Carbon emissions and banking stability: Global evidence

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Carbon Emissions and Banking Stability: Global Evidence

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Abstract

This paper examines the impact of per capita CO2 emissions on banking stability. To identify the causal effect of carbon emissions on the stability of banking system, we use plausibly exogenous source of variations in energy use as an instrumental variable (IV) for CO2 emissions. Using data for a panel of 122 countries over the period 2000-2013, our IV regression results indicate that there is an inverted U-shaped relationship between per capita CO2 emissions and banking stability. Our findings reveal that CO2 emissions have a positive effect on banking stability at a low level of emissions and an adverse effect at a higher emissions level. We also find that industrialization as proxied by the ratio of manufacturing value added to GDP can be a potential channel through which per capita CO2 emissions affect banking stability. Our results are robust to alternative specifications and have important implications for policy on banking stability.

Keywords: CO2 emissions; Banking stability; Energy use; Nonlinearity

JEL Codes: G21; Q50; Q53

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1 Introduction

Climate change has been on the development agenda for many years and more so recently due to its increased threats and potential adverse effects on the global economy. There is an undeniable environmental effects of greenhouse gases (hereafter GHG). Carbon dioxide (CO2) in particular constitute the biggest share (76%) of the total greenhouse gases that contribute to global warming and climate change (IPCC, 2014 and World Bank, 2019). Climate change has become even more important because it represents an existential threat to humanity. One of the reasons why action on climate change has been slow is because some state actors and policy makers doubt that climate change is real. However, recently, a large number of scientists (over 11,000) declared and warned humanity that we face a climate emergency (see Ripple et al., 2017). Another reason is that the consequences of our actions in not addressing climate change will mostly be felt by future generations. That is, we are unlikely to be here to suffer for the consequences of our actions. Mark Carney, formerly of the Bank of England (BoE) called this the 'tragedy of the horizon'.[1] The scale of any financial crisis resulting from climate change could exceed that of the global financial crisis in 2007/09 and the effects of a pandemic such as COVID-19. Though we are not aware of reliable estimates as to how large such a crisis could be, it could be far bigger than any financial crisis or 'black swan' event that has confronted economies across the world. The potential negative consequences of climate change on financial stability have been referred to as 'green swan' events (see for example, Svartzman et al. 2020).

It is becoming increasingly obvious that important linkages may exist between climate change and the stability of the financial system. Climate risk such as rises in temperature can lead to undesirable consequences such as irregular weather patterns, droughts, floods, and the like. Climate risk manifests through both physical and transition risks. Physical risks represent the damage that climate change can cause to the assets of economic agents.

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[1] Mark Carney is usually credited with highlighting the potential damaging impacts of climate change on financial stability. Refer to the speech: "Breaking the tragedy of the horizon – Climate change and financial stability" delivered by Mark Carney, former governor of Bank of England on 29th September, 2015.

This damage can lead to, for example, non-repayment of loans by economic agents who have borrowed from banks. Transition risks, on the other hand, refer to the changes that would have to take place regarding resource allocations to various sectors of the economy in the transition to a low-carbon economy. This will certainly lead to winners and losers. The potential failure of losers could impact the asset quality of banks and lead to potential bank failures. Physical and transition could have malign interactions sparking a systemic crisis in the banking industry on a scale that has not been seen before. Indeed, recognizing the potential for climate risk to affect banking stability, a number of regulators known as the Central Banks and Supervisors Network for Greening the Financial System (NGFS) was formed with the aim of better managing how climate risks affect financial systems across the world.

In this paper, we examine the impact of CO2 emissions (our proxy for climate change) on banking stability. We further test whether climate change has non-linear effects on banking stability. We conjecture that, initial increases in CO2 emissions may suggest early stages of industrialization. Firms therefore focus their investments on productive capital[2] which would have positive net benefits. This we believe would give borrowers the chance to grow and increase their ability to repay their loans. Later when firms attain certain levels of development, investments could be more focused on adaptive alternatives.[3] Consequently, the current discourse on regulating CO2 emissions level should be done with care taking into account the specific realities of each country. CO2 emissions regulatory decisions will ultimately affect banking stability[4] pushing firms to decide whether to allocate investment to productive capital or adaptation investments.

