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Financial Determinants of Carbon dioxide emissions

An econometric study of the relationship between finance and carbon emissions

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Abstract

In recent years, the raising concern about carbon dioxide emissions has been linked to not only environmental or industrial, but also financial aspects. Common financial determinants of carbon dioxide emissions analysed by previous studies include economic and financial development, financial structure, and trade openness of a country. The main aim of this paper is to investigate the financial determinants by estimating a regression model that accounts for them. By analysing a panel dataset, which consists of 55 countries during the time from 1996 to 2017, evidence of the Environmental Kuznets Curve is found, implying that the relationship between a country's GDP per capita and greenhouse gas emissions can be visualised by an inverse U-shaped curve with the turning point at around USD 15 900. It is also found that financial development is another significant determinant, having an increasing effect on carbon dioxide emissions. Including a spatial weight matrix in the panel regression model allows to control for the spatial effects. In addition, the paper summarizes most common environmental policies as The Paris Agreement and European Union Emissions Trading Scheme, which according to the difference-in-difference model estimates can be accounted for almost 30% reduction in carbon dioxide emissions.

Keywords: *carbon dioxide emissions, Environmental Kuznets Curve, panel data regression model, economic and financial development, environmental policy*

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1. Introduction

Climate change has been a hot topic for decades because it affects everyone. The increasing concern about heat waves, melting glaciers, abnormal weather conditions and other consequences that become more serious and visible is a result to a problem often referred to as the global warming, driven by growing greenhouse gas emissions, which warm the planet by trapping the heat in the atmosphere. Carbon dioxide (CO_2) is the most common greenhouse gas linked to global warming, and its concentration in the environment beyond certain limits can have irreversible consequences that would be difficult to address in the future (IPCC 2014, 2018). According to the scientific online publication Our World in Data (2020), the global average CO_2 atmospheric concentration has increased by 38.8% from 1900 to 2018. In the past 20 years alone, over 600 billion tons of CO_2 have been released into the Earth's atmosphere. And the total number is increasing year by year – in 2019 the emissions were 45% higher than in 2000. Yet it is not just the CO_2 – other gases responsible for the greenhouse effect include methane, nitrous oxide, and fluorinated water vapor.

The reasons for increasing carbon emissions are various – but mainly driven by overall worldwide improvement of life quality, which is connected to growing energy consumption to ensure all the necessary conditions for a qualitative life. But what are the financial reasons and factors resulting in the change of CO_2 emissions? The literature mostly refers to the Environmental Kuznets Curve, implying that in the first stages of economic development the greenhouse gas emissions increase, whereas after reaching a certain threshold of economic development they decrease (Grossman & Krueger, 1995; Boutabba, 2014; Dasgupta et al., 2002; Shi, Liu and Sunday Riti, 2019; De Haas & Popov, 2019; Churchill et al., 2018).

Other financial determinants of changes in the amount of emitted greenhouse gasses are the financial structure – implying that more equity-based economies are linked to smaller carbon emissions per capita (De Haas & Popov, 2019), and trade openness – trade is considered to affect total carbon emissions and the organisation of manufacturing significantly (De Haas & Popov, 2019; Levinson, 2009; Shapiro & Walker, 2018; Lv & Li, 2021; Dinda, 2004; Reppelin-Hill, 1999).

There have been many attempts to limit the growing portion of carbon dioxide emissions, for example, The Paris Agreement – a legally binding international treaty on climate change – that was signed by 196 states in 2016. The agreement requires all co-signing states to introduce a policy that yields a significant decrease in greenhouse gas pollution, a crucial aspect to reach a climate neutral global state. Other common carbon-efficient policies include green-investment banks (Haas & Kempa, 2020; Geddes, Schmidt & Steffen, 2018; De Haas & Popov, 2019), and trading systems, for example the European Union Emissions Trading Scheme.

The main aim of this paper is to investigate the financial determinants of carbon dioxide emissions by estimating a regression model that accounts for the determinants. By analysing a panel dataset, which consists of 55 countries during the time from 1996 to 2017, the significance of factors like economic and financial development, financial structure and trade openness is estimated. Besides that, the connection between the Environmental Kuznets curve and this dataset is studied, and the effectiveness of carbon-reducing policies is evaluated.

The study compliments the existing literature by merging various previously used approaches (panel/spatial panel regression) and financial determinants (economic and financial development, financial structure, trade openness, country and time fixed effects) into a united framework when estimating the influence of finance on carbon dioxide emissions. What is more, in most of the previous studies a regional sample (EU, OECD, provinces of China) is used, whereas in this study a sample covering all continents of the World is analysed. The empirical research uses the newest data available, hence it is possible to compare the results of this study to the ones before to see whether the significance of the financial determinants has changed over time. In addition, apart from making conclusions about the factors driving the changes in the carbon dioxide emissions, the paper analyses the efficiency of the existing environmental policy.

The paper is structured as follows: section 2 summarizes the previous studies of the related concepts and provides a broad theoretical background in the topic, whereas the methods applied, and data used are described in section 3. The empirical results and interpretations are deliberated in section 4, and the results are verified by robustness tests in section 5. Finally, section 6 gives an overall conclusion of the study.

2. Theoretical Background

2.1. Economic development as a determinant

One of the implied factors of increasing greenhouse gas concentration by previous research is the economic development of a certain country. A common framework that connects the economic development (in most cases, measured by GDP per capita) and the amount of CO_2 emissions is the Environmental Kuznets curve (EKC), developed by Grossman and Krueger (1995). It states that environmental deterioration occurs during the early stages of economic development, but after a certain degree of growth has been achieved, the benefits of economic growth are used to protect the ecosystem (Grossman & Krueger, 1995). It is referred to as the Environmental Kuznets curve due to its similarity to Kuznets inverted-U relationship between income inequality and income per capita.

The EKC theory implies that when an economy is in an early stage of development, usually because of being abundant in labour and natural resources (Boutabba, 2014), "pollution in the … curve grows rapidly because people are more interested in jobs and income than clean air and water, communities are too poor to pay for abatement, and environmental regulation is correspondingly weak" (Dasgupta, Laplante, Wang & Wheeler, 2002, p.147). The heavy industries, which usually are pollution-intensive, are promoted by accepting foreign direct investment of developed countries (Boutabba, 2014). Consumers benefit from economic growth because they can get credit at a lower rate to buy items that increase energy consumption, which as a result raise CO_2 emissions (Sadorsky, 2011; Shahbaz, Van Hoang, Mahalik & Roubaud, 2017). It additionally enables firms to obtain cheap credits and carry out new investment projects by putting in new offices, utilizing more work, and building new plants; in any case, such exercises increment the utilization of energy and assets (Sadorsky, 2011).

However, as Dasgupta et al. (2002, p.147) argue, "the balance shifts as income rises - leading industrial sectors become cleaner, people value the environment more highly, and regulatory institutions become more effective". In developed economies, once the curve reaches a certain middle-income level, pollution levels peak and start to decrease towards the pre-industrial level (Dasgupta et al., 2002). Wealthy societies shift from energy-intensive manufacturing to services and technology-intensive industries, which produce less emissions per unit of production and are thus more environmentally friendly (Grossman & Krueger, 1995). De Haas and Popov (2019) found that for their sample of 48 countries carbon emissions start to decline at an annual income of USD 44,606 (85^{th} percentile). After reaching the threshold – shifting point of the EKC, investors are more willing to invest in firms with significant corporate social responsibility and well-balanced environmental governance (e.g., emphasizing on green innovations), which results in a reduced level of CO_2 emissions (Renzhi & Baek, 2020).

The significant non-linear relationship between a country's stage of development and greenhouse gas emissions has been analysed by many researchers. Shi, Liu and Sunday Riti (2019) used 25-year data of 10 countries with the biggest CO_2 emissions to conclude that a 1% increase in per capita GDP raises emissions by 0.426%. De Haas and Popov (2019) found out that recessions are accompanied by decrease of CO_2. Dasgupta et al. (2002) came up with the slogan "Grow first, then clean up!" portraying the timeline of EKC. Churchill, Inekwe, Ivanovski and Smyth (2018, p.393) found evidence of a N-shaped curve, "suggesting that there is a second turning point, such that emissions begin to rise again when rich countries reach a second income tipping point". Hence, when income increases beyond a certain threshold that corresponds to the local minimum of the EKC, emissions begin to rise again, suggesting an N-shaped relationship between development and greenhouse gas emissions (Churchill et al., 2018).

One of the arguments against the theory of EKC is that even if such a relationship between development and greenhouse emissions existed in the past, it is unlikely to occur now because of the "pressures that global competition places on environmental regulations" (Dasgupta et al., 2018, p.159). Due to the high costs (usually in the form of taxes) imposed on polluters, shareholders force companies to migrate to low-income countries, whose residents are so desperate for employment and income that their environmental protections are lax or non-existent (Dasgupta et al., 2018). Therefore, governments in high-income countries are being pushed to loosen environmental requirements as a result of rising capital outflows.

The previously mentioned argument counteracts with the fact that economic development can encourage research and development activities, which promote economic growth and improve environmental performance (Tamazian, Chousa & Vadlamannati, 2009). Increase in development is usually associated with lower financing costs, especially to facilitate investments in environment-friendly projects, thereby leading to less pollution (Tamazian & Rao, 2010). So, the effect of the so called "carbon-dirty" outsourcing (analysed further in section 2.3.) might not equal the other effects that eventually decrease the emissions.

It is important to note the difference between terms "economic" and "financial" development. Economic development is usually described by GDP per capita and follows the framework of EKC, whereas Financial development, characterised by efficient financial systems (Churchill et al., 2018) is measured by various proxies (Boutabba, 2014), and corresponds to CO_2 emissions in a different way, described in section 3.1.

2.2. Financial structure as a determinant

Another aspect to take into consideration when analysing the financial implications on greenhouse gas emissions is the financial structure of the economies. The popular debate of whether to finance operations by increasing equity or debt reaches beyond just financial or managerial outcomes. As it turns out, the equity proportion of an economy has a significant effect on CO_2 emissions.

