FREE NETWORK
#AcademicsStandWithUkraine
POLICY BRIEF SERIES

Natalja Apanasovich, BEROC
Tatiyana Apanasovich, The George Washington University
April 2024

The Impact of Technological Innovations and Economic Growth on Carbon Dioxide Emissions

This policy brief offers an examination of the interplay between economic growth, research, and development (R&D), and CO_2 emissions in different countries. Analysing data for 83 countries over three decades, our research reveals varying impacts of economic and R&D activities on CO_2 emissions depending on country income level. While increased economic growth often leads to higher emissions due to greater industrial activity, our model indicates that increased GDP levels, when interacted with enhanced investments in R&D, is associated with reduced CO_2 emissions. Our approach also recognizes the diverse economic conditions of countries, allowing for a more tailored understanding of how to tackle environmental challenges effectively.

Technological Innovation and CO_2 Emissions

Human activity has over the past few decades significantly contributed to environmental problems, in particular CO_2 emissions. The consequences from increased CO_2 emissions, such as global warming and climate change, have motivated extensive research focused on understanding their impact and finding potential solutions to associated issues.

Economic growth, and research and development (R&D) can serve as differentiating factors between countries when it comes to their pollution levels, specifically measured by CO_2 emissions per capita. Higher levels of economic growth are associated with increased industrial activity and energy consumption, which may lead to increased CO_2 emissions. At the same time, countries that invest more in R&D often focus on developing cleaner technologies and implementing sustainable practices, which may result in reduced CO_2 emissions.

In this policy brief, we analyse CO_2 emissions' dependencies on technological innovation and economic growth. For our analysis we group the considered 83 countries into three wealth levels: High, Upper Middle, and Lower Middle income levels. This grouping facilitates a better understanding of the complex interplay between wealth, innovation and growth and their projection into emissions. Considering each wealth level group separately also allows us to account for varying economic and developmental contexts.

Data

Based on data availability, we analyse 83 countries, spanning from 1996 to 2019, inclusive. We follow current research trends and use R&D intensity as a proxy for technological innovation (see Chen & Lee, 2020; Petrović & Lobanov, 2020; Avenyo & Tregenna, 2022).

Data on energy use originate from Our World in Data. R&D data from after 2014 are based on figures from the UNESCO Institute for Statistics. All other indicators come from World Development Indicators (WDI).

Table 1 presents an overview of the variables considered in our empirical model. Our response variable is CO_2 emissions per capita. We include several covariates (i.e. urban population, renewable energy, trade), found to be significant in previous studies where CO_2 emissions was considered the dependent variable (Avenyo & Tregenna, 2022; Wang, Zeng & Liu, 2019; Petrović & Lobanov, 2020; Chen & Lee, 2020).

Table 1. Variable description.

Variable	Description/units of measurement
CO2	CO_2 emissions (metric tons per capita)
GDP	GDP per capita (US dollars)
R&D	R&D expenditure (% of GDP)
Trade	% of GDP
Renewable energy consumption	% of total final energy consumption
Medium and high-technology value added	% of total manufacturing
Urban population	% of total population
Energy Use	kg of oil equivalent per capita

Additionally, we include quadratic terms for GDP and R&D to account for nonlinearity and non-monotonicity. Also, we incorporate the interaction term between GDP and R&D (see Table 3). This allows us to evaluate whether the impact of technological innovations on CO2 emissions is dependent on the GDP level, or vice versa.

Wealth Level Classification

Existing literature highlights significant variation between countries in terms of economic growth and income levels, particularly in relation to R&D expenditure and CO_2 emission levels (see Cheng et al., 2021; Chen & Lee, 2020; Petrović & Lobanov, 2020; Avenyo & Tregenna, 2022). Given this we deployed the Mclust method (Scrucca et al., 2016;

Fraley & Raftery, 2002), and classified our considered countries into three distinct groups based on their median Gross National Income (GNI) over a specified range of years for each country. Following this methodology, we obtained three groups of countries: High, Upper Middle and Lower Middle. The list of countries categorized by their respective wealth level is presented in Table 2.

Table 2. Countries within each wealth group.

Wealth level group	Country
High	Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Israel, Italy, Japan, Kuwait, Luxembourg, Netherlands, New Zealand, Norway, Singapore, Spain, Sweden, Switzerland, United Kingdom, United States
Upper middle	Argentina, Belarus, Brazil, Bulgaria, Chile, Costa Rica, Croatia, Cuba, Cyprus, Estonia, Greece, Hungary, Kazakhstan, Latvia, Lithuania, Malaysia, Malta, Mauritius, Mexico, Panama, Poland, Portugal, Romania, Russia, Saudi Arabia, Slovakia, Slovenia, South Africa, South Korea, Uruguay
Lower middle	Algeria, Armenia, Azerbaijan, Bosnia and Herzegovina, China, Colombia, Ecuador, Egypt, El Salvador, Georgia, Guatemala, India, Indonesia, Iran, Iraq, Kyrgyz Republic, Moldova, Mongolia, Morocco, Myanmar, North Macedonia, Pakistan, Paraguay, Peru, Philippines, Sri Lanka, Thailand, Tunisia, Ukraine, Uzbekistan

Low-income countries, (as categorized by the World Bank in 2022) were not included in the analysis as the study focuses on the impact of technological innovations on CO_2 emissions, innovations which are less frequent in such economies. Limited infrastructure, financial resources, and access to technology often result in lower levels of R&D activities in low-income countries, which reduces the number of measurable innovations.