For instance, Safarzyńska, and van den Bergh (2017) show that energy policy decisions that quickly raise the share of firms' investment in renewable energy threatens financial

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[2] Productive capital refers to physical capital that can increase output but is vulnerable to climate change.

[3] Adaptive capital entails resources (financial, governance, and infrastructure) that are invested in climate related projects.

[4] For example, when borrowers are exposed to the adverse effects of climate change, banks can suffer from poor asset quality and consequently instability.

stability as the profits of the firms are not enough to withstand the burden of the energy policy, making it difficult for them to re-pay their loans. As implicitly found by Milliner and Dietz (2015), countries would inevitably put in measures to protect themselves from the vestiges of climate change as they develop. Particularly, these countries see structural changes in their economy as they develop leading to less dependence on climate sensitive sectors like the agriculture. This supports the reasoning of Schelling (1992), who indicate that development is the best form of combating climate change. A recent study by Haug and Ucal (2019) confirms that increases in GDP per capita and exports reduces CO2 emissions.

High levels of CO2 emissions above certain thresholds could well be the element that would erode the industrial progress and cause financial instability. While we found no studies testing the non-linear effect of CO2 emissions on banking stability, other studies like Dafermos et al. (2018) confirm in a global study with simulations that climate change destroys capital and profits of firms which affects their ability to repay loans and consequently harm financial stability. The dilemma would be to identify the reasonable policy decisions that can curb these environmental consequences of climate change resulting from the accumulation of greenhouse gases. The empirical issue therefore will be to test whether CO2 emissions improve or harm financial stability. Our study strives to answer this question. Specifically, we use aggregate data on banking stability and per capita CO2 emissions to examine the relation between CO2 emissions and banking stability across 122 countries. Our results show that there exists a threshold effect of per capita CO2 emissions on banking stability. Specifically, we find that initial levels of per capita CO2 emissions, suggesting initial levels of industrialization, improve banking stability while per capita CO2 emissions after certain threshold levels reduce banking stability. This suggests an inverted U-shaped relationship between CO2 emissions and banking stability. Our results are robust to different sensitivity checks.

Our study makes important contribution to the literature in the following ways. We examine the influence of per capita CO2 emissions on banking stability and the extent to which this can help to engender a balanced climate regulatory framework considering the level of industrialization of the country. Thus far, very few empirical investigations have been undertaken to identify the impact of climate change on financial stability. The exceptions to the best of our knowledge are IMF (2020) and Svartzman et al. (2020). The IMF study shows that climate change has had modest effects on equity markets across the globe and that sovereign financial strength and insurance penetration mitigate the negative consequences of climate change on financial stability. Svartzman et al. (2020) provide a framework for understanding how central banks ensure the stability of the financial sector in the era of climate change. None of these studies examine potential non-linear effects of climate change on bank stability.

Therefore, we propose and test empirically a novel framework that is used to examine the effect of per capita CO2 emissions on banking stability. More specifically, we argue that initial emissions of CO2 improve banking stability, while it hurts banking stability after a certain threshold. Hence, there is an inverted U-shaped relationship between per capita CO2 emissions and banking stability. We use an innovative identification strategy to tackle the endogeneity issue. In particular, we propose an identification strategy that utilises a plausibly exogenous source of variations in energy use as an instrumental variable (IV) for carbon dioxide emissions. We therefore provide new empirical evidence that investigates the causal effect of CO2 emissions on banking stability using an exogenous instrument, energy consumption, in an IV regression approach. Energy consumption is a strong predictor of CO2 emissions as high energy demand is a major contributor to the rising CO2 emissions: here, energy demand outpaces the speed at which decarbonisation of the energy system is taking place. Hence, our instrument is likely valid and satisfies both the relevance and exclusion restriction that energy use affects banking stability only through CO2 emissions.