De Haas and Popov (2019, p. 2) found that "for given levels of economic and financial development, carbon emissions per capita are significantly lower in economies where equity financing is more important relative to bank lending". In addition, increasing the average world equity financing to 50% would correspond to at least 11.5% reduction in carbon dioxide emissions worldwide (De Haas & Popov, 2019). For example, as agreed in the Paris Agreement (2015), by 2030 the CO_2 emissions must be reduced by 40% (compared to 1990); the EU has set the goal to reduce it by 55% (European Commission, online).

There are various reasons why equity is the "greener" source of financing. For instance, De Haas and Popov (2019) found the evidence that by promoting the implementation of cleaner technology in polluting industries, capital markets have a propensity to reallocate money into more carbon-efficient countries and sectors. Also, the reduction in carbon emissions is linked to shareholder value maximization – it is crucial to perform well in environmental terms to be rewarded by increased stock return, otherwise stock markets punish the pollutants (Bellon, 2020; Salinger, 1992; Krueger, 2015; Klassen & McLaughlin, 1996; Ferrell, Lang & Renneboog, 2016). What is more, companies that perform environmentally better than others usually face lower cost of equity (Trinks, Ibikunle, Mulder & Scholtens, 2022).

For a 48-country and 24-year panel De Haas and Popov (2019, p.21) discovered that "increasing the share of equity financing by 1 percentage point, while holding the overall size of the financial system constant, reduces aggregate per capita carbon emissions by 0.05 metric tons". They also note the significant difference between industries, by showing that the financial market encourages money to be redirected to greener industries, and in countries with growing equity markets carbon-intensive industries create less emissions per capita and per unit of output (De Haas & Popov, 2019).

2.3. Trade as a determinant

An important aspect to consider is the effect of trade on greenhouse gas emissions. First, trade is accompanied by transport of goods, and the transport industry accounts for 16.2% of global greenhouse gas emissions (Our World in Data, 2020). Second, trade openness eases foreign direct investment and capital inflows/outflows which directly correspond to the relationship between economic development and carbon emissions described in section 2.1. And third, it is believed international economic relations between countries result in a mutual dependence in the environmental policy and carbon efficiency.

Not always the reduction of carbon emissions is a result of the introduction of new, environment-friendly technology or the shift to green innovation. In some cases, to lower the domestic greenhouse gas pollution, companies move the carbon-heavy manufacturing to countries where the regulation is not so restricting. If considering the EKC, the countries where the manufacturing is moved to are the ones to the left of the curve (usually, developing countries). However, the goods produced are typically imported back to the country of initial production.

De Haas and Popov (2019) showed an empirical evidence of this carbon-dirty outsourcing: decrease of carbon emissions in carbon intensive sectors due to domestic stock market growth is followed by a rise in carbon emissions associated with the manufacturing of both final and intermediate products in other countries. "However, the domestic-greening effect dominates the pollution-outsourcing effect by a factor of ten" (De Haas & Popov, 2019, p.3). Hence, the carbon-dirty outsourcing to pollution havens does not neutralise the positive environmental effect that internal greenhouse gas reduction implies, but at least part of the reduction is due to carbon emission increase abroad, corresponding to the increase of trade (De Haas & Popov, 2019; Levinson, 2009; Shapiro & Walker, 2018).

Another phenomenon that has an impact on certain country's carbon emissions is the indirect effect of environmental policies of countries that are close geographically or in terms of mutual trade. As Lv and Li (2021, p.1) conclude, "financial development plays a fundamental role in the mitigation of CO_2 emissions, and that being surrounded by nearby countries with a high financial development could improve a country's environmental performance". Because no economy is fully isolated, researchers have adopted the spatial econometric approach to expand the analysis of financial effects on carbon emissions (Lv & Li, 2021; Kang, Zhao & Yang, 2016; Balado-Naves, Banos-Pino & Mayor, 2018). By using Moran's I that is a correlation coefficient measuring the overall spatial autocorrelation of a data set, the spillover effect of financial development was found to be significantly higher than the direct effect, implying that the harmful effect of a country's financial development on its environment is minor as opposed to the positive impact of neighbouring countries' local environment (Lv & Li, 2021). The spatial effect can also be accounted for in the EKC, shifting the turning point to a later stage of development (Lv & Li, 2021).

Although increasing trade is expected to result in growing pollution as more energy is demanded and consumed in the production and transportation of goods (Dinda, 2004), the trade openness ensures easier access to green technologies that can help in becoming more carbon-efficient (Reppelin-Hill, 1999). Therefore, trade must be regulated to stimulate the positive effects of international economic relations but limit the negative effects. The most common and known policies that are aimed to reduce the carbon emissions are described in the following section.

2.4. Existing and future policy, possible remedies

Due to the overall global economic growth and the effect financial development has on CO_2 emissions, in order to conduct a climate-friendly sustainability, governments are required to introduce environmental policy. More stringent environmental policy is proven to have a statistically important negative effect on net per capita carbon emissions (De Haas & Popov, 2019). Panayotou (1997) found efficient policies and institutions to be significantly effective in mitigating environmental deterioration at low-income levels while also speeding up progress at higher-income levels, lowering the environmental Kuznets curve and decreasing the environmental cost of growth.

One of the most significant steps towards a global approach to reduce greenhouse gas emissions is The Paris Agreement – a legally binding international treaty on climate change – that was signed by 196 states in 2016. "The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects" (United Nations Climate Change (UNCC), online, n.p.). To slow down the global warming, countries have agreed to decrease the total greenhouse emissions in order to reach a climate neutral state by 2050 (UNCC, online). The so-called zero-carbon solutions are becoming more popular, with them being planned to be majorly used in 70% of industries by 2030 (UNCC, online). Compared to the fixed level of greenhouse gas emissions by the time of Paris Agreement, in order to reduce the global pollution, around USD 376 billion investment per year is required (Bellon, 2020).

Carbon-efficient investments highly rely on financial markets, since they are very capital-intensive (Evans, Strezov & Evans, 2009; Painuly, 2001; Wiser, Pickle & Goldman, 1997). To stimulate the green projects, many governments have created public green investment banks to “facilitate private investment into domestic low-carbon, climate-resilient infrastructure” (OECD, online, n.p.). In most cases, the investments are targeted to urban areas, where already more than a half of the world’s population lives, in the near future for the proportion reaching more than two thirds (OECD, online). Not only the bank is financing environment-friendly projects, but also creation of an investment bank like this sends a signal to the stock market that a country and its economy is climate-responsible and sustainable in the long term. By governments intervening in credit markets with instruments as loan guarantees or subsidised loans, the credit rationing dissolves, stimulating renewable energy (Haas & Kempa, 2020; Geddes, Schmidt & Steffen, 2018).

Why is there a need for banks like that? De Haas and Popov (2019) argue that usual banks’ abilities to contribute to the reduction of CO_2 emissions are very limited because of them being technologically conservative – by financing new technology the existing collaterals depreciate, worsening banks’ position. They might not be willing to fund green innovations if it is related to intangible, firm-specific assets, which are therefore hard to collateralize (Hall & Lerner, 2010; Carpenter & Petersen, 2002). What is more, because of the loan maturity usually being relatively short, compared to shareholders, banks are not that interested in the long-term effect of existent (or non-existent) carbon efficiency (De Haas & Popov, 2019). On the other hand, as Dasgupta et al. (2002) state, banks may not want to finance companies whose environmental liability is questioned. But, as noted in section 2.2., it is possible to conclude that despite these doubts, debt financing is more carbon-heavy than equity financing.

“The first in the world and so far, the largest installation-level ‘cap-and trade’ system for reducing greenhouse gas emissions is the European Union Emissions Trading Scheme” (EU ETS) (Gretszel, Gurgul, Lach & Schleicher, 2020, p.2). This is another tool for the EU to reach its climate targets by limiting emissions from more than 11,000 power stations, industrial plants and airlines operating within the union (European Comission, online). It works on the 'cap and trade' principle. If a company does not adhere to the set cap (total amount of greenhouse gases emissions), heavy fines are imposed (European Comission, online).

Although being questioned by many, the system has proven to be effective with showing reduction in carbon emissions at the same time ensuring GDP growth (Gretszel et al., 2020). Zhang, Li, Li & Guo (2020) tested the EU ETS concept on provinces in China and found the system can reduce the carbon emissions by 24.2% while increasing the industrial output value by 13.6%.

As described in this section, it can be implied that there are various financial factors affecting the amount of carbon emissions. However, despite the significant impact, each of the value drivers have an individual interpretation and effect on the amount of how much an economy pollutes the atmosphere with CO_2. Therefore, these financial factors and their relationship with greenhouse gases must be analysed empirically. The following section describes a framework of evaluating the financial determinants of CO_2 emissions.

3. Methodology

3.1. Defining Financial development

Although multiple studies have estimated the relationship between financial development and CO_2 emissions, the method for deriving the measure for financial development differs. This inconsistency yields different interpretations on the effect the financial development has on greenhouse gas emissions. Therefore, it is important to use an appropriate indicator for the regression model.

One of the commonly used indicators for financial development (FD) is the sum of private credit and stock market capitalization divided by the country's gross domestic product (C) (De Haas & Popov, 2019, Boutabba, 2014). Churchill et al. (2018) argue that the ratio of broad money to GDP (M) is one of the usual proxies for FD, as well as bank assets to GDP (A). As mentioned previously, the differences in measures used for describing the financial development in an econometrical model results in possible flaws and inconsistencies in the interpretation of the regression. According to Lv and Li (2021, p.1), "the use of a single indicator to measure financial development means that some information is lost, thus leading to inaccurate results".

Hence, it is necessary to build an aggregate financial development index, and the principal component analysis (PCA) can be applied to do so, by avoiding biased estimates and multicollinearity (Shahbaz, Shahzad, Ahmad, & Alam, 2016). Taking into consideration the fact that the indicators included in the PCA are based on different scales and variations, they need to be normalized (Renzhi & Baek, 2020). The z-score method is used for normalization. Three indicators are used for the composition of FD index: C, M and A, each measured as mentioned previously in this section.