The Hybrid Model

Our leading hypothesis is that country income levels (measured by GDP) mediates the relationship between innovation (measured by R&D expenditures) and CO_2 emissions. To test this, one could estimate this relationship for each group of countries separately. This policy brief instead estimates the relationship for the whole sample of countries accounting for group differences via interaction effects. Specifically, our estimation allows for interaction terms between some or all covariates and the wealth level. This approach, which we refer to as the hybrid model, thus combines elements of both pooled and separate models. It is a great alternative to separate models as it allows for estimation of both group-specific and sample-wide effects, and as it contrasts differential impacts across wealth level groups.

We test two versions of the hybrid model, one full and one reduced. The full model incorporates interactions with all covariates while the reduced model includes some indices without interactions, resulting in a relationship shared across all wealth levels. The reduced model assumes that the variables Renewable energy consumption, Energy use and Trade exhibit the same relationship with CO_2 emissions across all wealth levels.

Both the reduced and full hybrid models have similar coefficients for the variables and interactions that they share. While the coefficients share signs in both the full and reduced hybrid models, they are smaller, in absolute values, in the reduced hybrid model. In Table 3 we present the estimates from the reduced hybrid model.

Table 3. Results from the reduced hybrid model with CO_2 emissions as dependent variable, by wealth group level.

	High	Upper Middle	Lower Middle
Interaction variables			
GDP	-0.0280	0.0677	0.4746**
R&D	1.7665**	0.3648*	0.2138
$(GDP)^2$	0.0006	0.0006	-0.0235
$(R\&D)^2$	0.0090	0.0149	-0.0079
Urban population	0.0121**	0.0026	0.0045
GDP*R&D	-0.1640**	-0.0350*	-0.0282
Medium and high-technology value added	0.0026	-0.0017**	-0.0006
Common variables			
Renewable energy consumption		-0.1549***	
Energy use		0.6180***	
Trade		0.0956*	

Note: The upper part of the table (denoted "interaction variables") depicts the coefficients for the interaction term between the variable in the respective row and the income group in the respective column. * denotes a 0.05 significance level. ** denotes a 0.01 significance level. ***denotes a 0.001 significance level.

Several things are to be noted from Table 3. First, for High and Upper Middle wealth level countries there is a significant positive association between innovation (as proxied by R&D) and CO_2 emissions. However, the significance levels of the interaction term for R&D and GDP reveal that the relationship between R&D and CO_2 is not constant across wealth levels even within each group. Specifically, it appears that relatively high values of GDP and R&D are associated with a decrease in CO_2 emissions in High and Upper Middle wealth level countries. This suggests that in wealthier countries, advancements in technology and efficient practices derived from R&D are likely contributing to reduced emission levels. Interestingly, GDP has no direct effect on emissions for countries in these two wealth groups. Rather, GDP only affects emissions through the interaction term with R&D.

In turn, for the Lower Middle wealth level countries, R&D has no impact on CO_2 emissions, whether directly or via interaction with GDP. Instead, higher GDP leads to a significant increase in emissions. This suggests that for these countries economic growth entail CO_2 emissions while R&D activities are too small to have a mediating effect.

Second, medium and high-technology industry value added manufacturing is only significant for countries within the Upper Middle wealth level. This is in line with previous literature (see Avenyo & Tregenna, 2022, Wang, Zeng & Liu, 2019). A higher proportion of medium and high-technology industry value added is often negatively associated with CO_2 emissions due to the adoption of cleaner and more environmentally sustainable technologies and practices within these industries. Additionally, these industries are often subject to stringent environmental regulations. As a result, these industries can contribute to reduced emission levels, becoming key drivers of sustainable economic growth and environmental protection (Avenyo & Tregenna, 2022). Interestingly, in our estimation, this result is evident only for Upper Middle wealth level countries.

Third, urban population is only significantly increasing emissions for High wealth level countries. Such positive relationship can be attributed to several factors. There is often a higher concentration of industrial and manufacturing activities in urban areas, leading to increased emissions of pollutants as urbanization increases (Wang, Zeng & Liu, 2019). Additionally, urban areas tend to have higher energy consumption and transportation demands, further contributing to higher emission levels.