Given that we know little about the transmission channels through which CO2 emissions impact banking stability, we further contribute to the existing studies by examining the role of manufacturing value added to GDP (MVA/GDP) ratio as a potential channel of the relationship between CO2 emissions and banking stability. Our empirical evidence shows that industrialization measured by MVA/GDP ratio serves as a channel through which CO2 emissions affect banking stability.

The remainder of the paper is structured as follows. Section 2 provides a brief review of related literature. In section 3, we discuss the data set. Section 4 presents the empirical approach undertaken in this study. Section 5 reports empirical findings, section 6 conducts channel analysis. Section 7 concludes with policy implications provided.

2 Literature Review

In this section, we review literature relating to GHG, climate change, extreme weather events and how these events influence financial activities. The empirical literature on greenhouse gases and financial stability is scanty but gradually gaining attention in the finance and economics literature. While the literature on climate finance suggests that GHG emissions contribute to the worsening climate change and extreme weather events (IPCC, 2014), there are however implications for financial and economic systems, markets, and participants (Batten et al., 2016; Aglietta and Espagne, 2016).

Stolbova et al. (2018) examines the impact of climate related policies on the financial sector by developing a financial network that accounts for how climate related policies are transmitted in the economy. The study finds that, shocks from green monetary policy and green macro-prudential regulations affect the valuation of equity and debt securities. This affects financial contracts as there could be risks of mispricing of financial assets; this effect can aggravate when many firms are financially exposed and are highly levered. Similarly, Dafermos et al. (2018) examine how financial stability can be influenced by climate change. Using global level data and simulations, they show four key findings. First, climate change destroys capital and capacity of firms to generate profits causing liquidity problems and increased credit defaults that can harm both financial and non-financial corporate sectors.

Second, climate change results in reallocation of financial resources which causes a fall in the prices of corporate bonds. Here, as a result of climate damages on the capital and profitability of firms, households reduce their demand for corporate bonds as they shift their funds to deposits and government securities leading to a decline in the price of corporate bonds. Third, climate change induced financial instability may result in decreased credit expansion, worsening the impact of climate change on economic activities. Fourth, the study found that using green quantitative easing programs by central banks can dampen climate change induced financial instability.

Battiston et al. (2017) examine the impact of climate risks on financial systems. The authors developed a networked-based climate stress-testing methodology and apply it to a large Euro Area banks in a ‘green’ and ‘brown’ scenario. The study finds that a huge portion of investors’ equity is directly and indirectly exposed to climate change risk. Also, the study found that a large portion of bank loan portfolios about the size of the bank capital is exposed to climate change risks. Similarly, implementing early climate policy frameworks allows for smooth asset value adjustment leading to potential net winners and losers. This implies that the timing of climate policy matters for the smooth running of financial systems. Batten et al. (2016) investigated the channels through which climate change and policies to mitigate it affect the central bank’s ability to achieve its monetary and financial stability objectives. Arguing that two types of risks including physical and transition risks are relevant for central banks, the study shows that weather-related natural disasters trigger financial and macroeconomic instability when they damage the balance sheets of households, corporates, banks, and insurers (physical risks). The study shows further that unanticipated stringent carbon emissions policies could affect the pricing of carbon-intensive assets which can affect financial stability.

Agelietta and Espagne (2016) examine climate change as a systemic risk in the financial space. Arguing that climate change is usually viewed as a negative externality, against which economies can insure themselves through carbon tax or emission trading market, the study finds that financial and climate fragility reinforce each other ensuring the economies through collective insurance approach can correct the shocks of climate change on the financial sector. Finally, Mirza (2003) investigates extreme weather events and climate change in developing economies where the adverse effects of climate change and extreme weather events are most devastating. The study finds that while extreme climatic events generate spiral debt burdens in developing economies, extreme weather events also worsen economic, social, and human damages; the impact on financial sector therefore cannot be overruled.