Table 1 presents the results obtained from the PCA, where the first principal component (PC1) was the only significant component with an eigenvalue of >1 (UCLA, online). Therefore, the PC1 factor loadings were utilized to construct the financial development index and scaled up to unity sum. As can be seen in panel B of table 1, the correlation coefficients between the standardized variables and the built index are positive and strong, verifying that the index is accurate, and the first principal component is a good proxy for all three variables included in the FD index.

Table 1. PCA of three financial development variables

Panel A: Principal Components and their eigenvalues from the observed matrix

Variable	*PC1*	*PC2*	*PC3*	*Index weights (normalized PC1)*
C	0.5934	0.4907	0.6380	0.3439
M	0.5063	-0.8438	0.1781	0.2934
A	0.6257	0.2173	-0.7492	0.3626
Eigenvalue	1.9858	0.6734	0.3383	

Panel B: Correlation matrix

	C	M	A	PC1
C	1.0000	0.3565	0.6480	0.8364
M		1.0000	0.4608	0.7139
A			1.0000	0.8821
PC1				1.0000

Note: In Panel A, this table reports the three Principal Components and their eigenvalues, as well as the weights of the three variables (*C, M, A*) used for the Financial development index, which corresponds to the normalized first principal component, as it is the only one with a significant eigenvalue (value higher than 1). *C* stands for the sum of private credit and stock market capitalization divided by the country's GDP, *M* is the ratio of broad money to GDP, and *A* stands for the bank assets to GDP ratio. Panel B reports the correlation coefficients between the variables used in the index and the first Principal Component.

3.2. Regression model

Taking into consideration all previously described factors that could affect CO_2 emissions in a particular country, the following regression model is constructed:

$$\frac{CO_{2c,t}}{Population_{c,t}} = \beta_1 \ln\left(GDP_{c,t}\right) + \beta_2 \ln\left(GDP_{c,t}\right)^2 + \beta_3 FD_{c,t} + \beta_4 \ln\left(FS_{c,t}\right) + \beta_5 \ln\left(T_{c,t}\right) + \gamma_c + \varphi_t + \varepsilon_{c,t} \quad (1)$$

$CO_{2c,t}$ in the model represents the total carbon dioxide emissions in country c during year t, whereas $Population_{c,t}$ stands for the total population of country c in the respective year. Therefore, the dependent variable is total per capita CO_2 emissions. As for the dependent variables, an important factor is the economic development, which, according to the EKC theory at early stages of development could affect the per capita CO_2 emissions positively (rising emissions associated with rising income), but after a certain turning point – negatively (De Haas & Popov, 2019; Churchill et al., 2018). To account for this non-linear relationship, the per capita GDP, both on its own and squared, is included as a measure of the economic development.

$FD_{c,t}$ is the financial development index, constructed by PCA, as described in section 3.1. Financial Structure variable $FS_{c,t}$ is defined as the share of stock market financing out of the total financing through credit and stock markets, calculated as in equation (2) (De Haas &

Popov, 2019). *Credit* refers to the total amount of credit provided to the private sector by deposit money banks and other credit institutions, while *Stock* refers to the total value of all publicly traded securities (De Haas & Popov, 2019).

$$FS_{c,t} = \frac{Stock_{c,t}}{Credit_{c,t} + Stock_{c,t}} \quad (2)$$

$T_{c,t}$ is the trade openness ratio, which is the total value of imports and exports in country c during year t as a share of GDP (Boutabba, 2014; Churchill et al., 2018). All variables are expressed in natural logarithms, except for the financial development index. Additionally, the country fixed effects, γ_c, control the unobserved variables within a certain country, and the time fixed effects, φ_t, control the global shocks (De Haas & Popov, 2019; Renzhi & Baek, 2020). $\varepsilon_{c,t}$ refers to the idiosyncratic white noise error term.

The parameters $\beta_1 ln(GDP)$, $\beta_2 ln(GDP)^2$, $\beta_3 ln(FD)$, $\beta_4 ln(FS)$, $\beta_5 ln(T)$ are the long-term estimators of CO_2 emissions with respect to per capita GDP, the square of per capita GDP, financial development, financial structure and the trade openness, respectively. Following the framework of the EKC, β_1 should be positive corresponding to the phenomenon wherein as income increases, the CO_2 emissions increase as well, whereas β_2 should be negative as it reflects the inverted-U-shape pattern of the curve for countries where the income is high enough to move manufacturing to more carbon-efficient technology (Boutabba, 2014; Churchill et al., 2018). In some cases, to account for the N-shaped EKC with two turning points, the cubic term of the GDP is introduced in the model (Churchill et al., 2018). The turning points can be calculated as follows:

$GDP^* = e^{-\frac{\beta_1}{2\beta_2}}$ (for a regression with squared term) (3)

$GDP^* = \frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_{cube}}}{3\beta_{cube}}$ (squared and cubed term, β_{cube} is the cubed GDP coef.) (4)

The long-term coefficient of financial development, β_3, could be both positive or negative. It has been argued that efficient financial development, as described by efficient financial structures, accelerates economic activities and, as a result, increases energy use and carbon emissions. (Sadorsky, 2010; Dasgupta et al., 2002). Financial growth, on the other hand, could encourage technical innovation and enable access to new technologies that can improve production efficiency and reduce carbon emissions (Tamazian & Rao, 2010). Although the empirical results for this variable are ambiguous, most studies tend to suggest a negative effect of financial development on CO_2 emissions; therefore, β_3 is expected to be positive (Churchill et al., 2018; Boutabba, 2014; Dasgupta et al., 2002; Hao, Zhang, Liao, Wei & Wang, 2016; Zhang, 2011).

The financial structure coefficient, β_4, should be negative as an increase in the proportion of equity financing in the economy has a greening effect (De Haas & Popov, 2019). Though, the interpretation of the trade openness coefficient, β_5, is not so straight forward. On one hand, trade is likely to increase emissions and degrade environmental quality because more waste is generated because of increased commercial activity and access provided by trade openness (Dinda, 2004). Trade openness, on the other hand, has been claimed to minimize emissions and increase environmental quality as it provides easier access to technology that enables cleaner manufacturing and improves environmental quality (Reppelin-Hill, 1999). Hence, the opinions and proof of the sign in front of the trade coefficient differ.

As supported by Lv & Li, 2021; Kang, Zhao & Yang, 2016; Balado-Naves, Banos-Pino & Mayor, 2018, the spatial effects must be accounted for when analyzing the financial determinants of CO_2 emissions. Therefore, the spatial econometric model is introduced. An important reason to introduce this model is that a spatial panel data set contains more information and less multicollinearity among the variables than the cross-sectional counterpart (Álvarez, Barbero & Zofío, 2017). As the number of countries in the model is relatively big, the generalized moments estimation method is used to compute the estimators (Kelejian & Prucha, 1999). The SARAR model (spatial autoregressive with additional autoregressive error structure model) is then as follows:

$$\frac{CO_{2c,t}}{Population_{c,t}} = \beta X_{c,t} + \tau W \left(\frac{CO_{2c,t}}{Population_{c,t}} \right) + \gamma_c + \varphi_t + \varepsilon_{c,t} \quad (5)$$

$$\varepsilon_{c,t} = \rho W \varepsilon_{c,t} + \vartheta_{c,t} \quad (6)$$

$X_{c,t}$ is the matrix of 5 independent variables included in model (1). The model also includes a spatial lag of the dependent variable, $W\left(\frac{CO_{2c,t}}{Population_{c,t}}\right)$ and a spatial lag in the error structure, $W\varepsilon_{c,t}$, whose coefficients are τ and ρ, respectively. *W* is the *n x n* spatial weight matrix of dummies where countries are allocated a value of 1 if the other country is in the same region and 0 otherwise. The classification of the countries in regions is based on geographical and economic factors (The World Bank, 2020), and the division can be seen in attachment A.

3.3. Estimating the efficiency of existing carbon-reduction policy: DiD model

The difference-in-difference (DiD) method is a common econometric technique for determining the impact of a policy action or other treatment of interest (Abadie & Cattaneo, 2018). The method divides the dataset into a control group and a treatment group. "The control group is the object that has not been affected by the policy, the treatment group is the object affected by the policy, and then the policy is implemented by changing the two groups of experiments accordingly" (Zhang, Li & Zhang, 2020, p.4).

Therefore, DiD can be applied to estimate the effects of the carbon emission reduction policy, for example, the EU ETS. The average causal influence of the EU ETS on a variable of interest is inferred using the DiD technique by comparing average deviations for a group of controlled countries (treatment group) and a group of non-regulated countries (control group) over a time period spanning the EU ETS's inception. The influence assigned to the EU ETS is the disparity between the two combinations (Verde, 2020).

EU ETS was introduced in 2005 in all EU states (by then, 25 countries) plus Iceland, Liechtenstein and Norway (European Commission, online). Countries who joined the EU ETS (Romania and Bulgaria in 2007, Croatia in 2013) are put in the treatment group considering pre-requirements of joining the EU necessary to fulfill, part of them being connected to the EU ETS. The control group with respect to the time of policy implementation is determined and divided into the before-period (set as 0) and the after-period (set as 1) (Zhang, Li & Zhang, 2020). The countries in effect are indicated by the dummy variable *treated*, treated = 0 represents the control group, treated = 1 represents the treatment group, and the interaction between the period and the treated area is the net effect of the policy. The treatment and time are used to differentiate the four sub-samples in the model. The DiD baseline model is constructed as follows:

$$\ln\left(\frac{CO_{2c,t}}{Population_{c,t}}\right) = \beta_0 + \beta_1 period_t + \beta_2 treated_c + \beta_3 period_t treated_c + \varepsilon_{c,t} \quad (7)$$

$CO_{2c,t}$ is the amount of carbon emissions per capita in country c during the year t, and the interaction term β_3 is the effect of the policy. The interpretation of the model variables is summarized in table 2. As noted in the table, subtracting $_{\Delta}CO_1$ from $_{\Delta}CO_0$ before and after the introduction of EU ETS in the treatment group, the net effect of this policy can be obtained, that is, $_{\Delta\Delta}CO = \beta_3$ (Zhang et al., 2020).

