Research article

Transmission channels between financial development and CO_2 emissions: A global perspective

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A R T I C L E   I N F O

A B S T R A C T

This paper aims to investigate the direct and indirect effects of financial development on CO2 emissions, using a global sample of 100 countries from 1990 - 2012. Our main contribution to the literature lies in the identification and explanation of possible transmission channels that allow financial development to affect environmental quality. The paper employs 2SLS and 3SLS estimators to investigate these channels. Empirical results confirm the positive direct effect of financial development on environmental degradation. Development of the financial system also gives rise to more energy demand and consequently leads to more pollutant emissions. Besides, there is evidence about a trade-off between income inequality and environmental quality. Financial development can help redistribute income more effectively. However, high living standards will put pressure on environmental conservation. The paper also considers the nonlinear effects of financial development on carbon emission rates. Only a small proportion of the population receive the benefits at the early stages of financial development. After a certain amount of time, financial development benefits a more significant part of the population and reduces income inequality.

1. Introduction

CO_2 emission and climate change are attracting considerable interest in the related literature due to its impacts on the global environment and economic activities (Cucchiella et al., 2020; Arioli et al., 2020). Financial development, which involves reducing information asymmetries and improving capital allocation, plays a critical role in economic development. Additionally, a large body of empirical studies postulates that financial development is a crucial determinant affecting the environment quality (Shahbaz et al., 2013; Khan et al., 2018; Boutabba, 2014; Zhang, 2011; Charfeddine and Kahia, 2019; Tamazian et al., 2009; Jiang and Ma, 2019). Financial development allows firms to finance their R&D activities or new facilities, which will have some effects on the environment. Although many authors have put their effort into examining the link between financial development and pollution, there is still no consensus about the sign and magnitude of the effect. On the one hand, growth in the financial sector provides more funds for the energy sector to research new technologies aimed to reduce emissions. On the other hand, financial development can stimulate manufacturing activities, thus increases pollution in the process.

Despite many studies on the effect of financial development on CO2 emissions, few of them have explained how improvement in financial systems can affect the environment quality. Most of the previous work only concentrates on the direct effect. However, the indirect effects can pass through several channels such as the energy demand channel, the growth channel or the income inequality channel. For instance, financial development can help fighting poverty and reducing inequality. This is because financial development facilitates the access of the poor and other vulnerable agents to various financial services, provides them with better risk management options, thus making them less susceptible to shocks. However, there is evidence that better income equality can lead to environmental degradation (Ravallion et al., 2000). Thus, when a country improves its financial system, it may have to choose between living standards and environmental quality. The importance of having a suitable policy to control energy consumption and develop new energy sources, such as renewable energy source is also highlighted in Caruso et al. (2020).

This study contributes to the related literature in several aspects. First, this paper takes a new look at several transmission channels, through which financial development can affect CO2 emissions. We examine three channels: the energy demand channel, the economic growth channel and the income inequality channel, which are somewhat neglected in the previous literature. In the literature, there are very few studies looking at these transmission mechanisms. For exam-

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ple, previous literature often looks at the direct effects and does not delve into the indirect effects (see Khan et al. (2018); Kim and Lin (2011); Ang (2010)). Furthermore, energy economics literature often concentrates on the link between economic growth and energy consumption (Shahbaz and Lean, 2012). As far as we know, no one has taken into account financial development, energy demand, economic growth, income inequality and energy consumption in a comprehensive study. Second, other authors have rarely focused on a global perspective (Jiang and Ma, 2019). Most of them investigate the financial development - CO2 emissions nexus using a single-country time series. Therefore, using a global sample will allow us to look at the whole picture and obtain more general results.

There are several points worthy of note. We find adverse effects of financial development on income inequality in all specifications. In other words, financial development brings better living standards. However, countries with lower income inequality tend to have higher emission rates of carbon dioxide, the main culprit of global warming. This result implies a trade-off between narrowing the income gap and preserving the environment, as shown in Ravallion et al. (2000). Besides, financial development also affects CO2 emissions through the energy consumption channel. Improving financial intermediaries also gives rise to more energy demand, by allowing more purchase of durable goods, consequently, leads to more pollutant emissions. However, the empirical results do not show any evidence of the growth channel.

The rest of the paper is structured as follows. Section 2 reviews the theoretical and empirical results about the relationship between financial development and CO2 emissions and identifies the main transmission channels. Section 3 elaborates the empirical specification and the scope of the study, while Section 4 discusses the empirical results. Finally, Section 5 concludes the study.

2. Literature review

The theoretical literature on financial development - CO2 emissions nexus is well developed. This study aims to show the possible transmission channels between financial development and environmental degradation, measured by CO2 emissions. The effect of financial development on environmental quality is inconclusive. Financial development can be both beneficial and detrimental to the environment.

Financial development leads to higher emission rates

It is one of the main drivers of various manufacturing activities, which contributes to more pollution and degrades the environment quality. This is because the consequences of asymmetric information are less severe when the financial system functions well. Thus, financing costs are lowered, and firms can facilitate their economy of scale through investing in new production lines and heavy machinery, eventually leading to higher pollutants emissions. Furthermore, well-developed financial markets can supply more consumer credits. These credits will help individuals to consume more durable goods such as automobiles, electronic devices, real property. The consumption will continue to expand as the financial markets provide more and more credit and further degrade the environment.

