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CO2, GDP and Openness: A Vector Error Correction Model Approach for the Eurozone

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Abstract

Since the 2015 Paris Agreement, it is obvious that sooner or later the countries will be compelled to align their carbon dioxide (CO2) emissions to the international standards. This paper investigates the transition risk measured by the CO2 emissions and its causal relationships with economic growth and openness thanks to an empirical approach. Given the data availability, the database is based on an annual frequency. It starts in 2008 to end in 2019. The sample takes into account 10 Eurozone countries. We run econometric dynamic specifications by using a vector error correction model (VECM). These models are very flexible and provide interesting information on the short term and the long-term dynamic relationships between the CO2 emissions, the Gross Domestic Product (GDP) and the openness. The impulse function gives interesting results on the variable's impacts generated by the CO2 emissions and the variance decomposition sheds light on the magnitude of the forecast error variance determined by the shocks to each of the causal variables over time. The main results show negative relationships between the CO2 emissions and the openness and between GDP per capita and CO2 emissions. This conclusion may be useful to review the economic growth factors and the transition risk measured by the CO2 emissions.

Keywords: carbon dioxide (CO2), transition risk, economic growth, openness.
JEL: C32, F18, F43, N55, O13, Q56

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Introduction

Climate change is happening. A transition is mandatory. However, this transition should be prepared and rationally organized. A disorderly transition is a threat to the economic and financial stability. Note that climate change issues are not new and are international in nature. Indeed, for years, scientists have been warning of the risks of rising global temperatures. With the 2015 Paris Agreement that proposes to maintain the temperature rise well below 2°C above preindustrial levels, the public discussions have been relaunched. Today, climate change issues loom menacingly. Economists based on the scientist's works have defined several risks. The Governor of the Bank of England highlighted these risks in his discourse in 2015. According to him, three risks are potential: the physical risk, the transition risks and the liabilities risk. Without national and international actions, the increase will be more likely than 4°C by the end of the century in most scenarios. According to the following adage if we want to go fast, we can do it alone, however to go far requires international actions. This famous adage reminds us how international collaboration is crucial to tackling climate change. Both public and private actors are invited to find solutions against the global rising in temperature. Moreover, to save the planet and hence humanity, several national and international coordinated actions are required at different levels (macro, micro or meso[4] scopes). However, given the nature of central banks, they can possibly propose a suitable solution to fight against the rise in temperature. This point is crucial since central banks (CBs) actively participate to counter the current sanitary crisis. Nowadays, the CB should introduce permanent measures to reorient the economy towards the COP21 standards. Central banks should understand better the impact of climatic change on output, labour markets and prices over the medium term and long term. While the global economic implications of climate change are dire, overall, they are poorly analysed or understood. Nowadays, the risks to the financial system are dramatic for the economies. Knowledge in this area is gaining ground. Central banks and supervisors have cooperated closely over recent years to increase and disclose their knowledge and best practices. The aim of the paper is threefold. The first one is to shed light on the current literature on the link between the CO2 emissions and economic growth. The second goal is to deal with the lack of access to CO2 emissions data and the efforts of EU and international institutions, in particular central banks, to provide solutions. The last target is to demonstrate that economic growth should be built on a greener basis. This conclusion is deduced from an empirical VEC model for the Eurozone during a recent period (2008-2019).

The remainder of the paper is organized as follows. Section 2 presents the literature related to CO2 emissions and growth concerns. Section 3 describes the necessity to use reliable databases in this field and the efforts of central banks to provide qualitative databases. Section 4 exposes the empirical model and the econometric specification used in the analysis. Section 5 proposes a conclusion based on the empirical results.

[4] In a nutshell, "the concept of meso takes on an intermediate position in the distinction between micro and macro" (Dopfer, 2012: 134, note 1).