Interestingly, there is little evidence of how climate change resulting from greenhouse gases like CO2 emissions affect banking stability. While we acknowledge the earlier studies on climate change-financial development nexus, our study differs from these previous studies. For instance, Dafermos et al. (2018) use simulation in a global sample and examined the effect of climate change on financial stability using temperature levels in a general equilibrium model. The present study differs from their paper as we use the CO2 emissions level. Given that different GHG can contribute to temperature levels and that CO2 emissions are proxied to show the level of industrialization, our paper is able to estimate how the major contributor to GHG, CO2, affects banking stability. This is important because most energy policies and regulatory requirements have been on limiting CO2 emission levels given that CO2 is the most important anthropogenic greenhouse gas (IPCC, 2007). Our approach allows us to test the non-linear relationship between CO2 and bank stability. Further, Stolbova et al. (2018) examine the effect of climate-related policies on the financial sector for the Euro Area. Our study is again different because we use the actual levels of CO2 emissions instead of climate related policies. We consequently use a global sample and provide robustness with sub-samples of different regions in the world to examine the impact of CO2 emissions on bank stability. Moreover, unlike the previous studies, our framework allows us to use an IV approach that helps to account for any possible endogeneity issues within the specification. It is important to note that banks are needed to finance investments to drive industries leading to higher CO2 emissions, and at the same time the level of industrialization may also determine the level of finance needed and thus the stability of banks. The IV approach helps us to account for these issues.

3 Empirical Methodology

Here, in order to relate banking stability with the level of per capita carbon dioxide emissions, we follow the basic econometric model below:

$$Stab_{it} = \alpha_i + \beta_1 Stab_{i,t-1} + \beta_2 CO2_{it} + \beta_3 CO2_{it}^2 + \gamma \mathbf{X}_{it} + \mu_t + \epsilon_{it} \tag{1}$$

where the subscript $i = 1, 2, ..., N$ represents countries; $t = 1, 2, ..., T$ denotes the time span in years; $Stab_{it}$ refers to the stability measured by Z-score; the introduction of lagged stability $Stab_{i,t-1}$, for instance, is necessary because previous year's stability is likely to influence the following period's stability levels; $CO2_{it}$ is per capita carbon dioxide emissions; $\mathbf{X}$ denotes a vector of control variables including: net interest margin (*NIM*); ratio of non-interest income to total income (*NONIM*); bank asset concentration measured as the assets of the five largest banks as a share of total assets of all commercial banks (*CONCEN*); percentage of foreign banks of the total banks in each country (*Foreign*); level of competition as measured by the Boone indicator (*Boone*); average consumer price index (*Inflation*); and institutional quality proxied by regulatory quality index (*Quality*); α_i and μ_t are country- and time-specific fixed effects, respectively and ϵ_{it} is the idiosyncratic error term. Our variable of interest is CO2, thus, β_2 captures the effect of per capita carbon emissions on banking stability. The quadratic term in Equation (1) helps to approximate the nonlinear relationship between carbon dioxide emissions and banking stability. That is, the quadratic term in CO2 emissions allows for the nexus between CO2 emissions and banking stability to be non-monotonic.

We first use a fixed effects model and system generalised method moments (sys-GMM) to estimate Equation (1). To identify the causal effect of carbon dioxide emissions on banking stability, our main empirical strategy is the IV method. In particular, to cater for endogeneity, we adopt an IV approach with the first stage corresponding to Equation (2) below:

$$CO2_{it} = \delta_0 + \delta_1 Energy_{it} + \delta_2 CO2_{it}^2 + \phi \mathbf{X}_{it} + u_{it} \tag{2}$$

where $Energy_{it}$ refers to GDP per unit of energy use; $\mathbf{X}$ is a vector of control variables in the structural regressions; and u_{it} is stochastic error term. Having the predicted values of $C\hat{O}2_{it}$, we estimate the second-stage regression following the same form as Equation (1).

