction

Economic development refers to the process through which the quality of life of individuals in a country or region improves as a result of structural changes such as industrialization, the attraction of foreign investment, and the development of infrastructure. One of the most used indicators for measuring economic development is GDP (Gross Domestic Product) per capita, expressed in purchasing power standard (PPS). However, development also has social implications, it being reflected in unemployment, employment, poverty, and level of education.

The last decades have shown that technology plays an important role in the process of economic development (Khan et al., 2025; Lu et al., 2025). Technology has contributed to greater labour productivity by replacing repetitive work and making the production process more efficient. In addition, research contributes to technological progress and, implicitly, to economic growth.

The COVID-19 pandemic has also shown that technology supported the continuation of economic activities, some companies moving their activity to a teleworking system (Anik and Habib, 2023), including teaching activities for students that have been carried out online.

The motivation for choosing the topic lies in the challenges faced by the EU in the field of technology, in particular in the research and development sector, which raises the need for quantitative assessments regarding the impact of technological progress on economic development. The main objective of our work is the examination of the short-term relationship between economic development and technology, it depending on the following specific objectives: estimating the impact of research and development expenditure on economic development; identifying the impact of the employment in technology and knowledge intensive sectors on economic development; analysing the feasibility of the results.

In this study, we used research and development expenditure as a proxy for technological development, considering the potential of innovation to enhance technological progress, while the indicator related to employment in technology and knowledge-intensive sectors was included to capture the technological preparedness of employees. In addition, GDP per capita expressed in purchasing power standard (PPS) was used as a proxy for economic development due to its widespread use in quantitative assessments.

The first part of the paper presents the relevant literature for the chosen topic. Subsequently, we presented the methods used to estimate the impact, while the results and discussion section presents the econometric results obtained. Within the last section we presented the main findings and limits.

1. Review of the scientific literature

Investment in research and development (R&D) contributes directly to the economic growth of a country. In recent decades, technological advancements have significantly contributed to the development of various economic sectors, thereby fostering economic expansion and enhancing social welfare. The Solow (1956) economic growth model analyses how technological progress, along with the accumulation of capital and labour, influence long-term economic growth. Furthermore, the endogenous economic growth model of Romer (1990), and later extended by Acemoglu et al. (2018), highlights the important role of technology in economic development.

In the economic literature, researchers have identified a positive relationship between R&D expenditure and gross domestic product (Bloom et al., 2013; Guttierrez-Sanchez & Beneitez-Andreas, 2025; Harrison et al., 2014), as well as its role in stimulating employment growth (Avenyo et al., 2019; Bogliacino et al., 2012; Harrison et al., 2014). However, public funding may, in some cases, crowd out private sector investment, particularly when it is not effectively allocated to high-potential areas (Bilbao-Osorio & Rodriguez-Pose, 2004). At the same time, Chmielewski et al. (2025) argue that an increase in public R&D spending contributes to an overall improvement in social indicators.

Magoutas et al. (2024) examine the relationship between technology and economic development in the member states of the European Union, finding that innovation and technologies have a strong impact on GDP and implicitly on the business sector, demonstrating the need to strengthen human capital in the growth of e-government technologies.

With regard to employment in technology-related fields, Garcia-Romanos & Martinez-Ros (2024) identify a positive relationship between this indicator and GDP, suggesting that it contributes to economic growth alongside investments in R&D and ICT infrastructure.

According to OECD (2023a), countries that invest substantially in research and development (Germany, United States, South Korea) create industries with value in the economy, together with tax incentives lead to the reduction of greenhouse gas emissions, economic resilience and digital transition (OECD, 2023b).