Literature survey

The nexus between the $CO2$ emissions, economic growth and openness have increased in interest in the empirical literature in the last decades. Indeed, several studies attempt to examine the causality between the variables. Grossman and Krueger (1993) have demonstrated that the environmental quality and the per-capita GDP are positively correlated. They have also defined a threshold for the correlation. Above/below \$4,000~5,000 (in U.S. dollars as of 1985), the relationship is positive/negative. This finding is not surprising since the link between the couple (GDP/CO2) is not new and reveals a non-linearity relationship. The Kuznets curve is an illustration. In the same vein, the works of Selden and Song (1994) based on a fixed and random panel ordinary least square (OLS) estimation have shown that the relationship between GDP per capita, nitrogen oxides (NOx) and sulfur dioxide (SO2) is a Kuznets curve representation. Later, few works failed to validate the EKC assumption (Coondoo and Dinda, 2002; Goldman and Zhelyazkova, 2023). With the development of econometric tools, several studies based on VAR approach attempt to analyse the relationship between the CO2 emissions[5] and economic growth. The results are quite diverse (Stern, 2004; Aruga, 2019; Crippa et al. 2020; Xiumei et al. 2021). Other recent works provide some interesting results. Indeed, according to Bekun et al. (2019) there is a cointegration link CO2, natural resources, renewable energy and economic growth (GDP). This conclusion is based on EU country (16) panel estimation. The period frequency of the study is annual (1996-2014). Moreover, according to the Panel Pooled Mean Group-Autoregressive Auto regressive distributive lag model (PMG-ARDL), the linkage between the natural resources and CO2 emissions is positive in the long term. A 2020 report shows that global fossil CO2 emissions per unit of GDP continued their decreasing trend (-1.7% in 2019 and -33.8% between 2019 and 1990) reaching the average value of 0.298 tCO2/kUSD/yr, while per capita emissions remained substantially stable in 2019 to 4.93 tCO2/capita/yr, confirming a 15.9% increase from 1990 (Grippa et al., 2020). This point is underlined by several works aiming at dealing with physical risk (Le Quéré et al., 2017; Le Quéré et al., 2020; Fanning and O'Neill, 2019; IPPC, 2023). According to Maneejuk et al. (2020), based on an econometric panel model applied to 44 countries, 17 countries have a nonlinear relationship (Australia, Austria, Bahrain, Denmark, Kuwait, Netherland, Norway, New Zealand, Oman, Portugal, Paraguay, Ireland, Saudi Arabia, Singapore, South Korea, Turkey and United Kingdom). The authors use a Regression Kink Design (RKD) to identify casual effects in linkages. This approach also reinforces the idea of a nonlinear relationship. Even though this kind of analysis is very interesting, it does not provide information about the long-term relationship between the economic growth and the CO2 emissions and the correction process to converge towards the equilibrium solutions. For this kind of problems, threshold estimation or a Vector Error Correction (VEC) model should be utilized.

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[5] In this paper we do not deal with the limits of the CO2 emissions database.

Since the Kuznets curve works, the focus has been oriented towards the link between the CO2 and economic growth. Despite the great interest in this question, some variables have been blacked out. The most important variable is the degree of countries' openness. This variable makes sense because of the globalization phenomena. Several empirical studies have demonstrated that the development of exchanges have contributed to the increase of pollution. Based on 49 high-emission countries panel VEC model taking into account trade, pollution variables and GDP, over the period 1991-2014, Sun et al. (2019) have found that for the openness variable (assumed to measure globalisation), the exchange trade has both negative and positive effects on the development of the pollution such as CO2 emissions. This result indicates that the relationship between these two variables is not linear. There are thresholds that conditioned the sign of the interlinkages.

For this paper, we have chosen to run a VEC model because of its ability to provide both short-term and long-term scopes. This approach has been used by several researchers (Kasperowicz, 2015; Zhou, 2018; Warsono et al., 2020; Onofrei et al., 2022). Moreover, we introduce openness, trade and GDP in our specifications since they contribute to the CO2 emissions developments as already highlighted by several UN reports. For instance, the World Meteorological Organization bulletin in 2020 (WMO, 2020) has shown that the lockdown[6] related to the sanitary crisis has led to a reduction in CO2 emissions.

The next section is dedicated to the description of the CO2 emissions databases and to explaining why the role of central banks is essential for the data collection. Note that the coronavirus pandemic has disrupted the world and its statistical perceptions (Tissot and De Beer, 2020; CCSA, 2020; IEA, 2020). It has also boosted the development of central bank control.