Table 2. DiD model variables

	Before implementation (*period=0*)	After implementation (*period=1*)	Difference
EU ETS member countries (*treated=1*)	$\beta_0 + \beta_2$	$\beta_0 + \beta_1 + \beta_2 + \beta_3$	$\Delta CO_0 = \beta_1 + \beta_3$
Other countries (*treated=0*)	β_0	$\beta_0 + \beta_1$	$\Delta CO_1 = \beta_1$
DiD			$\boldsymbol{\Delta\Delta CO = \beta_3}$

Note: This table reports the logic behind the difference-in-difference model, as described in the equation (7), coefficients. This model is connected to evaluating the effect of EU ETS on the reduction of carbon dioxide emissions. The value of *treated* = 0 represents the control group, *treated* = 1 represents the treatment group, and the interaction between the period and the treated area is the net effect of the policy. The value of *period* = 0 corresponds to the time before the implementation of the policy, and *period* = 1 is after that. The difference of the two subsamples, $\Delta\Delta CO = \beta 3$, shows the effect of the environmental policy, the DiD estimator.

3.4. Data used, its limitations

For the empirical analysis, data from several data sources is used. The dependent variable, carbon dioxide emissions per capita, is described by data from the International Energy Agency for CO_2 emissions from fuel combustion, as well as the annual population by the World Bank. Both databases provide data for more than 40 years and all the countries, without any significant missing data.

More data limitations are present with the independent variables. First, to conduct the PCA and derive the FD variable, data for three of the indicators included in the index is gathered. As for the private credit and stock market capitalization divided by the country's gross domestic product, the credit component is measured by the ratio of domestic credit to private sector (% of GDP) by the World Bank. However, considering the fact that many countries were missing data from years 1960-1990, the initial sample is reduced respectively. For a couple of missing data after 1990 the ratio of Private Credit by Deposit Money Banks and Other Financial Institutions to GDP is used as a substitute proxy. The stock market – the total value of stocks traded to GDP – data is not available for many countries, and many years. Out of 268 countries and territories, The World Bank data is available for all years from 1990-2019 only for 29 of them. Hence, the sample time period was reduced to 1996-2017, limiting the number of countries included to 55. Other indicators used in the PCA are proxied by the broad money to GDP ratio (World Bank) and bank assets to GDP ratio by International Monetary Fund.

Other data sources used are the GDP per capita (current US$) and total exports and imports to GDP ratio, both by The World Bank. These proxies for economic development and trade openness are available for all countries and years in the sample, therefore the final panel data set is constructed by 55 countries during the years 1996-2017. The data set is considered to be a good sample of the global situation as it includes countries from all regions of the world, and both developed and developing economies. For 2017, the 55 countries included in the sample account for 77.8% of total CO_2 emissions in the world. The full list of countries included in the sample can be found in the appendix A.

4. Empirical results

4.1. Descriptive statistics

The variables used in equation (1) correspond to 1210 observations (the panel consists of 55 countries for 22 years). The descriptive statistics of the main variables are summarized in table 3. The parameters included in the table are important to understand how diverse the panel is, considering country and time differences.

Table 3. Descriptive Statistics

	No. of obs.	*Mean*	*Min*	*Max*	*Stdev.*	*Skewness*	*Kurtosis*
GDP	1210	18375.0	258.5	118823.6	20309.1	1.87	7.21
GDP_sq	1210	7.50E+08	6.68E+04	1.41E+10	1.66E+09	4.40	26.5
FD	1210	0.0	-2.0	7.8	1.4	1.42	6.81
C	1210	115.0	6.2	1089.3	109.6	0.88	3.13
M	1210	93.6	3.7	938.7	98.6	2.27	8.63
A	1210	80.3	2.0	257.2	47.0	3.02	18.4
FS	1210	0.22	0.00	0.92	0.19	4.95	34.86
T	1210	95.2	15.6	442.6	75.2	0.65	3.07
CO_2/pop	**1210**	**6.1**	**0.1**	**24.7**	**4.5**	**1.06**	**4.36**

Note: This table reports the descriptive statistics of the variables used in the regression model described by the equation (1). The raw values of the variables are used. GDP stands for the country's gross domestic product, GDP_sq stands for the squared GDP term. FD is the financial development index of an economy, which is constructed by three variables: *C* stands for the sum of private credit and stock market capitalization divided by the country's GDP, *M* is the ratio of broad money to GDP, and *A* stands for the bank assets to GDP ratio. FS stands for the financial structure of the economy, measured by the share of stock. T is the trade openness variable, measured by total country's exports and imports divided by gross domestic product. CO_2/pop is the dependent variable, CO_2 emissions per capita.

GDP and its squared term, GDP_sq in the table, directly show how economically developed a country is. The sample includes both the wealthiest countries (GDP per capita over 80 TUSD) like Luxembourg, Norway and Switzerland, and poor, developing countries (GDP per capita below 1 TUSD) like Pakistan, Bangladesh, Kenya and Ghana. The global economic development can be observed as well: average GDP per capita in 1996 around 12 TUSD compared to over 24 TUSD in 2017, corresponding to 102% increase in average value of all the finished goods and services produced within a country per 1 inhabitant.

The financial development index, FD, is constructed by standardized PCA components, therefore, to get a deeper interpretation of it, the indicators included in the index are analysed. The ratio of sum of private credit and stock to GDP, C, is expected to be higher in countries where investments are bigger and more common, since private credit and stock are directly linked to debt and equity financing. Countries with very low financing ratio to GDP (less than

10%) in the sample are Ghana, Russia, Nigeria, Romania and Bulgaria, whereas countries and territories with the amount of private credit and stocks traded value exceeding their GDP by at least 5 times are Hong Kong, China and the United States. Hong Kong in 2007 had a record high ratio of 1089.3; as many countries at that time, the economic overheating resulted in huge investments that eventually led to the global financial crisis. Also, from a time point of view, the average C has increased around 5.3 times compared to 1996.

"Broad money is the most flexible method for measuring an economy's money supply, accounting for cash and other assets easily converted into currency" (Liberto, 2020, online). Hence, for an economy to be financially highly developed, a high ratio of broad money to GDP (M) is expected. Countries with historically low M ratio are Nigeria, Russia, Portugal and Spain. The latter two are had a low ratio during the adaption of euro from 1998-2000, reaching the average European country levels afterwards. Russia had a low ratio during the 1998 Russian economic crisis. On the other hand, countries like Hong Kong and Luxembourg have had high ratios (300 and above) during all the sample period. Bank assets is the last indicator of the financial development. Similarly, as for the other indicators, the best performing countries are Luxembourg and Hong Kong, whereas Nigeria, Russia and Ghana have the lowest ratios.

A higher proportion of equity financing in an economy has a "greening" effect (De Haas & Popov, 2019). Therefore, looking at the share of equity financing in the total financing can be an insightful link to the carbon emissions. The amplitude of this share is very high; for instance, the ratio was 0 for Bangladesh in 2002-2003 and 2016-2017, indicating a non-existent stock market, whereas in Saudi Arabia 2005-2006 the equity financing share was above 90%. Compared to 1996, the equity financing proportion in the average economy has increased from 16.0% to 19.2% in 2017, reaching its peak of around 34.6% in 2006 (over-heating period of global economy before the 2008 global financial crisis).

The average total exports and imports correspond to 95.2% of the sample GDP. Countries that have the highest trade to GDP ratio (above 400), signaling a significant trade openness, are Hong Kong, Singapore and Luxembourg, but Japan and Brazil have had the ratio below 20 historically, hence, those economies are more domestic trade based.

As for the independent variable, CO_2 emissions per capita, it has not increased significantly in time. This can be explained by the neutralizing effect carbon-efficient policies in developed countries have on carbon-heavy manufacturing in developing countries. It is important to note that the standard deviation is significantly high, showing a difference between countries in the amount of carbon pollution. The countries producing the least carbon dioxide emissions per capita are Asian and African countries: Bangladesh, Sri Lanka, Kenya, Ghana and Nigeria (less than 0.5 tonnes of CO_2 per capita). Countries that have produced more than 15 tonnes of CO_2 per capita include Luxembourg, United States, Saudi Arabia, Oman and Australia.

Both the dependent and all the independent variables, except for FD, are transformed to natural logarithms. The reason for doing this is to respond to the skewness in data and show the change of the factors in percentage terms. Since the financial development index, FD, is already transformed as described in section 3.1. and has a mean of 0, additional transformation is not needed.

4.2. Regression model estimates

To test whether the panel approach is accurate for this dataset instead of pooled model, the test of poolability is conducted. The null hypothesis for this test is that the dataset is poolable (i.e., having the same slope coefficients), however, since the p-value is less than 0.05, the null hypothesis is rejected. Therefore, a panel model with variable coefficients is used. De Haas and Popov (2019) recommend using country and time fixed effects in the regression model. To verify this idea, both fixed effects and random effects model is run, and the models are compared using the Hausman test (1978). The test statistic is higher than chi-square distribution critical value, therefore, the null hypothesis that variable coefficients in both models do not differ significantly is rejected, and fixed effects model is preferred as it is more efficient. To make sure both country and year fixed effects are jointly significant, they are grouped, and the overall significance of both dummy groups is confirmed. For detailed model specification tests described in this paragraph see appendix B.