The European Green Deal represents a commitment by European Union member states to set ambitious targets for reducing greenhouse gas emissions by 2030, combining climate action with economic growth and social welfare measures (European Commission, 2020). The relationship between greenhouse gas emissions and GDP has been intensely debated, with a positive relationship found between greenhouse gas emission reductions and GDP per capita (Arnandiani, 2024; Furkan at al., 2023; Jianu et al., 2022; Ozturk & Acaravci, 2010; UNCTAD, 2025; Yilmaz, 2025). On the other hand, Singh (2024) argues that in developed economies, GDP growth has historically been accompanied by high levels of greenhouse gas emissions, followed by a decline. In contrast, in developing economies, the trajectories of GDP growth and greenhouse gas emissions tend to diverge (Albanese et al., 2025; Zeraibi et al, 2022).

Based on the Kuznets curve, according to which income inequality affects economic growth (Kuznets, 1955), Grossman & Krueger (1991) applied this theory to see how the growth of GDP per capita is influenced by greenhouse gas emissions, taking into account the pace of pollution and development. The results observed were that technological development that produces economic growth leads to increased pollution, but at a certain threshold of economic growth, the need to protect the environment arises, which generates investments to stimulate economic growth.

The COVID-19 pandemic has affected all countries in the world, both economically and socially. As a result of the measures imposed to limit the spread of the coronavirus infection, some economic activities have been suspended or have operated at reduced capacity during the pandemic, causing unemployment, which has led to an economic contraction, implicitly to a reduction in GDP/capita (Boyd et al., 2025; Chong et al., 2020; Gagnon et al., 2023; Koning & Winkler, 2021)

Regarding the relationship between the unemployment rate and GDP, according to Okun's law, an increase in unemployment by 0.3 percentage points leads to a decrease in real GDP by one percentage point (Okun, 1962). Since the emergence of Okun's law, this relationship has been observed by numerous researchers (An et al., 2019; Ball et al., 2014; Foroni & Furlanetto, 2022; Karlsson & Osterholm, 2020), being considered a useful reference in public policies. At the same time, it is worth noting that high unemployment rates lead to inefficient use of resources, which leads both in the short and long term to a reduction in GDP / capita (Naji Meidani & Zabihi. 2011).

2. Research methodology

In order to assess the relationship between technology and economic development, we selected three main indicators in line with the economic literature, respectively research and development expenditure, employment in technology / knowledge intensive sectors and GDP per capita expressed in purchasing power standard (PPS), all variables being extracted from Eurostat for all European Union Member States, while covering the period 2010-2024.

Prior to the impact assessment, we tested the stationarity of the data using five tests, as follows: (i) Levin, Lin & Chu t*; (ii) Breitung t-stat; (iii) Lm, Pesaran and Shin W-stat; (iv) Augmented Dickey-Fuller – Fisher Chi-square; (v) PP – Fisher Chi-square. However, when the results did not provide a clear decision (a clear number of tests supporting stationarity hypothesis) on stationarity, we put a greater emphasis on the results provided by the Phillips-Perron and Augmented Dickey-Fuller tests. Following the stationarity checking process, we found that all selected variables are stationary at I(1), which raises the need to use the first difference of each variable in the model.

Considering the characteristics of the dataset, respectively the potential presence of heteroscedasticity and contemporanous correlation across cross-sections, we used Panel EGLS adjusted with Period SUR as a weighting method and coefficient covariance technique. The Period SUR weighting method was used to improve the efficiency of the impact coefficients in the presence of cross-sectional heterogeneity. Moreover, taking into account the scope of the paper to explore the short-term relationship between technological indicators and economic development, the EGLS method was considered more appropriate for assessing the association between the mentioned indicators.

In this respect, we applied the Panel Estimated Generalized Least Squares method (using Period SUR as a weighting method and as a coefficient covariance technique) on the following equation to estimate the impact mentioned above over the period 2012-2024 at EU level (2 year observations per country have been withdrawn from the model as a consequence of the first difference transformations and of the first autoregressive term inclusion, resulting in a final Panel sample of 351 observations):

$$D(LOGGDP\_PC\_PPS)_{it} = \alpha_0 + \alpha_1 D(LOGRD\_EXP\_PC)_{it} + \alpha_2 COVID_{it} + \alpha_3 D(LOGGHGEMPC)_{it} + \alpha_4 D(TECH\_EMPL)_{it} + \alpha_5 D(LOGGDP\_PC\_PPS(-1))_{it} + \alpha_6 D(LOGUNEM) + \varepsilon t \quad (1)$$

where:

- *it* indicates the analysed country and year;
- *D(LOGGDP_PC_PPS)* reflects the first difference of the natural logarithm of the GDP per capita expressed in purchasing power standard, while the *D(LOGGDP_PC_PPS(-1))* is the dependent variable lagged by one year;
- *D(LOGRD_EXP_PC)* is the first difference of the natural logarithm of the research and development expenditure per capita;

- *COVID* represents the dummy COVID crisis shock variable, where 1 has been attributed to the year when major restrictions were applied (2020 - excepting Sweden for that country - the restrictions being less stringent);
- *D(LOGGHGEMPC)* reflects the first difference of the natural logarithm of greenhouse gas emissions per capita;
- *D(TECH_EMPL)* is the first difference of the employment in technology and knowledge intensive sectors share in total employment;
- *D(LOGUNEM)* represents the first difference of the natural logarithm of number of unemployed persons;
- α_0 is the coefficient of the constant term, α_{1-6} are the coefficients of the independent variables, while εt is the error term.

The selected explanatory variables were chosen based on the existing economic literature on technological development and growth. In particular, research and development expenditure reflects the innovation intensity, its effect on spreading technological development being influenced by the efficiency of these investments, while the employment in technology and knowledge-intensive sectors captures technological specialization. The greenhouse gas emissions explore the economic consequences of the green transition, unemployment rate catch the labour market developments, while COVID-19 dummy variable addresses the structural break issue caused by the COVID-19 crisis.

Further, we performed additional tests to check the accuracy of the model, as: (i) R-squared; (ii) significance of the coefficients; (iii) Fisher test – statistical validity; (iv) Durbin Watson test - autocorrelation of the residuals; (v) Jarque-Bera test – distribution of the residuals; (vi) Breusch-Pagan LM – cross-section dependence; (vii) Variance Inflation Factors test – multicollinearity.

3. Results and discussion

The data analysed show a positive relationship between technological indicators and economic development, but also a positive effect of the greenhouse gas emissions on the dependent in the short-run. To this end, according to Figure no. 1, we found that the increase in the R&D expenditure per capita by 1% in the period 2012-2024 was associated with an increase in the GDP / per capita (PPS) by 0.109%, this highlighting the important role of research and development expenditure in boosting economic development. This finding is consistent with other studies reflecting the contribution of research and development expenditure to productivity and economic development.

Dependent Variable: D(LOGGDP_PC_PPS)
Method: Panel EGLS (Period SUR)
Date: 03/09/26 Time: 00:26
Sample (adjusted): 2012 2024
Periods included: 13
Cross-sections included: 27
Total panel (balanced) observations: 351
Linear estimation after one-step weighting matrix
Period SUR (PCSE) standard errors & covariance (d.f. corrected)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOGRD_EXP_PC)	0.109193	0.009045	12.07250	0.0000
C	0.031846	0.001638	19.44678	0.0000
COVID	-0.043002	0.004816	-8.928359	0.0000
D(LOGGHGEMPC)	0.105593	0.016526	6.389371	0.0000
D(TECH_EMPL)	0.006526	0.002963	2.202297	0.0283
D(LOGGDP_PC_PPS(-1))	0.128426	0.019975	6.429331	0.0000
D(LOGUNEM)	-0.060483	0.008347	-7.246097	0.0000

Weighted Statistics

R-squared	0.572313	Mean dependent var	1.454234
Adjusted R-squared	0.564853	S.D. dependent var	1.996346
S.E. of regression	0.975482	Sum squared resid	327.3385
F-statistic	76.72113	Durbin-Watson stat	2.034266
Prob(F-statistic)	0.000000		

Figure no. 1. Results of the model

The relatively small coefficient indicates that the technological preparedness of employees, when considered independently, may not be sufficient to generate a significant boost in economic development, highlighting the need for a more appropriate combination of high-tech skills, research and development expenditure, and new technologies endowment.