Transition risks: stock taking of CO2 emissions databases

Nowadays, according to the recent OECD report published in 2020 (OECD, 2020), the global emission of greenhouse gases (GHG)[7] has continuously increased for centuries. Indeed, since 1990 and 2000 they have increased respectively by 50% and 35%. This growth is partly explained by the economic growth based on the fossil energy use. However, there is a slowdown since 2007 because of the financial 2008 crisis followed by a huge decrease in production and possibly the public awareness of climate change risks. In 2018, the countries are responsible of about 35% of the global CO2 emission related to the energy use. Remind that in 1990, they emit more than 50% and in 2005 47%. There is a gradual reduction. This encouraging tendency also reveals some differences along the global value chains. Currently, the global economy is still heavily related to fossil fuels. Transport, industry and domestic use utilize carbon-based, non-renewable fuels such as coal, oil and

[6] The lockdown is characterised by an imposition of severe restriction on non-essential trade, travel, social relationship and access to public area.

[7] The Grenhouse Gases take into account six categories (Carbon dioxide (CO2), Hydrofluarocarbons (HFCs), Methane (CH4), Nitrous Oxide (N2O), Perfuorocarbons (PFCs) and Sulfure Hexafluoride (SF6)).

natural gas, which account for the vast majority of the energy. So far, every routine acts of daily life (cooking, heating, travelling etc.) consume fossil fuels or electricity generated by fossil fuels. The evolution of fossil variables depends on different sets of factors. Since the 1980s, there has been an interest in these factors and their evolution (Diekmann and Franzen, 1999; Dogru, 2020). Since 2015, efforts have stepped up to find solutions to climate change. All initiatives or attempts to measure climate change end up with the lack of definition/taxonomy of sustainable concepts and the unavailability of data related to climate change risks.

Moreover, international agreements, such as the Paris Agreement, recommend that countries should reduce their carbon emissions drastically in order to keep the temperature rises above 2 degrees Celsius below pre-industrial levels, defined as the temperature typical of 1850. To achieve this goal, an annual decarbonisation rate of 7,5% would be required, while, as of last year, the decarbonisation rate effectively achieved was a mere 1,6% (2,5% in the United States). In fact, even though the global economy seems to be more and more energy efficient in the recent periods, the Low Carbon Economy Index 2019 (LCEI 2019) exposes that energy consumption increased by 2,9% last year, leading to a rise in the CO2 emissions by 2%. These trends run counter to the Paris Agreement and the recent effort of the EU institutions. Indeed, the Task Force on Climate-related Financial Disclosures (TCFD) established in December 2015, takes into account two climate change risks. The transitional risk is related to the market and technology risk, the policy and legal risk, and the reputation risk). The physical risk describes flooding, drought, sea-level rise, heat stress, wind etc. All these risks are a threat to financial and economic stability. They have also direct impacts on GDP growth. Each of these risks needs to be taken into account at the sector level and at the level of every single security in the portfolio in order to be able to assess the overall climate-transition risk. Since 2015, several EU initiatives have emerged in order to focus on the need evaluate the impacts of the climate change and particularly the environmental, carbon footprint. These evaluations require a reliable harmonized and qualitative database. Different Expert groups (EG) appeared in 2020 oriented to the database problematics. Amongst them, we can cite the STC EG on Climate Change and Statistics, the NGFS workstream entitled “Bridging the Data Gaps” and a task force on the statistics on sustainable finance and climate related risks (TF SuFiR)). Based on surveys amongst the central banks, the STC EG has shed light on different needs. One of the most important points is the introduction of input-output report considering several environmental/carbon footprint variables. The goal is to better understand the impact of emission border tax and to shorten the global value chains. Moreover, there are different methodologies to evaluate the level of greenhouse gases of companies. This point raises the urgent question of harmonization. Methodological challenges are the challenges of the future. In a survey conducted during Covid-29 lockdown (NGFS, 2020), of 107 banks (represented 51 countries) only 26 central banks have responded to the survey aiming at evaluating the ecological concerns of central banks. Globally, the main result is an increasing of climate-related risks among central bankers. However, we need actions and no more words.

The point of view of Vikram Gandhi, Professor at Harvard Business School, is clear: “Regulation is a “missing piece” of the ESG puzzle right now” (*Financial Times*, 18 November 2020). The path to a common and reliable taxonomy is long. Note that several works related to ecological issues is still in progress despite the climate change urgency. Besides, in the current COVID-19 context that accelerated the sustainable finance policies, the Green New Deal taxonomy should be the priority.

The following section attempts to demonstrate the role of CO2 in economic growth.