4 Data and Sources

4.1 Data

We collect annual data from the year 2000 to 2013 for 122 countries.[5] The banking stability data used in this paper is Z-score. Z-score is calculated as (ROA+(equity/assets))/sd(ROA). In essence, Z-score compares the capitalization and returns - which shows the strength of the banking system - to how volatile those returns are. The higher the value of the Z-score, the more stable the banking sector. Carbon emissions are measured by per capita CO2 emissions (in metric tons).

On the controls, the study adds net interest margin (*NIM*) of the banks as a proxy for how banking spread affects the banking stability. This is calculated as the ratio of banks' net interest revenue to their average interest-bearing assets. We expect a positive relationship between net interest margin and banking stability. Very high NIM may however be detrimental to banking stability when borrowers find the cost of credit to be too high to repay.

We also include non-interest margin (*NONIM*) calculated as the ratio of non-interest income to total income. This captures how the income from banks' "non-traditional activities" affect the stability of the banking industry. Another variable that is added as a control is

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[5] All of the sample countries are listed in Appendix. The sample period is limited to 2013 because of data availability on the banking sector variables as provided in the Global Financial Development Database.

the bank asset concentration (*CONCEN*). This is measured as the assets of the five largest commercial banks as a share of total commercial banking assets. We also include foreign bank presence as a control variable. We proxy foreign presence as the percentage share of the total banks that are foreign banks. A bank that has majority (50% or more) shares owned by foreigners is classified as a foreign bank.

The study also adds the Boone indicator as a measure of banking competition. This is calculated as the elasticity of bank profits to marginal costs. Here, the intuition is that more efficient banks are those that can achieve higher profits. Hence, there is more competition when the indicator becomes more negative while more positive values show less competition in the banking system.

We also include Inflation which is measured as the log of the average consumer price index per year. As noted in Perry (1992), the impact of inflation on banking stability will depend on how banks anticipate inflationary changes and factor them in their pricing. Thus, inflation could improve banking stability when banks anticipate inflationary increases and hence correctly price their loans. A negative effect on stability may however happen when the increase in inflation is unanticipated. Hence, the impact of inflation on banking stability is therefore expected to be ambiguous. The data on *NIM*, *NONIM*, *CONCEN*, *Boone* and inflation are sourced from the World Bank Global Financial Development Database (GFDD).

To capture the role of institutional quality, we use the regulatory quality index from the World Development Indicators (WDI). The index is such that, higher values connote quality institutional framework in a country. These may include the quality of the regulations in relation to property rights where there is ease of securing property and enforcing property rights at the law courts. This also includes the ability of banks to engage in contractual or financial arrangements that help them to adjust their balance sheets. This can help to improve banking stability. As found by Klomp and de Haan (2014), better institutions or bank supervision helps reduce bank risk thereby improving stability. A positive impact of regulatory quality on Z-score would indicate that strong institutions help to improve banking

Table 1: Description of variables and data sources

Variable	Description	Source
Z-score	It captures the probability of default of a country's commercial banking system. Z-score compares the buffer of a country's commercial banking system (capitalization and returns) with the volatility of those returns.	Global Financial Development Database (GFDD)
NPL	Ratio of defaulting loans (payments of interest and principal past due by 90 days or more) to total gross loans (total value of loan portfolio).	Global Financial Development Database (GFDD)
CO2	Per capita CO2 emissions (in metric tons) which include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	Global Financial Development Database (GFDD)
Energy use	GDP per unit of energy use (constant 2017 PPP) is the PPP GDP kilogram of oil equivalent of energy use per constant PPP GDP	World Development Indicators (WDI)
Instituional quality	Regulatory quality institutional quality index	World Governance Indicators
Net interest margin	Accounting value of bank's net interest revenue as a share of its average interest-bearing (total earning) assets.	Global Financial Development Database (GFDD)
Non-interest income	Bank's income that has been generated by non-interest related activities as a percentage of total income (net-interest income plus non-interest income).	Global Financial Development Database (GFDD)
Bank asset concentration	Assets of five largest commercial banks as a share of total commercial banking assets	Global Financial Development Database (GFDD)
Foreign entry	Percentage of the number of foreign owned banks to the number of the total banks in an economy.	Global Financial Development Database (GFDD)
Boone indicator	Elasticity of profits to marginal costs.	Global Financial Development Database (GFDD)
Inflation	Log of the average consumer price index per year.	Global Financial Development Database (GFDD)
MVA/GDP	Manufacturing value added as a percent of GDP	World Development Indicators (WDI)