However, some progress in terms of economic development has been delayed in the period of COVID crisis, the major restrictions reducing GDP per capita (PPS) by 4.2% in European Union Member States. With a view to the impact of pollution, we found a short-term impact of 0.105% on the GDP per capita (PPS) at a 1% increase in the greenhouse gas emission, which reflects the short-term economic cost of green transition. This effect shows that the economic reality itself still favors pollution and environmental degradation on short term, while the transition to a climate neutral economy remains a real challenge.

Our results also indicate a positive impact of the GDP per capita (PPS) on the value that this indicator will reach next year. To this scope, our estimation shows that an increase in the GDP per capita (PPS) by 1% in the preceding year was associated to a growth of 0.128% in the current year GDP per capita (PPS) value, this effect suggesting persistence in GDP path over time. The last coefficient estimated was the one specific to unemployment, for which we found a 0.060% decrease in the GDP per capita (PPS) at a 1% increase in the number of unemployed individuals during the analysed period.

All calculated coefficients are significant at 1% significance threshold (including constant, in its case, GDP per capita increasing by 0.031% if all analysed factors remain constant which indicates that, there are also other factors driving the dependent variable, that were not taken into account), excepting the one specific to the employment in the technology sector, which is significant at 5%. In addition, the standard errors are quite low which does not endanger the adequacy of the coefficients.

Moreover, the R-squared value indicates that the evolution of the independent variables explains 57.23% of the GDP per capita (PPS) fluctuation, highlighting that the model did not cover all explanatory factors of the dependent variable. Our calculations also confirmed that the model is statistically valid, since the probability of the Fisher test is lower than 5%, while the result of the Durbin-Watson stat stands between DU and 4-DU, indicating the absence of autocorrelation between residuals.

According to Figure no. 2, we found a probability of 5.46% of the Jarque-Bera test, which confirms the normal distribution of the residuals. Even if the probability is quite close to the 5% threshold, we also considered the values of the Kurtosis and Skewness which are close to 3 and 0, these being the relevant thresholds.

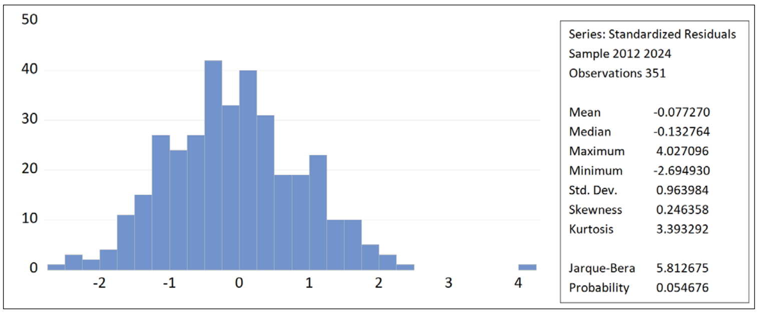

Figure no. 2. Distribution of the residuals

To examine the cross-section dependence which may affect the results if it is present, we run the Breusch-Pagan LM (prob. of 99%), which confirmed the absence of this issue. Next, we analysed the existence of multicollinearity at the level of the estimated model using Variance Inflation Factors. However, the results confirmed its absence, considering the values of the centered VIF coefficients which are lower than 4, this being the accepted threshold for accepting or rejecting the multicollinearity threshold, Table no. 1.

Table no. 1. Multicollinearity test - Variance Inflation Factors

Variable	Centered VIF coefficients
D(LOGRD_EXP_PC)	1.037760
COVID	1.098943
D(LOGGHGEMPC)	1.098056
D(TECH_EMPL)	1.054064
D(LOGGDP_PC_PPS)	1.086749
D(LOGUNEM)	1.081420

The tests performed confirm the consistency of the estimators, while the coefficients obtained support the important role of innovation in boosting economic development in the short-run, but also the short-term high cost of green transition, which should be properly taken into account in designing green transition policies.