Empirical research

The data is an annual time series and spanned from 2008 to 2019. Several countries from the euro zone are selected. Indeed, there are 10 countries (Belgium, Germany, France, Greece, Italy, Ireland, Luxembourg, Nederland, Portugal and Spain). We also use few key variables assumed to be in line with the energy problematics like the GDP per capita, the degree of openness and the CO2 per capita. The sample is small and this point has an impact on the estimation’s results. As underlined in the previous section, this variable may be questionable since the scope 3 is neglected. However, this variable is often used by economists to evaluate the impact of the carbon footprint on economic growth (Narayan et al., 2016; Syed, 2019). The link between the GDP and CO2 has been largely discussed by the theoretical and empirical literature and it is still debated given the complexity of this topic. The results are contrasted. Indeed, the Environmental Kuznets Curve (EKC) assumed that during the first stage of the development there is a positive link between the CO2 and GDP; later after a certain threshold is reached the relationship is reversed. Many econometric studies have attempted to validate the Environmental Kuznets Curve (EKC) theory. The main results are the EKC theory is not always validated (Luzzati et al., 2018; Mikayilov et al., 2018; Altintaş and Kassouri, 2020; Onofrei et al., 2022; Alkhars et al., 2022; Goldman and Zhelyazkova, 2023). These conclusions are not surprising since the interlinkage is not linear. Moreover, the short- and long-term impacts should be investigated more thoroughly. This point has led us to employ empirical tools that allow for making a distinction between long-term and short-term estimations. This section is therefore dedicated to the presentation of the empirical results. Table 1 presents the main variables used in the panel empirical analysis.

Table 1. Presentation of the panel database

Variables	Definition/Pays	Frequency	Units	Sources/Countries ISO codes
GDP per capita	GDP per capita measures the sum of marketed goods and services produced within the national boundary, averaged across everyone who lives within this territory. GDP per capita is calculated using a country's GDP in 2012 United States dollars (USD) which is then divided by the country's total population.	Annual	Current U.S. dollars (USD)	The Organisation for Economic Co-operation and Development (OECD)
CO2 per Capita	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	Annual	Tons per capita	The Organisation for Economic Co-operation and Development (OECD)
OPENNESS	The trade-to-GDP-ratio is the sum of exports and imports divided by GDP. This indicator measures a country's "openness" or "integration" in the world economy	Annual	% of GDP	The Organisation for Economic Co-operation and Development (OECD)
COUNTRIES	Belgium, Germany, France, Greece, Italy, Ireland, Luxembourg, Nederland, Portugal and Spain.		NA	BE, DE, FR, GR, IT, IE, LU, NL, PT and SP

Notes: All definitions are extracted from the OECD website (https://data.oecd.org/)

Source: OECD

The elementary statistics are displayed in the Table 2.

Table 2. Elementary statistics for the period from 2008-2018

Variables	Mean	Std-Dev.	Skewness	Kurtosis	Jarque-Bera
GDP	125.32	53.04	1.73	5.19	83.66
CO2	4.42E+08	2.50E+08	1.46	4.36	47.64
OPENNESS	66.41	51.79	4.8	4.80	68.84

Source: Authors' calculations

The correlation table (r) provides some interesting results (in bold). Indeed, openness and GDP are highly correlated (r = 0.93, p-value = 0.00) whereas the relationships between CO2 and other variables (GDP and openness) are negative and significant (for CO2/GDP r = -0.23 (p-value = 0.02) and for CO2/OPENNESS r = -0.44, p-value = 0.00). Table 3 exposes the intertemporal correlation.

Table 3. Inter-temporal cross-correlation

Couples	T = -3	T = -2	T = -1	T = 0	T = 1	T = 2	T = 3
(GDP/OPEN-NESS)	0.62	0.79	0.87	**0.94**	0.86	0.78	0.63
(CO2/GDP)	-0.15	-0.17	-0.20	**-0.23**	-0.24	-0.22	-0.20
(CO2/OPEN-NESS)	-0.30	-0.34	-0.38	**-0.44**	-0.45	-0.42	-0.39

Source: Authors' calculations

Whatever the lag, the cross-correlation is negative for the couples (CO2; GDP) and (CO2; OPENNESS). The next two tables provide the unit root test results in level (Table 4a) and in first differences (Table 4b).