stability. The variables description and data sources are presented in Table 1.

4.2 Descriptive statistics

The summary statistics, reported in Table 2, indicate large variations in our key variables from high to low values and from positive to negative values. The average value of banking stability (Z-score) was 14.229 with a minimum of -0.241 and a maximum of 64.426. The standard deviation of 9.149 suggests that there are wide variations in banking stability across the world. The mean value of 14.229 suggests that to a large extent, banks have a large distance to default or are relatively safe.

Table 2: Summary statistics

Variable	Obs.	Mean	Std.Dev	Min	Max
Z-score	1345	14.229	9.149	-0.241	64.426
NPL	1650	0.072	0.075	0.0001	0.741
CO2 emissions per capita	1345	5.651	7.307	0.021	63.354
GDP per unit of energy use	1221	127.599	77.840	35.195	673.845
Institutional quality	1345	0.258	0.875	-1.935	1.984
Net interest margin	1345	0.047	0.028	0.002	0.170
Non-interest income	1345	0.377	0.126	0.064	0.929
Bank asset concentration	1345	0.685	0.180	0.208	1.000
Foreign entry	1345	0.424	0.280	0.000	1.000
Boone indicator	1345	-0.075	0.153	-2.000	0.420
Consumer price index	1345	0.057	0.067	-0.098	0.982
MVA/GDP	2663	0.133	0.066	0.002	0.500

CO2 emissions per capita ranged from a low of 0.021 to 63.354 maximum over the study period with an average of 5.651. This allows the study to capture both high and low emitting countries to allow for proper policy issues related to the threshold levels of CO2 for different samples. GDP per unit of energy use also varies from 35.195 to 673.845 with a mean of 127.599 indicating that the energy requirement to support economic progress vary in our sample capturing both low and high energy users in our sample. As discussed earlier, the CO2 emission levels could well be driven by the level of economic progress of countries hence capturing both low and high users allow us to determine how energy requirements affects emission levels.