The Breusch-Pagan test is conducted to see if the model faces heteroscedasticity; as the p-value is less than significance alpha 0.05, the null hypothesis of homoscedasticity is rejected (Oxford Reference, online). Therefore, a technique to obtain unbiased standard errors under heteroscedasticity, robust standard errors, is used. Using the robust standard error usually increases the standard error; however, using them allow for the presence of data with unequal variability across a set of predictor variables. The correct standard errors are computed as clustered-robust standard errors using the observation groups as the different clusters in the following way (Álvarez, Barbero & Zofío, 2017):

$$VAR(\hat{\beta}) = \frac{n}{n-1}\frac{N-1}{N-k}\left(\tilde{X}^T\tilde{X}\right)^{-1}\left[\sum_{i=1}^{n}\tilde{X}_i^T e_i e_i^T \tilde{X}_i\right](\tilde{X}^T\tilde{X})^{-1} \quad (8)$$

, where n is the number of countries, N is the total number of observations, k – number of explanatory variables, $\tilde{X}$ is the within transformation of the explanatory variables, e are the residuals from the within regression.

Table 4 summarizes the estimates of three regression models. The fixed effects model with robust standard errors is significant at a 99% confidence level (p-value < 0.01). The goodness-of-fit measure, adjusted R-squared, indicates that 33.06% of the variance in CO_2 emissions per capita is explained by the independent variables of the model. Out of the five explanatory variables, three are found to be significant: *GDP*, *GDP_sq* and *FD*. Hence, using this regression model, the effect of the financial structure of the economy, as well as trade openness cannot be proven. The significant coefficients follow the expectations described in section 3.2. A 1% increase in a country's gross domestic product leads to an approximately 1.15% increase in the CO_2 emissions to population ratio. However, the EKC assumptions hold as the squared term has a significant, negative coefficient: a one percent increase in this variable reduces the dependent variable by 0.06%. It is worth noting that this is the average effect for all the sample; for developed countries the reducing effect is believed to be bigger while for developing economies that have not yet reached the EKC turning point the effect does not apply. According to the results, the financial development has an increasing effect to the carbon dioxide emissions – for a one unit increase in the financial development index, the emissions per capita rise by 4.94%.

For the spatial regression model, all the included variables are significant on a 90% confidence level (all variables except for *Trade* are significant on a 99% level). Table 4 shows that the coefficients for GDP, the squared GDP term and the financial development variables are similar to the fixed effects model with robust standard errors. Hence, the previously mentioned coefficient interpretation can be applied, adjusting it for the relatively small differences. The spatial variable is significant as well, proving that geographic and economic proximity influences a country's environmental performance. For this model, it can also be seen that a 1% increase in the FS variable results in 0.02% decrease in carbon emissions. Therefore, De Haas and Popov (2019) hypothesis of equity financing having a greening effect is confirmed for this dataset as well. However, this must not be the main driver of the carbon emissions reduction the countries have agreed on in the Paris Agreement. If keeping all variables constant, a 1% decrease in CO_2 emissions per capita would require 50% increase in the current equity financing proportion. That is a huge increase, which would probably result in a collapse of the economy since the banking industry would lose too much of their market share.

Table 4. Regression model estimates

	(a)	**(b)**	**(c)**
GDP	1.1479***	0.9915***	-0.1226
	(0.2366)	(0.0605)	(1.2671)
GDP_sq	-0.0594***	-0.0512***	0.0906
	(0.0133)	(0.0035)	(0.1435)
GDP_cube			-0.0058
			(0.0053)
FD	0.0494***	0.0334***	-0.0103
	(0.0182)	(0.0083)	(0.0010)
FS	-0.0086	-0.0242***	0.0050***
	(0.0105)	(0.0045)	(0.0178)
T	-0.0339	0.0400*	-0.0351
	(0.0679)	(0.0236)	(0.0712)
*W*CO2/pop*		0.0627***	
		(0.0036)	
P		-0.0115	
		(0.1232)	
N	1210	1210	1210
Country dummies	55	55	55
Year dummies	22	22	22
R-squared	0.3633	0.3530	0.3701
Adj. R-squared	0.3306		0.3372
p-value	0.0000	0.0000	0.0000
EKC holds	Yes	Yes	No
Turning points	USD 15 818	USD 15 989	

Note: This table reports estimates of three regression models: **(a)** panel regression model with fixed effects, within transformation, clustered standard errors; **(b)** spatial panel regression model with fixed effects; **(c)** panel regression model with fixed effects and cubed term of GDP, within transformation, clustered standard errors. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term, *GDP_cube* – cubed natural logarithm of the GDP term. *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. *W*CO2/pop* is the multiplication of the spatial weight matrix W and the dependant variable, CO_2 emissions per capita. ρ is the coefficient of the spatial error term. Numbers in parenthesis below the coefficient estimates show the standard errors. *N* shows the total number of observations included in the regression. *** symbolizes significance at 99% level, ** at 95% level and * at 90% confidence level.

The trade openness in this model has an environmentally negative effect on the carbon efficiency, as 1% increase in the total exports and imports to GDP ratio yields a 0.04% increase in the carbon dioxide emissions. However, as the significance is only 90% and for other models the trade variable coefficient has the opposite sign, it could be argued this interpretation is ambiguous.

The introduction of the cubic term could show the N-shaped EKC in the regression (Churchill et al., 2018). However, as can be seen in table 4, the regression model with the cubic term does not return any significant coefficients except for a positive financial structure coefficient. As for the other models the FS coefficient is either negative or insignificant, due to the mixed results, no direct interpretation can be made. One of the reasons why an N-shaped curve cannot be seen for the model is that this curve is typical only for very developed countries (reaching already two turning points – income levels), whereas the sample is balanced with both poor and wealthy countries. Therefore, for the whole panel this relationship is not seen. The curve on a more country-specific level is described in section 4.3.

As the sample is very diverse, exact coefficient estimates just give an average, global coefficient of each financial determinant. Hence, it is crucial to look at the coefficient signs and confidence intervals to get a broader insight of the question of study. Table 5 shows the confidence intervals for both panel and spatial panel regression models with fixed effects. As can be seen in the table, evidence can be found for the U-shaped curve when analysing the economic development, for the negative impact of financial development on carbon efficiency, and greening effect of an increase in equity financing. The trade factor cannot be interpreted so directly, as the confidence interval allows for both increasing and reducing effects. As predicted, not every country has the same significant financial determinants of carbon emissions and allowing for a longer time data could give clearer results.

Table 5. Regression coefficient 95% confidence intervals

	Raw panel			**Spatial panel**		
	Lower	**Upper**	**Effect**	**Lower**	**Upper**	**Effect**
GDP	0.6734	1.6223	Increase	0.8730	1.1101	Increase
GDP_sq	-0.0860	-0.0327	Reduce	-0.0581	-0.0443	Reduce
FD	0.0129	0.0859	Increase	0.0172	0.0497	Increase
FS	-0.0296	0.0124	N/A	-0.0331	-0.0153	Reduce
T	-0.1700	0.1021	N/A	-0.0063	0.0863	N/A

Note: This table reports the regression coefficient intervals with 95% statistical confidence. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term. *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. The section "Raw panel" refers to the coefficient intervals for panel regression model, whereas the section "Spatial panel" refers to the spatial panel regression model. The column "Effect" for both sections shows the effect of the variable on CO_2 emissions.

As can be seen in the appendix C, the initial panel regression model with fixed effects has a significant cross-sectional dependence, therefore, introducing the spatial panel regression is a good way how to tackle this aspect. The spatial regression finds a 99% significant effect of 4 out of 5 variables studied in this paper, and the only insignificant variable is trade openness which can be partially explained by the spatial instrument included in the equation (5).

4.3. EKC application to the regression model estimates

As mentioned previously, the Environmental Kuznets theory (Grossman & Krueger, 1995) predicts an inverse U-shaped curve when visualising the relationship between economic development (measured by GDP per capita) and CO_2 emissions per capita. To capture the non-linear relationship, the squared GDP is included in the regression model. Since evidence for an N-shaped curve was not found, the cubed GDP term is not included in the visual analysis.

As can be seen in Figure 1, the regression model (1) returns an inverse U-shaped curve as expected. It is important to determine the global maximum of the function to get an estimate of the turning point when an increase in GDP leads to a decrese in the carbon emissions. It is calculated, using the equation (3). As stated in table 4 and fixed in figure 1, the turning point of this sample is around USD 15`818 (with the spatial panel model – USD 15`989). Therefore, when talking about the average of the 55-country panel, after reaching around USD 15`900 GDP per capita, the carbon emissions of the country should decrease.

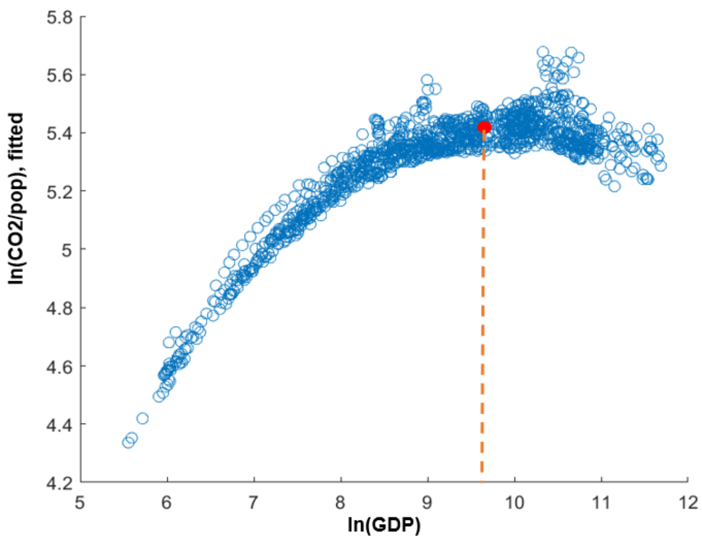

Figure 1. Environmental Kuznets curve, panel regression model estimates

Note: This figure shows the non-linear, inverse U-shaped relationship between country GDP per capita and CO_2 emissions per capita. Both variables are transformed into natural logarithms. The global maximum of the function – the turning point of the curve is at ln(GDP)=9.67, which corresponds to USD 15`818. This curve is graphed and estimated, assuming other variables of the model (financial structure, financial development, trade openness and the fixed effects) remain constant.