For example, financial development is among the determinants of increasing CO2 emissions in China (Zhang, 2011). Similarly, financial development has a positive impact on CO2 emissions and deteriorate the environment in India (Boutabba, 2014; Khan et al., 2018). Shahbaz et al. (2016) propose that the impact of financial development on pollution can be asymmetric. They establish an index of financial development for Pakistan using quarterly data from 1895Q1 - 2014Q4. The paper confirms the positive unidirectional impact of banking sector development on CO2 emissions. Similarly, this one-way effect is also found in Bekhet et al. (2017) for Gulf Cooperation Council economies such as the United Arab Emirates (UAE), Oman and Kuwait.

Using VECM Granger method with a sample of Turkey from 1960-2013, Cetin et al. (2018) conclude that economic growth, energy demand, trade openness and financial development cause more CO2 emissions. These impacts are also unidirectional. In a similar vein, Ali et al. (2019) investigate the relationship between financial development, energy consumption, trade openness, economic growth and carbon emission in Nigeria from 1971-2010. Their long-run estimation results show that the development of the financial system contributes significantly to pollution.

For European economies, Al-Mulali et al. (2015) also confirm the adverse effect of financial development on environmental quality, using a sample of 23 countries and the panel-pooled FMOLS model. Similarly, financial development in 12 Asian economies contributes to high emission rates of carbon dioxide in these countries. These results are confirmed in Lu (2018), using panel estimation techniques. They propose that these countries should use other energy sources to replace fossil fuels. In a recent article, Jiang and Ma (2019) also conclude that financial development positively affects CO2 emissions from a global perspective. That is, their results hold for both developed countries and emerging markets.

Financial development reduces emission rates

However, other authors argue that financial development can help reduce air pollution (Tamazian et al., 2009; Khan et al., 2018; Shahbaz et al., 2013; Salahuddin et al., 2015). This goal can be achieved through the adoption of new technologies that are energy-efficient and through reinforcing environment regulation. Improving financial intermediation also reduces financing cost and can channel more funds into environmentally friendly projects. Development in the financial sector promotes carbon trading activities, which helps control the emission of harmful air pollutants (Claessens and Feyen, 2007). Following Tamazian and Bhaskara Rao (2010), local and national governments are responsible for environmental projects. Thus, they may induce financial institutions to channel more funds into environmental-friendly purposes. Using system GMM estimators, they find that financial development in transition economies helps improve environmental quality. Using the same econometric method, Saidi and Mbarek (2017) reveal that financial development reduces CO2 emissions in 19 emerging countries in the long run.

According to Dogan and Seker (2016), higher consumption of renewable energy sources and financial development decreases carbon dioxide emissions for a sample of the top renewable energy countries. Similar positive impacts of financial development on environmental quality are confirmed in the study of Zafar et al. (2019) for OECD countries and Zaidi et al. (2019) for APEC economies. Claessens and Feyen (2007) also state that better emission management can be achieved by developing the financial system and practising high governance standards.

Previous papers also conclude that the impact of financial development on carbon dioxide emissions can be insignificant. For example, Ozturk and Acaravci (2013) and Ali find no significant effect of financial development on pollutant emissions in Turkey for the period 1960-2007. Dogan and Turkekul (2016) do not find enough evidence to support the link between financial development and carbon emissions in the USA from 1960-2010. Existing literature suggests several possible transmission channels through which financial development affects environmental quality.

$FD \rightarrow GINI \rightarrow CO_2$ **channel**

The first channel through income inequality is often being neglected in the literature. On the empirical ground, few studies consider the indirect effects of financial development on environment degradation through income inequality. Khan et al. (2018) investigate these relationships, but they do not account for the transmission. Imperfections in under-developed financial markets can result in a consistent income gap, due to asymmetric information and high transaction costs. These imperfections will create financial barriers and constraints, thus limiting the access of small firms and the poor to credits in the markets. Hence, financial development, which reduces financial frictions, can

help allocate capital more efficiently and reduce inequality (Kim and Lin, 2011). A variety of empirical studies support this framework. For instance, financial development in 83 countries over the period 1960 - 1995 reduces income inequality (Clarke et al., 2006). Beck et al. (2007) also find that financial development helps the poor and lessens the income gap in 72 countries from 1960 to 2005. Time-series data confirms the similar results in India from 1951-2004 (Ang, 2010). However, according to the previous literature, improving income equality may have some detrimental effects on the environment quality. Cross-country studies imply that countries with improved living standards can have high carbon emissions. When income inequality is reduced, the marginal impacts of economic growth on pollutant emissions can decline. So better income equality can lead to environmental degradation because income from countries with a low marginal propensity to emit will be redistributed to those with a higher propensity (Ravallion et al., 2000). Hence, when a country's financial system develops, there is a trade-off between lowering income inequality and controlling global warming.