Nevertheless, the estimated coefficients should be interpreted with caution, given the potential presence of reverse causality and omitted explanatory variables, as also suggested by the moderate R-squared value of the model.

Conclusions

Our analysis confirmed the positive impact of technology on economic development. However, our study does not reflect all technological factors and is focusing exclusively on research and development expenditure and employment in technology and knowledge intensive sectors.

The results show a positive association between research and development expenditure per capita and GDP per capita (expressed in purchasing power standard). Regarding the relationship between employment in technology and knowledge-intensive sectors and economic development, we found a positive but modest association during the analysed period, which may suggest that high-tech skills alone are insufficient to significantly boost economic development. However, combining this effect with the strong potential of research and development activities may generate positive effects across the European Union.

Our finding is even more relevant for the current times, since European Union does not succeeded in meeting its research and development expenditure target from 2010 until 2024, its share in GDP increasing only by 0.25 pp of GDP in the last 15 years (from 1.96% of GDP in 2010 to 2.21% of GDP in 2024). To this end, more efforts should be made to increase the national research and development expenditure, but in a qualitative manner.

The paper also confirms a negative relationship between unemployment and GDP per capita expressed in PPS, this finding being in line with Okun's law, as well as with the negative shock generated by the major COVID-19 restrictions on economic development. Regarding the relationship between greenhouse gas emissions per capita and the dependent variable, we found a positive association, reflecting the short-term economic cost of the green transition in terms of economic development.

Nevertheless, our results operate within certain limits. In this context, there is a need to mention that the findings should be interpreted at the aggregate EU level and not as country-specific effects. To address this issue, in our further studies we will try to accommodate a Panel ARDL/PMG model to obtain the impact at country-level or other techniques to isolate the country-specific effects such as dummy variables per country. Moreover, further research could include additional explanatory factors of economic development such as, institutional factors, human capital variables or other technological indicators (including factors related to digitalisation).

Generative Artificial Intelligence (GenAI) usage statement:
No GenAI tool was used in the development of this paper.

References

Acemoglu, D., Akcigit, U., Bloom, N., & Kerr, W.R. (2018). Innovation, reallocation, and growth. *American Economic Review*, 108 (11), 3450-3498. https://doi.org/10.1257/aer.20130470.

Albanese, M., Busato, F., Ulloa Severino, C., & Varlese, M. (2025). Exploring the link between economic growth and GHG emissions: insights from BRICS+ and beyond. *MPRA Paper no. 123550*., from https://mpra.ub.uni-muenchen.de/123550/

An, Z., Ball, L., Jalles, J., & Loungani, P. (2019). Do IMF forecasts respect Okun's law? Evidence for advanced and developing economies. *International Journal of Forecasting*, 35 (3), 1131-1142. https://doi.org/10.1016/j.ijforecast.2019.03.001

Anik, M.A., & Habib, M.A. (2023) , COVID-19 and Teleworking: Lessons, Current Issues and Future Directions for Transport and Land-Use Plannig. *Journal of the Transportation Research Board*, 2676 (12), https://doi.org/10.1177/03611981231166384

Arnandiani, N. (2024). The impact of GDP per capita, trade openness, environmental policy stringency, population and renewable energy consumption on carbon emissions in the BRICS, 1990-2020. *Proceedings of the International conference of Economics Business and Economics Education Science*

(ICE-BEES-24), series Advances in Economics, Business and Management Research 298. https://doi.org/10.2991/978-94-6463-522-5_60

Avenyo, E.K., Konte, M., & Mohnen, P. (2019). The employment impact of product innovations in sub-Saharan Africa: firm-level evidence. *Research Policy*, 48 (9), 103806. https://doi.org/10.1016/j.respol.2019.103806