Table 4a. Panel unit root tests: summary in level

Variables	Statistic and Probability Levin, Lin & Chu t* (LLC)	Statistic and Probability Im, Pesaran and Shin W-Stat (IPS)	Statistic and Probability ADF-Fisher Chi-square	Statistic and Probability PP-Fisher Chi-square
GDP	-9.16 (0.00)	-3.03 (0.00)	45.94 (0.00)	29.61 (0.08)
CO2	-2.15 (0.01)	0.23 (0.59)	16.31(0.70)	64.83 (0.00)
OPENNESS	13.53 (0.00)	-6.91 (0.00)	80.06 (0.00)	12.22 (0.91)

Source: Authors' calculations

According to Table 4a, only the GDP per capita is stationary. However, the LLC test is more adapted when N and T are very high (superconsistency) since the panel test statistics have limiting normal distributions (Maddala and Wu, 1999). As N = 10 (short cross-section) and T = 12 (short period), we take into consideration the value probabilities of IPS, ADF and PP. To make the variables stationary, we have filtered the variables (see Table 4b).

Table 4b. Panel unit root tests: summary in first differences

Vari-ables	Statistic and Probability Levin, Lin & Chu t*	Statistic and Probability Im, Pesaran and Shin W-Stat	Statistic and Probability ADF-Fisher Chi-square	Statistic and Probability PP-Fisher Chi-square
CO2	-0.71 (0.24)	-1.44 (0.07)	29.56(0.07)	122.8 (0.00)
OPEN-NESS	0.65 (0.74)	-3.02 (0.00)	44.24 (0.00)	110.76 (0.00)

Source: Authors' calculations

Through such a filter, the variables become stationary, but the first difference process (or integration of order 1) of time series may entail some loss of the long-term characteristics of the original times series. Nonetheless, the VAR (vector auto-regression) or VEC (Vector Error Correction) models require the stationary of each variable.

The next paragraph is dedicated to the presentation of the empirical results. Having described the relationship between CO2 emissions, GDP and openness, we use a vector auto-regression (VAR) to both test the short-run relationship between CO2, GDP and Openness. The VAR model has been often used to evaluate the interrelationships between the variables. The VAR model has advantages but also drawbacks (see Stock and Watson, 2001). However, for this kind of problems, it provides interesting results. As the relationship between CO2, GDP and OPENESS is both a long-term and a short-term process, we choose to make use of a VEC approach. Before that, the Johansen's Cointegration test was run to shed light on the number of equilibrium relationship.

Table 5. Cointegration tests

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None*	0.35	43.72	29.80	0.00
At most 1*	0.24	18.20	15.50	0.02
At most 2	0.02	1.55	3.84	0.21

Notes: Trace test indicates 2 cointegrations eqn(s) at the 0.005; * denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis (1999) p-values.

Source: Authors' calculations

According to Table 5, there are 2 cointegrated relationships. Therefore, we run the Vector Error Correction Model (VECM). According to Engle and Granger (1987), the cointegrated variables lead to an error correction process. The dependent variable variations depend on the level of disequilibrium in the cointegrated relationship materialized by the error correction term (ECT). Table 6 and Table 7 summarize the main results of the VEC model. Table 6 provides the long-term estimation of the relationship.

Table 6. Long-run estimated coefficients[8]

	CO2	GDP	OPENNESS
β Coefficients of ETC t-statistics ( )	1.00	-0.31* [1.90]	-0.0003*** [-2.44]
Coefficients of ETC(α) t-statistics [ ]	-1.42*** [-4.65]	-0.57* [1.69]	-60.03** [-2.10]

Notes: Significant at * 10%, ** 5%, ***1%.

Source: Authors' calculations

We established that all β coefficients are negative and significant.

[8] See Appendices for the Portmanteau tests and the Lagrange Multiplier (LM) tests.

The coefficient on the ECT (α), assumed to adjust the speed in the long-run for CO2 and GDP is respectively -1.42 and -0.57. Note that if the coefficient value is over-valued (under-valued), then a downward (upward) adjustment process sets in. To be concise, the ECT is a kind of corrective mechanism. Indeed, when a shock appears, the speed of the convergence to equilibrium is relatively rapid and the size of coefficient of the ECT(α) is an adjustment speed. The coefficients on the error correction term indicate that a deviation from the equilibrium level during the current period will be corrected in the next period. Hence, the size of coefficient on the GDP ECT is interpreted as speed of adjustment, where -0.57 means that about -57% of the imbalance situation is adjusted in the first period. For the OPEN coefficient is highly negative and significant (at 10%). Table 7 displays the short-term coefficients of the model.