$FD \rightarrow$ **Energy demand** $\rightarrow CO_2$ **channel**

Financial development can directly affect energy demand by providing more consumer credits to buy durable items like cars, houses, and other household appliances such as washing machines, TVs, dishwashers, refrigerators, air conditioners. Companies can also benefit larger pool of credits to finance their machinery and equipment or employ more labours. The energy demand of these items will put pressure on the country's total energy demand (Sadorsky, 2010). Using a sample of 53 countries from 1999 to 2008, Chang (2015) find that financial development contributes positively to energy demand. Then, it is documented that energy consumption is a key determinant of CO2 emissions. For example, Arouri et al. (2012) find that energy consumption positively affects CO2 emissions in the long-run for a group of 12 the Middle East and North African. Similar results are confirmed in Pao and Tsai (2010) for BRIC economies, in Nasir and Ur Rehman (2011) and Rehman for Pakistan, in Sharif Hossain (2011) for a group of newly industrialised countries. Al-mulali et al. (2012) investigate a sample of low-income economies and find that 84% of the countries in their sample report a positive relationship. Hence, a possible indirect effect of financial development on environmental quality passes through the channel $FD \rightarrow$ Energy demand $\rightarrow CO_2$.

$FD \rightarrow$ **Growth** $\rightarrow CO_2$ **channel**

Additionally, financial development can also affect air pollution through the growth effect. First, the literature on financial development and growth is well-established. The work of Levine (2005) sets the central theoretical pillar of this relationship. Countries with highly developed financial systems can achieve high growth because available funds are allocated efficiently, and borrowing barriers are removed. This growth can benefit a large proportion of the population, especially the poor. Second, the link between growth and environmental quality is examined extensively in the literature. One well-known result is the Environmental Kuznets Curve (EKC). In the early stages of development, economic growth causes environmental degradation. However, when growth passes a threshold level, environmental responsibility kicks in, and growth will focus on environmental-friendly activities (Grossman and Krueger, 1995). The EKC hypothesis is investigated in various empirical studies (Park and Hong, 2013; Salahuddin et al., 2015; Sharif Hossain, 2011; Omri, 2013; Charfeddine and Kahia, 2019). However, there is no consensus in term of the direction of the effect and its significance. To this end, the paper investigates the channel $FD \rightarrow$ Growth $\rightarrow CO_2$.

3. Empirical methodology

3.1. Empirical model

This paper aims to examine the relationship between CO2 emissions, energy consumption, financial development and income inequality us-

ing a global sample. The basic specification for energy consumption is modified from Shahbaz and Lean (2012):

$$EC_i = f(FD_i, PGDP_i, IND_i, URB_i, RENEW_i) \quad (1)$$

where EC_i is total energy consumption per capita, FD_i is the financial development index, measured by total domestic credit to private sector as a share of GDP, $PGDP_i$ is GDP per capita growth, IND_i is the industrial value added as share of GDP, a proxy for industrialisation, URB_i is the ratio of urban population to total population, representing urbanisation and $RENEW_i$ denotes renewable energy consumption.

The model for CO_2 emissions is developed from Sharif Hossain (2011); Khan et al. (2018); Shahbaz et al. (2013):

$$CO2_i = f(EC_i, GINI_i, FD_i, PGDP_i, IND_i, URB_i, RENEW_i, TRADE_i)$$

$$(2)$$

where $CO2_i$ is the per capita carbon dioxide emissions in metric tons, $GINI_i$ is a proxy for income inequality, and $TRADE_i$ is trade openness, measured by the ratio of exports and imports values over GDP.

Most of the recent literature on CO_2 emission and energy consumption neglect the relationship between financial development and income inequality. However, this relationship can be an important channel transmitting the indirect effect of financial development on carbon dioxide emissions. From the literature in the financial development-income inequality nexus (Kim and Lin, 2011), the model for income inequality is:

$$GINI_i = f(FD_i, PGDP_i, IND_i, URB_i, RENEW_i, INF_i) \quad (3)$$

where INF_i represents inflation, which is measured by the Consumer Price Index. Lastly, the equation for per capita GDP growth is set as:

$$PGDP_i = f(EC_i, FD_i, PGDP_i, IND_i, URB_i, RENEW_i, TRADE_i) \quad (4)$$

Overall, the relationship in the paper can be summarized in the path diagram Fig. 1. The red path indicates the direct effect of financial development on CO_2 emissions. The indirect effects of financial development on CO_2 emission pass through the blue paths. This study considers these channels: the first one passes through energy consumption; the second one passes through income inequality; the last one passes through the per capita income.

As a result, we estimate a system of simultaneous equations:

$$EC_i = \alpha_0 + \alpha_1 FD_i + \alpha_2 PGDP_i + \alpha_3 IND_i + \alpha_4 URB_i$$
$$+ \alpha_5 RENEW_i + \alpha_6 PGDP_i^2 + \epsilon_{1i}$$

$$CO2_i = \beta_0 + \beta_1 EC_i + \beta_2 GINI_i + \beta_3 FD_i + \beta_4 PGDP_i + \beta_5 IND_i$$
$$+ \beta_6 URB_i + \beta_7 RENEW_I + \beta_8 TRADE_i + \beta_9 PGDP_i^2 + \epsilon_{2i}$$