Table 6 summarizes the regression model estimated EKC on a country-level scale. For 47 out of 55 countries (corresponding to 85.5%) analysed in this study, the EKC holds with the respective regression coefficient estimates. The accuracy of the model is high, which therefore leads to a conclusion that the main EKC idea can be applied for the global economy. Most of the countries for which the curve does not hold are European Union (EU) countries with relatively lower income (Croatia, Hungary, Poland and Romania): although their GDP is lower than the threshold, the CO_2 emissions have decreased. This could be explained by those countries being members of the EU and having to adhere to the strict environmental policy, for example, the EU ETS which is further analysed in the following subsection.

Possibly most significant country non-compliant to the EKC is South Korea. South Korea's massive economic growth over the last few decades has left it with a large carbon footprint and making it one of the largest greenhouse gas emitters in the world, despite being dwarfed by those of its neighbours China and Japan (Gabbatiss, 2020). As the country's economic development is mainly driven by energy-intensive industries like electronics, car and ship building, an increase in GDP is not associated with a decrease in CO_2 emissions, despite South Korea being a high-income country. "In fact, even as much of Europe and North America progressed towards cleaner power over the last decade, the carbon intensity of electricity in South Korea increased as it relied more heavily on coal" (Gabbatiss, 2020).

An opposite example of a country whose CO_2 emissions have reduced despite a relatively low GDP, is Jordan. Jordanian utilities depend on energy-intensive water pumping to meet everyone's needs due to several conflicting demands on narrowly restricted water supplies (Water and Wastewater Companies for Climate Mitigation, 2020). Therefore, the country is forced to decrease the energy consumption, which yields reduced carbon emissions as well. Apart from that, Jordan has set a goal for reducing greenhouse gas emissions by 14% by 2030 (Water and Wastewater Companies for Climate Mitigation, 2020).

It must be noted, however, that the EKC is only a framework that generalizes a common trend, hence it gives a good idea of the average situation in the global economy without being very specific about country-level data. As the carbon efficiency is affected by many aspects, not only financial, a naïve expectation of a reduction in carbon dioxide emissions if a country's GDP reaches specific threshold might not turn out to be accurate. Every country has an individual turning point of the curve, and it is dynamic: changing year to year depending on global economy, competition in market, inflation and various other factors.

The curvature of the function also depends on the time period when the coefficients are estimated: for a more accurate, country-specific information that can be derived from the curve (especially the turning point and how it shifts in time), a longer time horizon should be used as to see an actual shift from carbon-heavy to carbon-efficient manufacturing takes a long time.

Table 6. Country classification according to EKC

Country	**ΔCO2, 1996-2017**	**ΔCO2, 2003-2017**	**ΔCO2, 2010-2017**	**Effect**	**Curve tail**	**EKC holds**
Argentina	18.0%	21.2%	-0.8%	increase	left	Yes
Australia	-3.4%	-10.8%	-10.3%	decrease	right	Yes
Austria	-8.3%	-18.6%	-10.8%	decrease	right	Yes
Bangladesh	244.4%	136.6%	44.3%	increase	left	Yes
Belgium	-30.6%	-26.7%	-16.6%	decrease	right	Yes
Brazil	37.7%	27.7%	8.4%	increase	left	Yes
Bulgaria	-4.8%	0.8%	1.6%	increase	left	Yes
Chile	58.5%	52.0%	16.0%	increase	left	Yes
China	182.7%	111.2%	13.9%	increase	left	Yes
Colombia	-3.1%	13.7%	7.9%	increase	left	Yes
Croatia	22.1%	-16.3%	-7.6%	decrease	left	No
Cyprus	-11.7%	-23.5%	-17.2%	decrease	right	Yes
Czech Republic	-20.6%	-19.3%	-10.6%	decrease	right	Yes
France	-23.0%	-21.7%	-11.4%	decrease	right	Yes
Germany	-19.7%	-12.5%	-6.3%	decrease	right	Yes
Ghana	127.0%	47.5%	8.5%	increase	left	Yes
Greece	-18.5%	-31.7%	-21.7%	decrease	right	Yes
Hong Kong	8.8%	-6.3%	-0.3%	decrease	right	Yes
Hungary	-15.9%	-16.6%	-0.8%	decrease	left	No
Iran	75.2%	34.7%	4.5%	increase	left	Yes
Ireland	-20.5%	-29.5%	-14.3%	decrease	right	Yes
Israel	-11.6%	-19.8%	-18.6%	decrease	right	Yes
Japan	-2.4%	-4.2%	0.5%	decrease	right	Yes
Jordan	-5.3%	-15.5%	-3.6%	decrease	left	No
Kenya	50.1%	93.3%	22.6%	increase	left	Yes
Korea	39.3%	27.8%	5.1%	increase	right	No
Lebanon	7.0%	14.8%	7.0%	increase	left	Yes
Luxembourg	-27.9%	-33.7%	-31.2%	decrease	right	Yes
Malaysia	56.6%	26.0%	0.7%	increase	left	Yes
Malta	-47.0%	-50.5%	-47.9%	decrease	right	Yes
Mauritius	131.9%	45.7%	12.7%	increase	left	Yes
Mexico	9.2%	-4.7%	-7.4%	decrease	left	No
Morocco	74.1%	47.2%	13.9%	increase	left	Yes
Netherlands	-18.6%	-13.3%	-11.6%	decrease	right	Yes
Nigeria	36.9%	9.9%	25.5%	increase	left	Yes
Norway	-8.7%	-12.2%	-17.6%	decrease	right	Yes
Oman	109.0%	31.7%	-0.3%	increase	left	Yes
Pakistan	36.7%	34.4%	22.6%	increase	left	Yes
Panama	54.9%	42.4%	-3.1%	increase	left	Yes
Peru	52.5%	74.1%	10.6%	increase	left	Yes

Table 6 (continuation)

Country	**ΔCO2, 1996-2017**	**ΔCO2, 2003-2017**	**ΔCO2, 2010-2017**	**Effect**	**Curve tail**	**EKC holds**
Philippines	38.2%	44.7%	46.5%	increase	left	Yes
Poland	-10.9%	5.0%	-0.4%	decrease	left	No
Portugal	9.4%	-9.4%	9.6%	increase	right	No
Romania	-32.3%	-19.6%	-2.1%	decrease	left	No
Russia	3.6%	3.0%	-0.7%	increase	left	Yes
Saudi Arabia	46.0%	31.6%	2.3%	increase	left	Yes
Singapore	-19.5%	-8.9%	1.2%	decrease	right	Yes
Slovenia	-11.0%	-11.4%	-11.9%	decrease	right	Yes
South Africa	18.2%	1.2%	-8.1%	increase	left	Yes
Spain	-0.2%	-24.0%	-3.1%	decrease	right	Yes
Sri Lanka	139.2%	67.2%	69.7%	increase	left	Yes
Switzerland	-26.9%	-25.9%	-21.1%	decrease	right	Yes
Thailand	34.8%	28.4%	6.0%	increase	left	Yes
Turkey	62.5%	51.9%	26.1%	increase	left	Yes
United States	-24.5%	-24.2%	-15.3%	decrease	right	Yes

Note: This table reports the Environmental Kuznets curve concept of the fixed effect panel regression model estimated in section 4.2. Columns 2-4 show the percentage change of CO_2 emissions per capita for the full sample period, for last 15 and last 8 years. If at least two of three columns show a positive change for a country, the effect is classified as "increase" and vice versa. The column "Curve tail" refers to the tail of the EKC where according to the EKC concept a country should be located at, considering that the turning point of the curve is as estimated in section 4.2. – USD 15`808 per capita. If a country during the sample 22 years have moved from GDP below the turning point, it is classified as in the right or left tail based on in which tail it was for majority of the years. Column "EKC holds" compares the effect with the respective tail of the curve, and if a country whose emissions have increased is located on the left tail and a country whose emissions have decreased is located on the right tail, the concept of EKC is verified by "Yes".

4.4. Evaluating EU ETS, using DiD model

As mentioned in section 3.3., the effectivity of the European Union Emissions Trading System can be estimated, using DiD model. Grouping the panel data by countries being members of EU ETS (the treatment group) and non-members (the control group) before 2005 (pre-treatment) and in 2005 and after (post-treatment) and applying equation (7) gives the coefficient estimates summarized in table 7. With the DiD approach, the average causal effect of the EU ETS on the CO_2 emissions per capita is inferred by comparing its average variations for a group of 21 treated countries and for another group of 34 non-regulated countries, over a time interval since the start of the EU ETS. The estimation of the DiD effect rests on the common trend assumption, which means that if the EU ETS had not been introduced, the averages of CO_2 emissions per capita for treated and non-treated countries would have continued to develop in parallel (Verde, 2020).

The coefficient that attracts the biggest interest is the difference-in-difference estimator, β_3 of the variable *period x treated*, corresponding to the carbon dioxide emissions per capita in countries that joined the EU ETS after 2005. The coefficient estimate shows that the EU ETS accounts for 28.8% reduction in CO_2 emissions, which is a very significant decrease. All the coefficients in the model are significant on a 95% confidence level, hence the effect can be logically derived from the regression model.

Table 7. Difference-in-difference model estimates

	Estimate	**Standard error**	**p-Value**
intercept	0.9564	0.0561	0.0000
period	0.1978	0.0730	0.0068
treated	1.0542	0.0908	0.0000
period x treated	-0.2878	0.1181	0.0150
number of observations	1210		
Adj. R-squared	0.164		

Note: This table reports the coefficient estimates, standard errors and p-values of the variables in a difference-in-difference model, described by equation (7). The variable "period" stands for a dummy variable with value of 1 for the observations after the introduction of EU ETS (European Union Emissions Trading System) in 2005, and a value of 0 otherwise. The variable "treated" stands for a dummy variable with a value of 1 for countries that are members of the EU ETS (EU member states plus Norway and Switzerland) and 0 for other countries included in the sample. The multiplication variable of the two dummies, "period x treated", gets a value of 0 only for countries that have been treated with the EU ETS and only after 2005. All three previously mentioned variable coefficients, as well as the intercept are statistically significant with a 95% confidence level (p-value < 0.05).