Table 7. Short-run estimated coefficients

Error Correction	D (CO2)	D (GDP)	D (OPEN)
D (CO2 (-1))	0.12	0.43	37.98
D (CO2 (-2))	0.13	0.20	37.48*
D (CO2 (-3))	0.13	0.13	5.86
D (GDP (-1))	-0.24	-0.94***	-21.42
D (GDP (-2))	-0.01	-0.67***	-26.67*
D (GDP (-3))	0.16	-0.34***	-8.79
D (OPEN (-1))	0.001	-0.0001	0.18
D (OPEN (-2))	-0.001	-0.001	-0.10
D (OPEN (-3))	-0.003***	-0.002	0.03

Notes: Significant at * 10%, ** 5%, ***1%.

Source: Authors' calculations

According to Table 7, there are no significant short-term relationships between CO2, GDP and *openness*. The relationships between *openness* and CO2 are significant and negative at t-3. However, the coefficient value is very small. Globally, the results reaffirm the idea that the CO2, GDP and openness have a long-term relationship and any policy should be based on a far-sighted programme to counter the ecological damage. This specific point raises the question of the role of regulators in the ecological transition. Indeed, the green transition is crucial and it should be prepared in a long-term perspective. In the case of a disorderly transition, a threat to the economic and financial stability may occur. The analytical conclusion hides the most important obstacles, namely, the data availability. That is the most important challenge that central banks and national statistic organizations face (NGFS, 2022).

The analysis of the variance decomposition is useful with regard to understanding the evolving interactions between the three variables.

Table 8. Variance decomposition of CO2 emissions

Period	S.E.	CO2	GDP	OPENNESS
1	0.039	100	0	0
2	0.042	92.40	6.64	0.96
3	0.043	89.10	9.28	1.62
4	0.045	83.11	9.62	7.27
5	0.045	83.43	9.44	7.13
6	0.046	80.40	12.66	6.94
7	0.046	80.00	13.09	6.91
8	0.047	78.47	14.55	6.97
9	0.047	77.52	15.54	6.94
10	0.048	76.42	16.76	6.81

Source: Authors' calculations

According to Table 8, the forecast error variance for CO2 is largely explained by its own impulse (or innovation) by about 76.42% at the end of 10 years. The GDP variable has an increasing impact that is almost 2.5 times bigger than openness variable.

The Granger causality tests show that there is bidirectional causality for all variables at 5% (see Appendices). This result is not surprising since thresholds effects explain it. As already underlined, the relationships between the GDP and CO2 are not linear and this may indicate the existence of thresholds and the notion of endogeneity. The empirical results are therefore in line with the theoretical literature.

Conclusion

Despite the notable findings, this study has some limitations. Most importantly, the sample size was too small. Access to data was limited, and only annual time series data on individual countries were available. The OLS method, short-run and long-run dynamic relationships, variance decomposition, and impulse response functions may provide different results if the data set is expanded to reflect quarterly or monthly series.

To conclude, this study has the advantages to feed the empirical debate on the nexus between the CO2 emissions, the GDP and openness variable. We have reached several interesting results. Indeed, the CO2 emissions should be studied within a long-term perspective. Moreover, for our sample that takes into account 10 EU countries for a recent annual period (2008-2019), we find that there is a negative long-term relationship between the CO2, GDP and openness. This result is not surprising since the database takes into account several advanced countries. The short-term estimation coefficients are not significant because the issie is a longs-tanding one. However, this empirical study has some limitations. Unfortunately, the database is too short. To avoid any bias in terms of definitions or sources, we prefer to use the annual OECD database. Moreover, this data provider is reliable and recommended by the EU Expert Groups, for instance. The methodology chosen has also drawbacks. Indeed, this kind of approach is based on noise estimations, for instance. More sophisticated models - mixing data frequencies and introducing thresholds - are required to assess with accuracy the impacts of CO2 emissions on economic growth or other variables.