$$GINI_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 PGDP_i + \gamma_3 IND_i + \gamma_4 URB_i$$
$$+ \gamma_5 RENEW_i + \gamma_6 INF_i + \gamma_7 PGDP_i^2 + \epsilon_{3i}$$

$$PGDP_i = \theta_0 + \theta_1 EC_i + \theta_2 FD_i + \theta_3 IND_i + \theta_4 URB_i + \theta_5 TRADE_i$$
$$+ \theta_6 RENEW_i + \epsilon_{4i}$$

$$(5)$$

This paper employs two-stage least squares (2SLS) to estimate the system (5). 2SLS is valid when the dependent variable's error terms are correlated with the explanatory variables. In particular, 2SLS is relevant when there are feedback loops in the system of equations. Existing literature in the energy-growth nexus admits that the problem of endogeneity can come from various unobserved sources (Wong et al., 2013). Moreover, macroeconomic variables tend to be correlated with each other, which leads OLS estimator to produce spurious results.

3.2. Data

The empirical results depend on the data set of 217 countries from 1990 - 2012. However, many countries have reported missing values
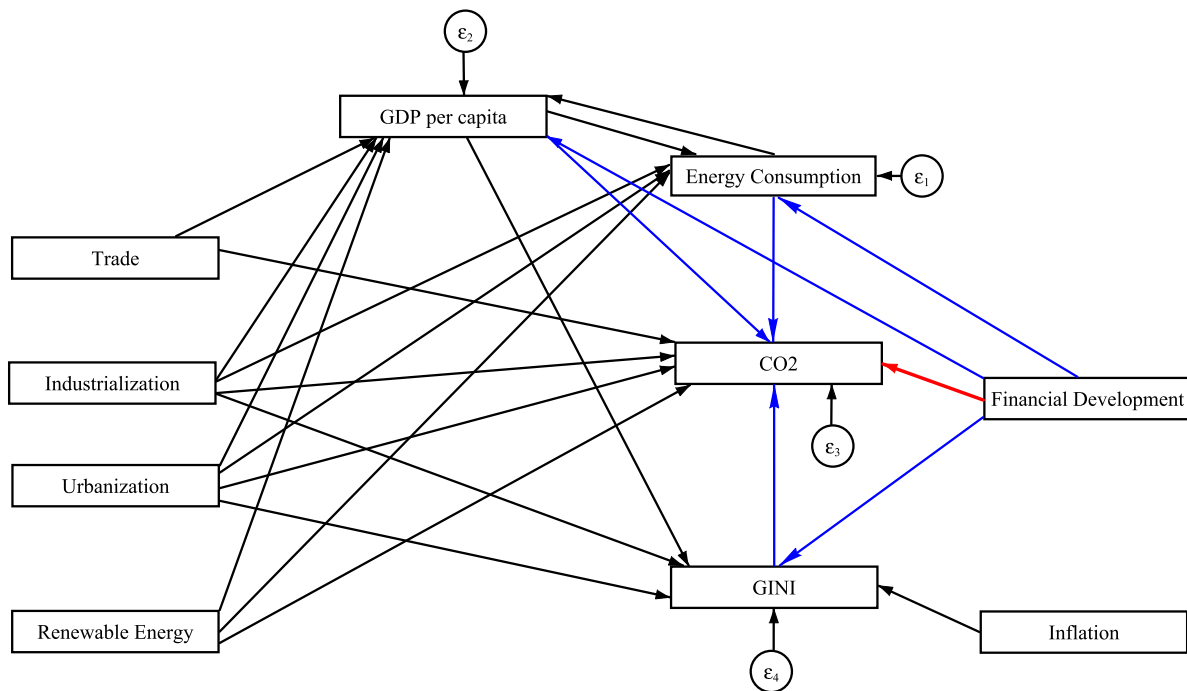
Fig. 1. CO_2 emissions, financial development and income inequality: Direct and indirect effects.

and thus, do not appear in the final data. As a consequence, the final sample consists of only 100 countries. Table 5 in the Appendix A lists all the countries in the sample. It is necessary to emphasize that the evidence of this paper is based on the cross-section of countries, as in Kim and Lin (2011). To this end, the analysis relies on using the average of the data over the sample period.

This paper measures income inequality using the Gini coefficient. The Gini can be calculated by divide the average difference in income between all pairs in a population by twice the average income in the population (Solt, 2019). This index is the most common statistic to measure income inequality. The Solt (2019)'s Standardized World Income Inequality Database (SWIID) is the most comprehensive database of Gini indices in the world. A higher score means more income inequality. The main Gini index used in this study is based on household disposable income. This database calculates the Gini coefficient for a wide range of countries and time periods. The SWIID collects information about inequality up to 2018, but only a few countries report the latest scores. To this end, the paper limits the end year at 2012 to maximise available observations.

The remaining variables for this study are obtained from the World Development Indicator database of the World Bank. All variables are log-transformed. Table 4 in the Appendix A shows the summary, definitions and data sources.

Fig. 2 shows some facts about the correlations among the key variables. The scatterplot highlights the trade-off between improving income inequality and reducing CO_2 emissions. The top-right panel shows that financially developed economies have lower income inequality than countries with poor financial development levels. However, financial-developed countries tend to emit more CO_2 and consume more energy than under-developed economies. Table 6 shows some key descriptive statistics for the data used in the paper.