When it comes to the factors jointly estimated across wealth groups, the positive relationship between renewable energy consumption and CO_2 emissions is well-documented within the literature (Chen & Lee, 2020) which emphasizes the need for sustainable energy practices and efficient resource management to mitigate adverse environmental impacts. In line with this, the significant negative relationship between renewable energy consumption and CO_2 emissions suggests that an increase in renewable energy usage is associated with a reduction in CO_2 emissions. This is in line with previous findings demonstrating that technological progress helps reduce CO_2 emissions by bringing energy efficiency (Akram et al., 2020; Sharif et al., 2019).

Conclusion

This policy brief analyses the effects of GDP and technological innovations on CO_2 emissions. The theoretical channels linking economic development (and technological innovations) and CO_2 emissions are multifaceted, warranting the need for an econometric assessment. We study 83 countries between 1996 and 2020 in a setting that allows us to disentangle the effects across countries with different income levels.

Our findings underscore the importance of considering the various income levels of the considered countries and their interplay with R&D expenditures in environmental policy discussions. Countries with Lower Middle income levels exhibit insignificant effects from R&D expenditures on CO_2 emissions, while for Upper Middle and High wealth level nations, increased R&D expenditures incurs higher emissions.

The moderating role of GDP adds complexity to this relationship. At sufficiently high wealth levels, GDP weakens the effect of R&D on emissions. This alleviating effect becomes stronger as GDP increases until reaching a turning point, at which the impact reverses and R&D expenditures instead decrease emissions.

Our results on the significant nonlinear relationship between R&D, GDP and CO_2 emission levels highlights the complexity of addressing environmental challenges within the context of macroeconomics. It suggests that policies promoting both R&D and economic growth simultaneously can foster more sustainable development paths, where economic expansion is accompanied by a more efficient and cleaner use of resources, leading to lower CO_2 emissions. This decoupling of economic growth from emissions is likely to be further enhanced by governments incentivising research and development focused on improved energy efficiency and emission reduction.

References

Akram, R., Chen, F., Khalid, F., Ye, Z., & Majeed, M. T. (2020). Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. *Journal of cleaner production*, 247, 119122.

Avenyo, E. K., & Tregenna, F. (2022). Greening manufacturing: Technology intensity and carbon dioxide emissions in developing countries. *Applied energy*, 324, 119726.

Chen, Y., & Lee, C. C. (2020). Does technological innovation reduce CO2 emissions? Cross-country evidence. *Journal of Cleaner Production*, 263, 121550.

Cheng, C., Ren, X., Dong, K., Dong, X., & Wang, Z. (2021). How does technological innovation mitigate CO2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, 280, 111818.

Fraley C. and Raftery A. E. (2002) Model-based clustering, discriminant analysis and density estimation. *Journal of the American Statistical Association*, 97/458, pp. 611-631.

Petrović, P., & Lobanov, M. M. (2020). The impact of R&D expenditures on CO2 emissions: evidence from sixteen OECD countries. *Journal of Cleaner Production*, 248, 119187.

Scrucca, L., Fop, M., Murphy, T. B., & Raftery, A. E. (2016). mclust 5: clustering, classification and density estimation using Gaussian finite mixture models. *The R journal*, 8(1), 289.

Sharif, A., Raza, S. A., Ozturk, I., & Afshan, S. (2019). The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. *Renewable energy*, 133, 685-691.

Wang, S., Zeng, J., Liu, X., (2019). Examining the multiple impacts of technological progress on CO2 emissions in China: a panel quantile regression approach. *Renew. Sustain. Energy Rev.* 103, 140–150.

Natalja Apanasovich

Belarusian Economic Research Center (BEROC)
apanasovich@beroc.org
www.beroc.org

Natalja Apanasovich is a Research Associate at BEROC, and a Green Economy project coordinator. She completed her PhD at the University of Deusto (Spain).

Tatiyana Apanasovich

The George Washington University
apanasovich@gwu.edu
www.gwu.edu

Tatiyana Apanasovich is an Associate Professor at the George Washington University in Washington, D.C., USA, where she is part of the Department of Statistics. She completed her PhD at Texas A&M University.

freepolicybriefs.com

The Forum for Research on Eastern Europe and Emerging Economies is a network of academic experts on economic issues in Eastern Europe and the former Soviet Union at BEROC (Minsk), BICEPS (Riga), CEFIR (Moscow), CenEA (Szczecin), ISET-PI (Tbilisi), KSE (Kyiv) and SITE (Stockholm). The weekly FREE Network Policy Brief Series provides research-based analyses of economic policy issues relevant to Eastern Europe and emerging markets. Opinions expressed in policy briefs and other publications are those of the authors; they do not necessarily reflect those of the FREE Network and its research institutes.

FREE NETWORK