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Appendices

I/ Post-tests

Portmanteau tests

VEC Residual Portmanteau Tests for Autocorrelations

Null Hypothesis: No residual autocorrelations up to lag h

Sample: 2008 2019

Included observations: 60

Lags	Q-Stat	Prob.*	Adj Q-Stat	Prob.*	df
1	0.849258	---	0.863652	---	---
2	4.223522	---	4.354270	---	---
3	6.511747	---	6.762928	---	---
4	10.98401	0.7537	11.55464	0.7124	15

*Test is valid only for lags larger than the VAR lag order.

df is degrees of freedom for (approximate) chi-square distribution after adjustment for VEC estimation (Bruggemann, et al. 2005)

LM tests

VEC Residual Serial Correlation LM Tests

Sample: 2008 2019

Included observations: 60

Null hypothesis: No serial correlation at lag h

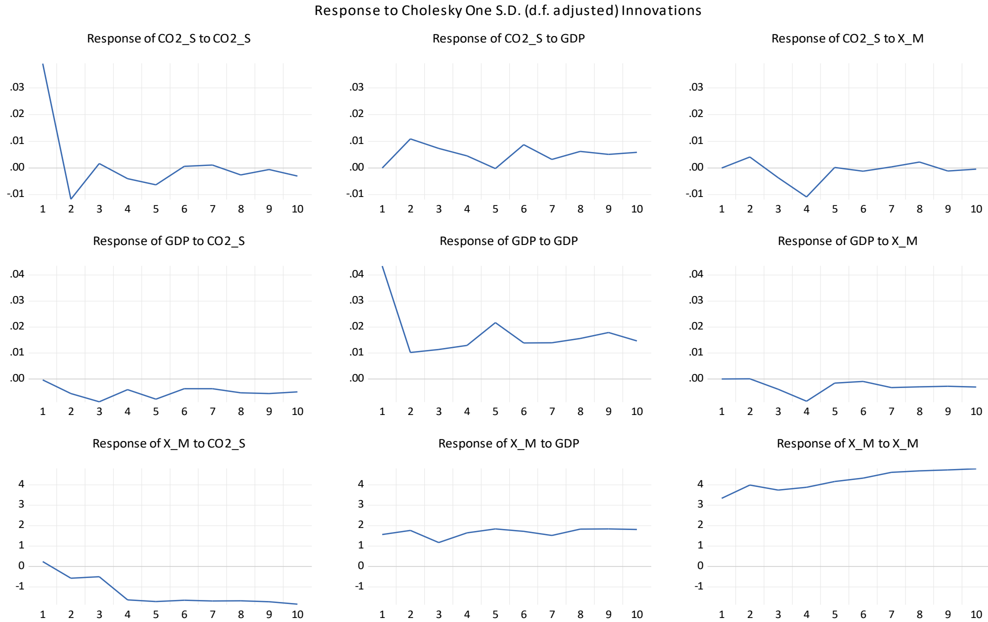
Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	5.183453	9	0.8180	0.570995	(9, 107.2)	0.8182
2	11.47882	9	0.2443	1.301399	(9, 107.2)	0.2447
3	7.501816	9	0.5850	0.835159	(9, 107.2)	0.5854
4	11.54920	9	0.2399	1.309801	(9, 107.2)	0.2403

Null hypothesis: No serial correlation at lags 1 to h

Lag	LRE* stat	df	Prob.	Rao F-stat	df	Prob.
1	5.183453	9	0.8180	0.570995	(9, 107.2)	0.8182
2	21.95229	18	0.2341	1.248011	(18, 116.5)	0.2359
3	32.31493	27	0.2206	1.229420	(27, 111.6)	0.2255
4	41.27006	36	0.2511	1.174191	(36, 104.1)	0.2621

*Edgeworth expansion corrected likelihood ratio statistic.

II/ Impulse



III/ Granger causality tests

VEC Granger Causality/Block Exogeneity Wald Tests

Sample: 2008 2019 Included observations: 60

Dependent variable: D(CO2_S)			
Excluded	Chi-sq	df	Prob.
D(GDP)	6.175090	3	0.1034
D(X_M)	7.947872	3	0.0471
All	10.53690	6	0.1038
Dependent variable: D(GDP)			
Excluded	Chi-sq	df	Prob.
D(CO2_S)	2.476815	3	0.4795
D(X_M)	2.808850	3	0.4220
All	4.879513	6	0.5594
Dependent variable: D(X_M)			
Excluded	Chi-sq	df	Prob.
D(CO2_S)	8.611413	3	0.0349
D(GDP)	3.488779	3	0.3222
All	11.30558	6	0.0794