4. Empirical results

This section presents and discusses the relationship among CO_2 emissions, financial development and income inequality. In particular, the analysis will focus on the direct effect, indirect effect and total effect of financial development on CO_2 emissions.

Table 1 reports the estimation results of the system of equations (5). The table consists of four columns, which correspond to each equation in the system. Financial development positively impacts energy consumption and CO_2 emissions. However, it negatively affects the GINI index, which implies that more financial development would decrease income inequality. All these effects are statistically significant at 5% level. There is evidence of a nonlinear relationship between financial development the income growth.

The coefficient of financial development in the CO2 emissions equation (column (2)) represents the direct effect of financial development on carbon dioxide emissions. This direct impact is significantly positive, implying that high financial development is associated with high carbon emissions from a global perspective. Previous studies, like Boutabba (2014), also confirm that environmental quality decreases with higher levels of financial development. Previous results on the link between financial development and environmental preservation are mixed. Financial development can help control global warming by channelling more capital into environmental-friendly projects, or by funding R&D activities that preserve the environment. These actions will result in lower carbon emission rates and a better environment. This is called the beneficial effect of financial development on the environment. However, financial development can also stimulate production and consumption on a larger scale and cause more pollution. It will lead to the degradation of the environment. It can be regarded as the detrimental effect. From a global view, this study confirms that the detrimental effects dominate the benefits, which is in line with Jiang and Ma (2019). The lower panel of Fig. 2 also shows the dominant effect of financial development on CO_2 emissions in our sample.

The estimations results confirm the first indirect effect, which connects through the energy demand channel. Its coefficient captures the effect of financial development on energy consumption in column (1). The result is in line with Shahbaz and Lean (2012); Chang (2015). Chang (2015) uses a similar indicator of financial development, which is the share of GDP of private and domestic credit. Easier access to credits allows people to purchase more durable consumer goods, leading to more energy demand. On the other hand, energy consumption is positively related to CO_2 emissions. Its coefficient is significant at 1% level. The path of the indirect effect is thus: $FD \to^+ EC \to^+ CO2$. Financial

CO2 Emissions, Financial Development
and Inequality
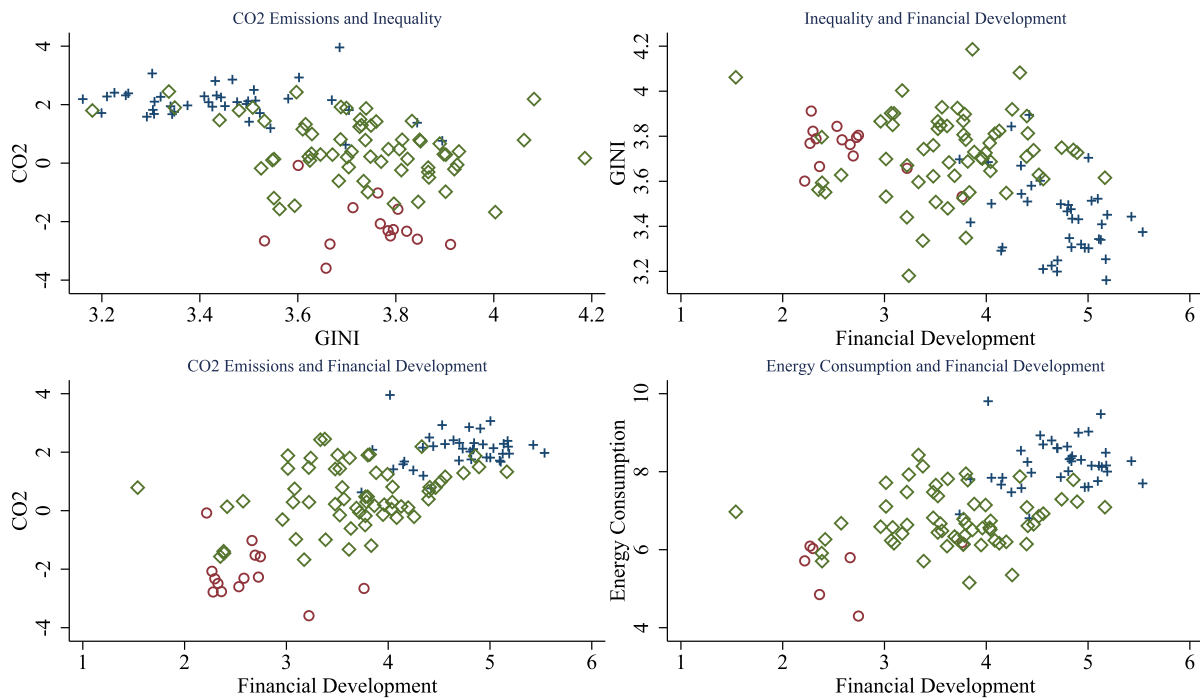
The + symbol represents high income countries, the ◇ symbol represents middle income countries, whereas the ○ symbol represents low income countries
Source: Author's calculation

Fig. 2. Relationship among key variables.

Table 1. 2SLS estimation results.