Ball, L., Jalles, J.T., & Loungani, P. (2014). Do forecasters believe in Okun's Law? An assessment of unemployment and output forecasts. *IMF Working Paper*, WP/14/24., from https://www.imf.org/external/pubs/ft/wp/2014/wp1424.pdf

Bilbao-Osorio, B., & Rodrigues-Pose, A. (2004). From R&D to innovation and economic growth in the EU. *Growth Change*, 35, 434-455. https://doi.org/10.1111/j.1468-2257.2004.00256.x

Bloom, N., Schankerman, M., & Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry. *Econometrica*, 81 (4), 1347-1393. https://doi.org/10.3982/ECTA9466

Boyd, M., Baker, M.G., Kvalsvig, A., & Wilson, N. (2025). Impact of Covid-19 control strategies on heath and GDP growth outcomes in 193 sovereign jurisdictions. *PLOS Global Public Health*, 5 (10), e0004554. https://doi.org/10.1371/journal.pgph.0004554

Bogliacino, F., Piva, M., & Vivarelli, M. (2012). R&D and employment: an application of the LSDVC estimator using European microdata. *Economics Letters*, 116 (1), 56-59. https://doi.org/10.1016/j.econlet.2012.01.010

Chmieleesky, W., Postula, M., & Gawkowski, K. (2025). Linking R&D expenditure to labour market and economic performance: empirical evidence from the European Union. *Sustainability*, 17 (14), 6596. https://doi.org/10.3390/su17146595

Chong, T.T.L., Li, X., & Yip, C. (2020). The impact of COVID-19 on ASEAN. *Economic and Political Studies*, 9, (2), 166-185. https://doi.org/10.1080/20954816.2020.1839166

European Commission (2020). Committing to climate-neutrality by 2050: Commission proposes European Climate Law and consults on the European Climate Pact. Retrieved March 12, 2026, from https://ec.europa.eu/commission/presscorner/detail/en/ip_20_335

Eurostat. (2026). Eurostat database., from https://ec.europa.eu/eurostat/data/database

Foroni, C. & Furlanetto, F. (2022). Explaining deviations from Okun's law. *Working Paper Series*, no. 2699/August 2022, European Central Bank., from https://www.ecb.europa.eu/pub/pdf/scpwps/ecb.wp2699~a1985f19ed.en.pdf

Furkan, H., B., Hasan, K.M.R.H., & Uddin, M.J. (2023). Greenhouse gas emission, GDP, tertiary education, and rule of law: a comparative study between high-income and lower-middle income countries. *Heliyon*, 9(6), e16265. https://doi.org/10.1016/j.heliyon.2023.e16265

Gagnon, J.E., Kamin, S.B., & Kearns, J. (2023). The impact of the COVID-19 pandemic on global GDP growth. Journal of the Japanese and International Economies, 68, 101258. https://doi.org/10.1016/j.jjie.2023.101258

Garcia-Romanos, J., & Martinez-Ros, E. (2024). Digitalization and employment in Europe: the role of firm's size and the complementarity of R&D. *R&D Management*, 54 (4), 695-712. https://doi.org/10.1111/radm.12656

Grossman, G.M., & Krueger, A.B. (1991). Environmental impacts of a North American free trade agreement. *NBER working papers series*, 3914. https://doi.org/10.3386/w3914

Guttierrez-Sanchez, G., & Beneitez-Andres, E. (2025). The impact of R&D investment on economic growth: evidence from Panama using elastic net and bootstrap techniques. *Economies*, 13 (10), 293. https://doi.org/10.3390/economies13100293

Harrison, R., Jaumandreu, J., Mairesse, J., & Peters, B. (2014). Does innovation stimulate employment? A firm-level analysis using comparable micro-data from four European countries. *International Journal of Industrial Organization*, 35, 29-43. https://doi.org/10.1016/j.ijindorg.2014.06.001

Jianu, I., Jeloaica, S.M., & Tudorache, M.D. (2022). Greenhouse gas emissions and its main drivers: a panel assessment for EU-27 member states. *American International Journal of Business Management*, 5 (4), 138-146. https://doi.org/10.48550/arXiv.2205.00295