Taking into consideration the relatively high significance of the EU ETS effectiveness in reducing the CO_2 emissions, it can be confirmed that this policy is successful. The policy, apart from other environmentally restricting policies, not only sets limits for certain manufacturing and trade flows but also creates a positive climate for carbon-efficient business. This is one of the main aspects why EU ETS is supported as a successful carbon-reducing policy. Various countries (e.g., China) have already implemented the system to some extent on a regional scale, and it is expected to become even more common in the future, as countries are forced to come up with new environmental policies to balance the negative effect of an increasing economic and financial development (see subsection 4.2.).

5. Robustness tests

To verify the robustness of the regression model estimates analysed in the previous section, various adjustments are tested: winsorizing the data, excluding the variables of the regression model, using other data source for CO_2 emissions variable, using different measure of financial development, and analysing the lagged variables in the regression model. This section introduces the adjustments and compares the initial regression estimates with the adjusted ones to see whether changing a particular aspect in the regression model or its assumptions significantly changes the results.

5.1. Winsorizing data

To reduce the influence on the regression results of outliers in the data sample, winsorization is used. There are several methods for winsorizing the data (e.g., reducing the weight of outliers in the calculations), but for this data set the bottom and top 5% data points are winsorized by "cutting" the value to equal the value of 5% or 95% percentile, respectively. Therefore, by adjusting the values of lowest and highest 5% of total observations, a 100% - 5% - 5% = 90% winsorization is conducted. As a result, the variance of the data sample is reduced.

As can be seen in the appendix D, for the panel regression model only the GDP, GDP_sq and FD variables are significant at the 95% level. What is more, adjusting the outliers has not changed the coefficient estimates to a big extent. An exception could be the financial structure variable whose coefficient has changed from negative to positive; however, considering it is not significant, no deeper interpretation is derived. Similar situation is seen for the spatial panel regression as well – apart from the fact that in the adjusted version the trade variable is not significant anymore. Slight changes in the coefficient estimates yield in different turning points for the EKC – for the panel model it increases to USD 17`634, while for the spatial panel model is decreases to USD 14`552.

5.2. Excluding variables

To see whether the regression model is stable and performs similarly under a different specification, certain variables are excluded from the regression. Table 8 shows the different coefficient estimates, running the panel regression model as in equation (1), excluding variables in various ways. The coefficient estimates do not change to a great extent and gives a similar economic interpretation as the initial regression model. Therefore, again it is verified the model is robust to different changes.

It should be noted that the turning point of the EKC differs for the various selections of independent variables included in the regression model. For instance, the reason why for versions (c) and (d) the turning point is around USD 5`000 higher is the exclusion of the financial development variable. It is significant on a 95% confidence level, and its impact on the CO_2 emissions and the GDP threshold after which countries tend to become more carbon-efficient is also significant. Therefore, the main model should include this variable, otherwise flawed conclusions about the economic relationship could be made.

Table 8. Robustness check, excluding various variables

Variable	**(a)**	**(b)**	**(c)**	**(d)**
GDP	1.1686***	1.1601***	1.1170***	1.1148***
GDP_sq	-0.0607***	-0.0601***	-0.0562***	-0.0560***
FD	0.0472**	0.0470**		
FS	-0.0090		-0.0085	
T			-0.0083	
N				
Adj. R-squared	0.3301	0.3285	0.3119	0.3110
p-value	0.0000	0.0000	0.0000	0.0000
EKC holds	Yes	Yes	Yes	Yes
Turning point	USD 15 254	USD 15 536	USD 20 802	USD 20 911

Note: This table reports the coefficient estimates of the panel regression model as in equation (1), excluding variables in four different ways. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term. *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. *** symbolizes significance at 99% level, ** at 95% level and * at 90% level.

5.3. Other CO_2 emission data

Another contribution is to check the robustness of the empirical results across two alternative carbon emissions data series. Therefore, data for CO_2 emissions that does not come from the International Energy Agency (IEA) is used. The alternative data source is Carbon Dioxide Information Analysis Center (CDIAC). Data for other variables remains the same. Compared to the CDIAC data, the cement output and gas flaring are not included in the IEA data set, which is based on energy balances. "The IEA data set appears to be more precise mainly because it has used specific emission coefficients for different energy products, while in the CDIAC case, a single coefficient is used for gas, oil, and solid fossil fuels without any distinction among individual energy products" (Galeotti, Lanza & Pauli, 2006, p.156).

The differences between the data series are significant. The CDIAC data is available only until 2014, therefore the comparison is conducted to corresponding IEA data. The IEA numbers are bigger, due to differences in methodology in data gathering and calculation. The mean value of CO_2 emissions per capita for CDIAC (IEA) are 1.8 (6.1), the minimal and maximal values are 0.1 (0.1) and 6.9 (24.7), respectively. The standard deviation is 1.3 (4.5), hence, the variance is bigger for IEA data.

The estimated coefficients are similar in magnitude to the coefficients of the initial regression with the IEA data, however, there are differences. For the initial regression model GDP, GDP squared term and FD coefficients are significant, however, for the CDIAC data regression only the GDP terms are significant at a 95% confidence level. For both data sets the EKC can be obtained, however, the turning point differs: changing the dependent variable data source increases the turning point from USD 15`818 to USD 21`885. It is important to note, however, that the initial regression turning point is estimated by using data for years 1996-2017, while for CDIAC it is 1996-2014. The last three years can partially explain the turning point difference, as in recent years most countries have become more carbon-efficient, therefore, the GDP required for a shift to a reduction in CO_2 emissions also decreased. Using different CO_2 data for the model lowers the adjusted R-squared from 0.3306 to 0.2284. The regression model output can be found in the appendix E.

Overall, the results appear to follow a similar trend across the two data sets. Thus, it can be concluded that the relationship between the independent variables and the CO_2 emissions do not seem to differ much using different measures and data for CO_2 emission data. Yet the IEA data portray the relationship to a bigger extent.

5.4. Different measure of Financial development

Various studies argue the inconsistency in defining the financial development variable. Instead of using the PCA derived financial development index as described in the section 3.1., a different measure of FD is applied, as done by De Haas and Popov (2019). To check whether the assumption of an accurate financial development measure is robust, the index is replaced by one of the components of the index, sum of private credit and stock market capitalization divided by the country’s gross domestic product (C).

Using the natural log-transformed version of the C ratio does not change the regression coefficient estimates to a big extent (see appendix E). Both GDP and GDP squared are significant at a 99% confidence level, while FD is significant at a 90% confidence level. For a comparison, the index used previously is significant at a 99% level. For both versions, financial structure and trade openness variable coefficients are not significant. The turning point for the model with C as the only FD measure increases to USD 17`213. Therefore, this shows that a change in a definition of an explanatory variable can change the interpretation of the regression slightly; however, as argued in section 3.1., using one ratio as a measure of financial development is not recommended as a composite index explains the aspects of the variable better.

5.5. Lagged variables

The ultimate robustness check is to use lagged variables for the regression model. As De Haas and Popov (2019) argue, variables as financial development and financial structure do not have an immediate effect on the carbon-efficiency, therefore a one-year lag is recommended to be used. The same applies for other variables in the main model. Therefore, the panel regression model is as follows:

$$\frac{CO_{2c,t}}{Population_{c,t}} = \beta_1 \ln\left(GDP_{c,t-1}\right) + \beta_2 \ln\left(GDP_{c,t-1}\right)^2 + \beta_3 FD_{c,t-1} + \beta_4 \ln\left(FS_{c,t-1}\right) + \beta_5 \ln\left(T_{c,t-1}\right) + \gamma_c + \varphi_t + \varepsilon_{c,t} \quad (9)$$

Using the lagged values of the explanatory variables reduces the scope of the observations to 1155. However, as can be seen in appendix E, also for this regression the results remain stable and have a similar interpretation. GDP, GDP squared (99% significance) and FD (90% significance) are the determinants that are proven to be statistically significant, and their coefficients are similar in the magnitude as the initial panel regression estimates. For this model, the EKC also holds yet the turning point in this case decreases to USD 13 468. This difference is related to the lag in the GDP, as normally assumed an increase in the gross domestic product has a long-term effect on manufacturing, carbon-heavy industries included. However, the actual lag effect differs country by country as the economies are different in the flexibility of adjusting to certain financial shifts.

To sum up, as tested in subsections 5.1.-5.5., the panel regression model as in equation (1) is robust to various adjustments, hence, the model describes the relationship between the CO_2 emissions and financial determinants well. As seen in majority of the regression outputs, the main variables that are significant are GDP and financial development of the country. To portray the non-linear relationship, the squared GDP is used, and is significant in all tested models with 99% confidence level.

6. Conclusions

CO_2 emissions, as greenhouse gas emissions overall, are a raising concern to the World, as they have various climate, economic and social effects – mostly of which are negative. Several aspects are considered to be of a big importance in the amount of the pollutants emitted in our planet's atmosphere, including financial aspects. The set aim of the paper is to estimate a regression model that accounts for the main financial determinants of carbon dioxide emissions. As studied in other papers, the most common financial determinants are economic development of a country (usually measured by GDP), financial development and structure of an economy, as well as trade openness of country.

To carry out the necessary empirical analysis, a data panel of 55 countries during the time period of 1996-2017 is created. The panel represents a variety of economically and geographically different countries, which in total correspond to a little below 80% of total carbon dioxide emissions in the world, therefore, it is used as a proxy for making conclusions on a global scale. However, it is important to note the fact that the necessary information and data is limited time and variable-wise, thus making it more complicated to derive very specific and in-depth interpretations about the global situation.

The dependent variable of the regression model, CO_2 emissions per capita, has not increased significantly in the sample time period on average. However, that is due to the balancing of countries that have become more carbon-efficient and other countries that have become more carbon-heavy in time. On a country-level scale, the dependent variable changes over time significantly for all countries included in the sample.