	(1)	(2)	(3)	(4)
	Energy Consumption	CO2	GINI	GDP per capita
GDP per capita	0.023	-0.136	-0.170	
	(0.11)	(-0.59)	(-1.40)	
GDP per capita squared	-0.006	0.021	0.019	
	(-0.22)	(0.74)	(1.27)	
Financial Development	0.193**	0.196*	-0.107***	9.280**
	(2.14)	(1.84)	(-2.98)	(2.20)
Industrialization	0.703***	0.252	0.115	1.508**
	(3.16)	(0.99)	(1.32)	(2.19)
Urbanisation	0.807***	0.305	-0.064	-1.061*
	(4.64)	(1.36)	(-0.97)	(-1.94)
Renewable Energy	-0.053	-0.204***		-0.117
	(-0.98)	(-3.95)		(-0.65)
GINI		-1.466***		
		(-2.82)		
Energy Consumption		1.119***		
		(5.59)		
Trade		0.032		0.978**
		(0.23)		(2.35)
Inflation			-0.299	
			(-1.17)	
Financial Development Squared				-1.257**
				(-2.30)
r2	0.476	0.859	0.021	0.089
Observations	100			

*, **, *** indicate statistical significance at 10%, 5% and 1% level respectively.

development creates more demand for energy. Then, higher energy consumption gives rise to more CO_2 emissions through the use of durable consumer goods.

The second indirect effect passes through the income inequality channel. In the Gini equation estimation (column (3)), the coefficient of financial development is significantly negative at 1% level. This result suggests that improvement of financial intermediaries can facil-

itate access for the poor to various financing options and narrow the income inequality gap in the process. However, a lower income inequality score can be associated with higher CO_2 emissions, as shown by the significantly negative coefficient of the Gini index in the CO_2 equation. The finding suggests that financially developed countries can lower income inequality, but will suffer from environmental degradation. In Khan et al. (2018), income inequalities in Pakistan and India

Table 2. 2SLS estimation results: Interaction with income status.

	Energy Consumption	CO2	GINI	GDP per capita
GDP per capita	0.002	-0.155	-0.045	
	(0.01)	(-0.68)	(-0.48)	
GDP per capita squared	-0.003	0.023	0.003	
	(-0.13)	(0.83)	(0.28)	
Financial Development	0.185**	0.208**	-0.099***	-0.179
	(2.10)	(2.07)	(-3.63)	(-0.61)
Financial development × LMIC			0.070***	
			(5.81)	
Industrialization	0.706***	0.259	0.000	2.331***
	(3.16)	(1.01)	(0.00)	(3.00)
Urbanisation	0.810***	0.305	0.028	-0.476
	(4.65)	(1.34)	(0.52)	(-0.62)
Renewable Energy	-0.055	-0.205***		
	(-1.02)	(-3.91)		
GINI		-1.396***		
		(-2.79)		
Energy Consumption		1.117***		-0.742
		(5.53)		(-1.11)
Trade		0.040		0.939**
		(0.29)		(2.55)
Inflation			0.111	
			(0.54)	
r2	0.476	0.855	0.451	0.174
Observations	100			

*, **, *** indicate statistical significance at 10%, 5% and 1% level respectively.
$LMIC$ denotes low and middle income countries.

also reduce carbon emissions. It implies a trade-off between income equality and the environment. Thus, the second indirect effect channel is $FD \rightarrow^- GINI \rightarrow^+ CO2$.

Industrialisation is one of the key determinants of energy consumption and pollution emissions. In this paper, the impacts of industrialisation on both energy demand and GDP growth are significantly positive. More plants and increasing industrial production demand more energy and emit more pollution. Moreover, growth in the industrial sector benefits the labour force through job creation and increasing income. People then have access to more expensive goods (cars, electronic equipments), which causes more energy demand.

The coefficient of urbanisation is significantly positive in the energy consumption equation (column (1)). Expanding the urban population can cause certain structural changes in the economy, increasing economic activities and energy demand. This finding is consistent with the recent empirical literature (Shahbaz and Lean, 2012; Li and Lin, 2015). However, urbanisation slows down the growth rate of GDP per capita, as can be seen by its coefficient in column (4). It is noteworthy to mention that urbanisation is positively related to the level of income, but not the growth rate. As an economy becomes more urbanised and developed, its per capita income level increases but the growth rate slows down.

The regression results show that renewable energy sources are key determinants in reducing CO_2 emissions. This piece of empirical evidence supports the findings of Waheed et al. (2018). Increasing the share of renewable energy sources in total final energy consumption would make an economy less dependent on non-renewable energy sources, and thus decreasing the CO_2 emissions in the process.

The next empirical findings will test the difference between high-income status and low-and-middle-income status. In Table 2, the empirical analysis goes further by incorporating an interaction term between the financial development level and the income status in the Gini equation in the structural system (5). The Gini equation is then modified as:

$$GINI_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 PGDP_i + \gamma_3 IND_i + \gamma_4 URB_i + \gamma_5 RENEW_i$$
$$+ \gamma_6 INF_i + \gamma_7 PGDP_i^2 + \gamma_8 FD_i \times LMIC + \gamma_9 LMIC + \epsilon_{3i}$$

The coefficient of financial development in the Gini equation is still significantly negative at 1% level. However, the coefficient of the in-

teraction term between financial development and income status is significantly positive. This result implies that the trade-off between environment and equality is more relevant in high-income economies than low- and middle-income countries.