Karlsson, S., & Osterholm, P. (2020). A hybrid time-varying parameter Bayesian VAR analysis of Okun's law in the United States. *Economics Letters*, 197, 109622. https://doi.org/10.1016/j.econlet.2020.109622

Khan, A., Khan, T., & Ahmad, M. (2025). The role of technological innovation in sustainable growth: Exploring the economic impact of green innovation and renewable energy. *Environmental Challenges*, 18, 101109. https://doi.org/10.1016/j.envc.2025.101109

Koning, M., & Winkler, A. (2021). The impact of government responses to the COVID-19 pandemic on GDP growth: Does strategy matter?. *PLOS ONE*, 16 (11), e0259362. https://doi.org/10.1371/journal.pone.0259362

Kuznets, S. (1955). Economic growth and income inequality. *American Economic Review*, 45, 191-224., from https://assets.aeaweb.org/asset-server/files/9438.pdf

Lu, Y.F., Ahmad, S., Noureen, S., & Salman, M. (2025). Green growth and sustainable energy transitions: evaluating the critical role of technology, resource efficiency, and innovation in Europe's low-carbon future. Humanities & Social Sciences Communications, 12 (1), 1527. https://doi.org/10.1057/s41599-025-05823-7

Magoutas, A.I., Chaideftou, M., Skandali, D., & Chountalas, P.T. (2024). Digital progression and economic growth: analyzing the impact of ICT advancements on the GDP of European Union Countries. *Economies*, 12 (3), 63. https://doi.org/10.3390/economies12030063

Naji Meidani, A.A., & Zabihi, M. (2011). The dynamic effect of unemployment rate on per capita real GDP in Iran. *International Journal of Economics and Finance*, 3 (5), 170-177. https://doi.org/10.5539/ijef.v3n5p170

OECD (2023a). Main science and technology indicators. Retrieved March 11, 2026, from https://www.oecd.org/en/data/datasets/main-science-and-technology-indicators.html

OECD (2023b). OECD science, technology and innovation outlook 2023: Enabling transitions in times of disruption. Retrieved March 11, 2026, from https://www.oecd.org/en/publications/oecd-science-technology-and-innovation-outlook-2023_0b55736e-en.html

Okun, A. (1962). Potential GNP: Its measurement and significance. *Proceedings of the Business and Economics Statistics Section of the American Statistical Association*, 98-104.

Ozturk, I., & Acaravci, A. (2010). CO2 emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews*, 14 (9), 3220-3225. https://doi.org/10.1016/j.rser.2010.07.005

Romer, P.M. (1990). Endogenous technological change. *Journal of Political Economy*, 98 (5), S71-S102.

Singh, S. (2024). The relationship between growth in GDP and CO2 has loosened; it needs to be cut completely. Retrieved March 19, 2026, from https://www.iea.org/commentaries/the-relationship-between-growth-in-gdp-and-co2-has-loosened-it-needs-to-be-cut-completely

Solow, R.M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics*, 70 (1), 65-95. https://doi.org/10.2307/1884513

UNCTAD (2025). GDP and CO2 emissions: Record temperatures heighten urgency to break the link. Retrieved March 19, 2026, from https://unctad.org/news/gdp-and-co2-emissions-record-temperatures-heighten-urgency-break-link

Yilmaz, S. (2025). The impact of environmental protection expenditures on reducing greenhouse gas emissions. *Sustainability*, 17 (7), 3192. https://doi.org/10.3390/su17073192

Zeraibi, A., Ahmed, Z., Shehzad, K., Murshed, M., Nathaniel, S.P., & Mahmood, H. (2022). Revisiting the EKC hypothesis by assessing the complementarities between fiscal, monetary, and environmental development policies in China. *Environmental Science and Pollution Research*, 29 (16), 23545-23560. https://doi.org/10.1007/s11356-021-17288-7