In most versions of the regression model three out of the five explanatory variables are found to be significant: economic development – measured by the gross domestic product of a country and the squared term of it, corresponding to the non-linear relationship between it and carbon dioxide emissions –, as well as financial development, measured by the financial development index. The financial development has an increasing effect to the carbon dioxide emissions – for a one unit increase in the financial development index, the emissions per capita rise by 4.94%.

The effect of financial determinants on the CO_2 emissions is often visualised by the Environmental Kuznets curve - implying that in the first stages of economic development the greenhouse gas emissions increase, whereas after reaching a certain threshold of economic development they decrease, visualised as an inverse U-shaped curve. In the empirical study, EKC holds for all the regression models run for the panel data globally, and the concept works accordingly for 85.5% of the countries included on a country-by-country level. Although found in several previous studies, for this dataset an N-shaped EKC curve is not verified, as the regression model with the cubic GDP term does not return any significant coefficients. The turning point of the U-shaped EKC differs based on the methodology used when estimating the regression coefficients, however, as derived by the main regression model, after reaching around USD 15`900 GDP per capita in the average sample country, the carbon emissions of the country should start to decrease.

In several other studies and a few of the regression models run in this study, evidence for "greening" effect of an increase in equity financing in the economy is found. Although the literature (e.g., De Haas & Popov, 2019) supports the idea that the bigger the proportion of equity financing, the bigger the carbon-efficiency of an economy, in this study the determinant is not always proven to be significant and the magnitude of the effect is ambigious.

Despite the trade openness, measured by a ratio of total exports and imports of a country divided by the country's GDP, is not found to be significant in most of the regressions, including a spatial weight matrix in the panel regression model gives an evidence of the fact that geographical and economic relations between countries do affect country's environmental performance.

Apart from the previously mentioned financial determinants, there are several environmental-financial policies that affect the carbon dioxide emissions, for example the European Union Emissions Trading System introduced in 2005. By using a difference-in-difference regression model, it is shown that the policy accounts for 28.8% reduction in CO_2 emissions, which is a very significant decrease. Therefore, environmental policy is a successful tool in making economies more carbon efficient.

Overall, finance is very closely linked to carbon dioxide emissions and the dynamics of the changes in them. For a further in-depth study, creating a bigger panel covering more countries and years would be recommended, as the greenhouse gas emissions increase has been present for centuries both in global economic growth and recession times, yet the data is available only for a couple of decades. Testing other measures of the determinants, especially for the financial development, could provide a wider economic interpretation. The research question is based on many assumptions, and as proven by various studies in the past, the regression models used must be adjusted regularly, due to evolving economic and technological aspects in the global economy as well as new environmental policies in place.

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Appendix A

List of countries and territories included in the sample, grouped by The World Bank classification (2020)

Europe & Central Asia
Austria
Belgium
Bulgaria
Croatia
Cyprus
Czech Republic
France
Germany
Greece
Hungary
Ireland
Luxembourg
Netherlands
Norway
Poland
Portugal
Romania
Russia
Slovenia
Spain
Switzerland
Turkey

Middle East & North Africa
Iran
Israel
Jordan
Lebanon
Malta
Morocco
Oman
Saudi Arabia

South Asia
Bangladesh
Pakistan
Sri Lanka

Sub-Saharan Africa
Ghana
Kenya
Mauritius
Nigeria
South Africa

East Asia & Pacific
Australia
China
Hong Kong
Japan
Korea
Malaysia
Philippines
Singapore
Thailand

Latin America & Carribean
Argentina
Brazil
Chile
Colombia
Mexico
Panama
Peru

North America
United States

Appendix B

Panel regression model specification tests: poolability, Hausman test and individual effects

Test of poolability

```
H0: Stability of coefficients
F(324,880) = 314.281329
p-value = 0.0000
```

Hausman's test of specification

Varname	A:FE	B:RE	Coef. Diff	S.E. Diff
GDP	1.147873	1.154765	-0.006892	0.000000
GDP_sq	-0.059359	-0.058997	-0.000361	0.000000
FD	0.049394	0.048990	0.000404	0.000000
FS	-0.008617	-0.006430	-0.002187	0.000000
T	-0.033932	-0.022924	-0.011008	0.000000

```
A is consistent under H0 and H1 (A = FE)
B is consistent under H0        (B = RE)
H0: coef(A) - coef(B)  = 0
H1: coef(A) - coef(B) != 0
      H = 251.6549542 ~ Chi2(5)
      Critical value = 1.1454762
```

Individual Effects

id	ieffect	Std. Error	t-stat	p-value
OVERALL	-3.888622	0.307959	-12.6271	0.000 ***

Note: This appendix reports results for three panel regression model specification tests: **(a)** test of poolability to test whether the regression coefficients are stable over time and can be pooled; as the p-value is less than significance alpha 0.05, the hypothesis is rejected and panel regression is used. **(b)** Hausman test compares fixed and random effect models and their efficiency. As the test statistic is higher than chi-square distribution with 5 degrees of freedom critical value, the null hypothesis of no significant difference between the model coefficients is rejected and fixed effects are preferred. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term, *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. **(c)** Individual effects test considers the joint significance of the fixed effects. As the overall term p-value is less than 0.05, the effects are proven to be significant.

Appendix C

Panel regression model specification tests: multicollinearity, cross-sectional dependence

(a) cor = 5×5

	GDP	GDP_sq	FD	FS	T
GDP	1.0000	0.9964	0.5967	0.2282	0.3457
GDP_sq	0.9964	1.0000	0.6097	0.2206	0.3478
FD	0.5967	0.6097	1.0000	0.1739	0.4148
FS	0.2282	0.2206	0.1739	1.0000	-0.1447
T	0.3457	0.3478	0.4148	-0.1447	1.0000

(b) VIF = 1×5

GDP	GDP_sq	FD	FS	T
144.9394	147.7309	1.8044	1.1522	1.3291

(c) Baltagi, Song, Jung and Koh's test for serial correlation, spatial autocorrelation and random effects

```
H0: No spatial autocorrelation, no serial error correlation and no re.
H1: Spatial autocorrelation or serial error correlation or random effects.
Chi2(3) = 7104.266008
p-value = 0.0000
```

Note: This appendix reports **(a)** correlation matrix between 5 independent variables – financial determinants; **(b)** VIF values of all 5 independent variables and **(c)** specification test for serial correlation, spatial autocorrelation and random effects of the regression model. As the p-value of (c) is less than significance alpha 0.05, the null hypothesis is rejected and cross-sectional dependence is diagnosed. VIF values higher than 10 are considered problematic, however, they are only higher than 10 for the same term in different transformations (GDP), so the model does not face significant multicollinearity. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term, *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product.

Appendix D

Panel and spatial panel regression model outputs, using 90% winsorization

Panel A: Fixed effects (within) (FE)

N = 1210 n = 55 T = 22 (Balanced panel)

R-squared = 0.31964 Adj R-squared = 0.28473

Wald F(5, 54) = 8.307917 p-value = 0.0000

RSS = 15.668010 ESS = 3673.125857 TSS = 3688.793867

Standard errors robust to heteroskedasticity adjusted for 55 clusters

CO2/pop	Coefficient	Rob.Std.Err	t-stat	p-value
GDP	1.142801	0.294909	3.8751	0.000 ***
GDP_sq	-0.058440	0.016263	-3.5933	0.001 ***
FD	0.051800	0.022325	2.3202	0.024 **
FS	0.009039	0.011021	0.8201	0.416
T	-0.086241	0.064951	-1.3278	0.190

Panel B: Fixed effects spatial two stage least squares (FES2SLS)

N = 1210 n = 55 T = 22 (Balanced panel)

R-squared = 0.35245

Wald Chi2(6) = 411.656321 p-value = 0.0000

RSS = 28755.187475

CO2/pop	Coefficient	Std. Error	z-stat	p-value
GDP	1.059253	0.082925	12.7736	0.000 ***
GDP_sq	-0.055253	0.004744	-11.6470	0.000 ***
FD	0.047109	0.010156	4.6385	0.000 ***
FS	-0.014573	0.006573	-2.2171	0.027 **
T	-0.011805	0.027343	-0.4317	0.666
W*CO2/pop	0.059892	0.004995	11.9914	0.000 ***
rho	0.107504	0.127395	0.8439	0.399

Endogenous: W*CO2/pop

Note: This appendix reports estimates of two regression models, using 90% winsorization of the input data: Panel **A** is a panel regression model with fixed effects, within transformation, clustered standard errors; Panel **B** is a spatial panel regression model with fixed effects. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term. *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy, measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. *W*CO2/pop* is the multiplication of the spatial weight matrix W and the dependant variable, CO_2 emissions per capita. *Rho* is the coefficient of the spatial error term. *** symbolizes significance at 99% level, ** at 95% level and * at 90% level.

Appendix E

Regression model outputs, testing for several robustness adjustments

Variable	**(a)**	**(b)**	**(c)**
GDP	0.9376***	1.0837***	1.2045***
GDP_sq	-0.0469***	-0.0556***	-0.0633***
FD	0.0238	0.0584*	0.0363*
FS	0.0025	-0.012	-0.0016
T	0.0233	-0.0298	0.0105
N	1045	1210	1155
Adj. R-square	0.2284	0.3221	0.3102
p-value	0.0002	0	0
EKC holds	Yes	Yes	Yes
Turning point	USD 21 885	USD 17 213	USD 13 468

Note: This appendix reports estimates of three panel regression models: **(a)** using CDIAC data for CO_2 emissions data; **(b)** using different measure for FD – C ratio; **(c)** using one-year lagged values of the explanatory variables. *GDP* stands for the natural logarithm of a country's gross domestic product, *GDP_sq* stands for the squared natural logarithm of the *GDP* term. *FD* is the financial development index of an economy, whereas FS stands for the financial structure of the economy (for (a) and (c)), measured by the natural logarithm of the share of stock. *T* is the natural logarithm of trade openness variable, measured by total country's exports and imports divided by gross domestic product. *N* shows the total number of observations included in the regression. *** symbolizes significance at 99% level, ** at 95% level and * at 90% confidence level.