Recent literature has shown that the relationship between financial development and income inequality may be nonlinear, as in Kim and Lin (2011). At low levels of financial development, improving financial intermediation may hurt poor people and widen the income inequality gap. However, at higher development levels, the poor may receive more benefits, and thus, the income disparities are narrowed. The detrimental effects at low financial development levels can be caused by high fixed costs of financial services or financial barriers (Kim and Lin, 2011). To this end, we add a quadratic term of financial development in the Gini equation.

$$GINI_i = \gamma_0 + \gamma_1 FD_i + \gamma_2 PGDP_i + \gamma_3 IND_i + \gamma_4 URB_i + \gamma_5 RENEW_i$$
$$+ \gamma_6 INF_i + \gamma_7 PGDP_i^2 + \gamma_8 FD_i^2 + \epsilon_{3i}$$

Table 3 reports the estimation results with nonlinearity. The coefficient of financial development is significantly positive at 10% level, whereas the coefficient of the quadratic term is significantly negative at 5% level. The signs of the coefficients imply that the relationship takes an inverted-U shape. Accordingly, the indirect effect of financial development on CO_2 emissions is also nonlinear with respect to the development of financial intermediation. The effect of financial development on CO_2 emissions through the Gini channel can be calculated as $0.106 FD_i - 0.642$. Thus, at the early stages of financial development, this indirect effect is negative. It becomes positive when financial development surpasses a threshold level. An early theoretical paper of Greenwood and Jovanovic (1990) explains why only a small proportion of the population receive the benefits of financial development. They use a household portfolio selection model and show that there is a fixed cost incurred when household capital income is increased by financial development. The cost prevents the poor from accessing banking services but does not affect the accessibility of the rich to those services. Consequently, the income gap becomes more considerable. Eventually, the poor population can overcome this fixed cost and has access to various financial services, which are formerly the rich's privileges. Hence, after a certain amount of time, financial development benefits a larger part of the population and reduces income inequality.

Table 3. 2SLS estimation results: Nonlinearity.

	Energy Consumption	CO2	GINI	GDP per capita
GDP per capita	-0.017	-0.081	-0.196*	
	(-0.09)	(-0.40)	(-1.66)	
GDP per capita squared	-0.001	0.014	0.022	
	(-0.04)	(0.58)	(1.51)	
Financial Development	0.184**	0.214**	0.455*	-0.175
	(2.09)	(2.17)	(1.83)	(-0.60)
Financial Development Squared			-0.075**	
			(-2.28)	
Industrialization	0.712***	0.237	0.106	2.344***
	(3.20)	(0.95)	(1.22)	(3.01)
Urbanisation	0.809***	0.318	-0.063	-0.459
	(4.64)	(1.43)	(-0.95)	(-0.60)
Renewable Energy	-0.056	-0.205***		
	(-1.03)	(-4.00)		
GINI		-1.410***		
		(-2.79)		
Energy Consumption		1.108***		-0.762
		(5.60)		(-1.14)
Trade		0.014		0.939**
		(0.11)		(2.55)
Inflation			-0.182	
			(-0.75)	
r2	0.475	0.860	0.014	0.171
Observations	100			

*, **, *** indicate statistical significance at 10%, 5% and 1% level respectively.

We conduct several robustness tests, including using alternative variables to measure financial development, using another estimator to estimate the empirical models. First, we use Domestic credit to private sector as a % of GDP as an alternative measure for financial development. Table 1, 2 and 3 in Appendix B (see Supplementary material) report the results of these specifications. The overall results do not change while using another proxy for financial development. Second, we re-estimate the system (5) using three stages least squares estimator (3SLS). 3SLS uses an instrumental-variables approach to give consistent estimates and generalized least squares to account for the correlation structure in the disturbances across the equations. Table 4, 5 and 6 show the estimation results of 3SLS estimators. The empirical findings do not depend on the correlation structure of the shocks in the system.

5. Conclusion and policy implications

This paper develops from the existing literature and provides empirical evidence on the effect of financial development and CO_2 emissions, as well as several transmission channels that connect the two variables. Using a global sample of 100 countries from 1990 to 2012, we show that financial development is positively associated with CO_2 emissions. In addition, we confirm two transmitting channels from financial development to environmental quality. The first one is the $FD \to^+ EC \to^+ CO2$ channel. Financial development creates more demand for energy. Then, higher energy consumption gives rise to more CO_2 emissions. The second one is the $FD \to^- GINI \to^+ CO2$ channel. This channel implies that improving financial system would reduce income inequality, but it also put pressure on the environment.

The evidence from this study indicates two mechanisms transmitting the impacts of financial development to environmental degradation. These findings add substantially to our understanding of these mechanisms. This paper has highlighted the importance of the energy demand channel, which is often overlooked in the literature. We have provided further evidence that financial development can induce more pollution by allowing people to purchase more durable consumer goods, which will give rise to energy demand and consumption. Besides, considerable progress has been made with regard to the interlinkage among financial development, income inequality and CO_2 emissions. However, this study provides a stimulus for a new way to look into the above-mentioned relationships. The findings theoretically contribute to the related literature by explaining the role of financial development and income inequality on the environmental issue. In particular, financial development can reduce the income gap in society by increasing people's income, thus leading to better living standards. However, richer countries tend to emit more greenhouse gas, thus degrading the environment. This mechanism implies a trade-off between controlling global warming and having better living standards.

In addition, the indirect effect that passes through the income inequality channel is found nonlinear. Early stages of financial development would disproportionately favour the rich and hurt the poor. In other words, financial development does not contribute to better living standards and thus, does not create any drivers for CO_2 emissions. However, when the financial system is sufficiently developed, it will benefit the poor. However, lower income inequality leads to more CO_2 emissions. In either stage of financial development, the country has to choose between living standards and the environment.

Overall, financial development can positively affect CO2 emissions through various channels. The finding implies that the adverse effects of financial development on environmental quality dominate the beneficial effects. These results suggest several courses of action in order to mitigate the effects of financial development on the environment. Government interventions should focus on policies that are energy-efficient to boost the favourable effects of financial development. In particular, the use of renewable energy sources and the adoption of energy-saving technology are viable solutions in the long run. This implication is also relevant for developed economies. Energy demand in these countries continues to increase as their financial systems develop.

The empirical findings also imply a choice between the environment and income inequality, which are two relevant objectives of governments worldwide. Income redistribution is essential, but the authorities should also care for the effects of growth on global warming. Given this trade-off, policymakers should place emphasis on investment of renewable energy sources, eco-friendly energy sources or development of effective energy savings solution, while still being able to improve a better living standard for the people. For example, promoting CCUS, i.e. carbon capture, utilisation and storage, can be a viable solution for countries who want to reduce the income gaps at the same time with preserving the environment. Furthermore, developing solar and wind power is proven as an effective method in reducing CO_2 emissions.

Declarations

Author contribution statement

D.T. Bui: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Declaration of interests statement

The author declares no conflict of interest.

Additional information

Data associated with this study has been deposited online at Mendeley (https://data.mendeley.com/datasets/vfy3zkrznk/1).

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Appendix A

Table 4. Variable definitions and sources.

Variable	Abbreviation	Definition	Source
Energy consumption	EC	Energy use (kg of oil equivalent per capita)	WDI
Financial development	FD	Domestic credit provided by financial sector (% of GDP)	WDI
GDP per capita	$PGDP$	GDP per capita (constant 2010 US$)	WDI
Urbanisation	$URBAN$	Urban population growth (annual %)	WDI
Industrialisation	$INDUS$	Industry, value added (% of GDP)	WDI
Renewable energy	$RENEW$	Renewable energy consumption (% of total final energy consumption)	WDI
CO_2 emissions	$CO2$	CO2 emissions (metric tons per capita)	WDI
Gini index	$GINI$	Gini coefficient	SWIID
Openness	$TRADE$	Imports plus exports as a share of GDP	WDI
Inflation	INF	Consumer price index (2010 = 100)	WDI

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Table 5. List of countries in the sample.

Country	Country	Country	Country	Country
Albania	Cambodia	Croatia	El Salvador	Denmark
Armenia	Kazakhstan	Estonia	Panama	Dominican Republic
Australia	Kenya	Ethiopia	Paraguay	Ecuador
Austria	Korea	Finland	Peru	Egypt
Bangladesh	Kyrgyzstan	France	Philippines	Germany
Belgium	Latvia	Gambia	Poland	Israel
Bolivia	Lebanon	Georgia	Portugal	Italy
Botswana	Lithuania	Ghana	Romania	Jamaica
Brazil	Luxembourg	Greece	Russia	Japan
Bulgaria	Malaysia	Guatemala	Serbia	Jordan
Cameroon	Malta	Honduras	Singapore	Netherlands
Canada	Mauritius	Hong Kong	Sweden	New Zealand
Cape Verde	Mexico	Hungary	Tajikistan	Nicaragua
Chile	Moldova	Iceland	Tanzania	Norway
China	Mongolia	India	Thailand	Pakistan
Colombia	Morocco	Indonesia	Tonga	South Africa
Costa Rica	Namibia	Iran	Tunisia	United States
Cote d'Ivoire	Niger	Ireland	Turkey	Venezuela
Cyprus	Sri Lanka	Spain	Ukraine	Vietnam
Switzerland	St. Lucia	United Kingdom	Uruguay	Zambia

Table 6. Descriptive statistics.

	Mean	Median	S.D	Min	Max
CO2	0.947	1.266	1.330	-2.766	3.068
Financial Development	4.060	4.137	0.843	1.539	5.537
GINI	3.630	3.656	0.226	3.161	4.186
GDP per capita	0.996	1.029	0.555	-0.477	2.211
Trade	4.323	4.262	0.511	3.230	5.939
Energy Consumption	7.188	7.099	1.048	4.299	9.479
Renewable Energy	2.742	3.047	1.312	-1.109	4.552
Industrialization	3.225	3.253	0.301	2.120	3.859
Urbanization	0.220	0.505	1.093	-3.155	1.603
Inflation	4.378	4.439	0.160	3.951	4.619

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