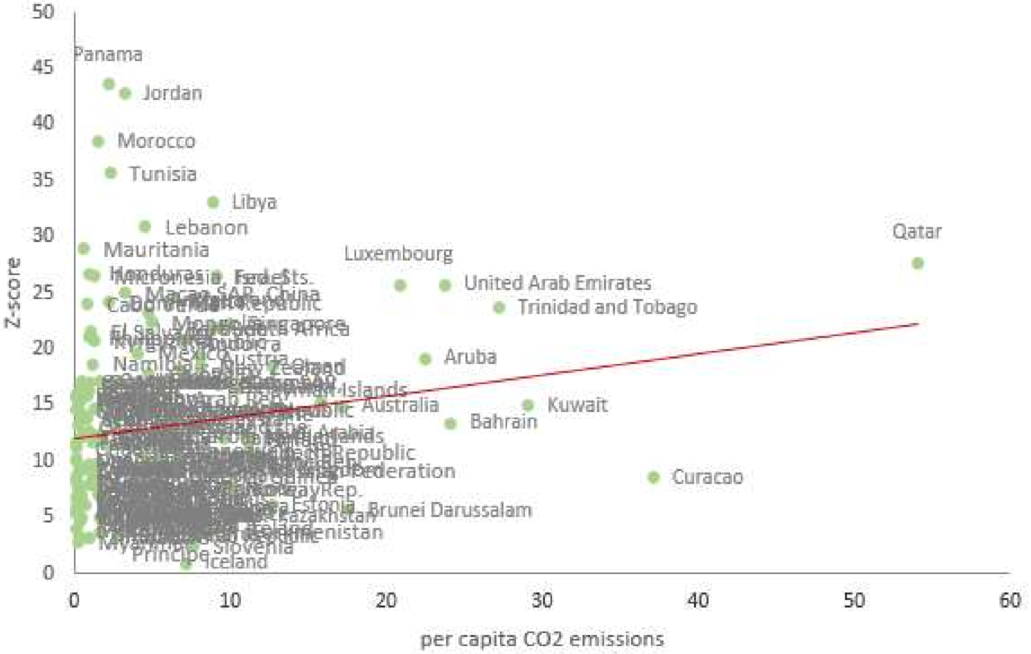
Institutional quality proxied by regulatory quality ranges between -2.5 (weak) and +2.5 (strong). Thus, higher values indicate better or stronger institutions. The mean value of 0.258 suggests that on the average, institutional quality across the world is not very strong. The variable recorded a minimum of -1.935 and a maximum of 1.984 with a standard deviation of 0.875. Net interest margin has a mean of 0.047 with a minimum of 0.002, a maximum of 0.17 and a standard deviation of 0.028. Non-interest income on the other hand reports a mean of 0.377 with a minimum of 0.064 and a maximum of 0.929. The indicator of foreign banking activities suggest that foreign banks own about 42% of banking assets across the globe. The Borne indicator has a mean of -0.075 with a minimum of -2 and a maximum of 0.42. Finally, the consumer price index which proxy's inflation or macroeconomic uncertainty has a mean value of 0.057 with a minimum of -0.098 and a maximum of 0.982.

5 Empirical Results and Discussion

5.1 Preliminary analysis

Before proceeding to our main results, we present scatter plot as a precursor to preview the nature of the relationship between CO2 emissions and banking stability. Figure 1 shows that per capita CO2 emissions have a positive relationship with Z-score, such relationship however is stronger at lower level of CO2 emissions. In sections 5.2 and 5.3, we report results from different estimations as a step to a more rigorous causality analysis.

Fig.1: Z-score vs. CO2 emissions



5.2 Benchmark results

We begin with the estimation of the fixed effects (FE) and system GMM models. Table 3 shows the results from estimating Equation (1). All standard errors are adjusted for heteroscedasticity. As we see in the Table, the results from the fixed effect show an ambiguous effect of CO2 emissions on banking stability; this is mainly due to the endogeneity bias. Column (1) of Table 3 shows the coefficient on CO2 emissions is statistically significant, suggesting that endogeneity is causing a downward bias. We see a negative bias when we include the quadratic term of CO2 emissions resulting from the direction of the endogeneity bias in the emissions-stability nexus.

While the fixed effect method is appealing given that it controls for the time-invariant determinants of Z-score and CO2 emissions, it may not necessarily identify the causal effect of CO2 emissions on banking stability. Specifically, the estimates from the FE may be unreliable when there are time-varying omitted factors that impact CO2 emissions and banking stability.

Table 3: Benchmark estimation results

	FE		System GMM	
	(1)	(2)	(3)	(4)
L.dependent	0.570***	0.570***	0.861***	0.880***
	(0.064)	(0.064)	(0.038)	(0.031)
CO2	0.037	-0.066	0.264***	0.241***
	(0.083)	(0.187)	(0.090)	(0.080)
CO2sq		0.002		-0.003***
		(0.002)		(0.001)
Nim	34.518***	34.292***	15.727**	12.892***
	(8.631)	(8.608)	(6.209)	(4.638)
Boone	-3.290***	-3.313***	4.701	1.092
	(1.018)	(1.019)	(3.009)	(2.445)
Quality	0.903	0.996*	-0.453	-0.414
	(0.580)	(0.566)	(0.319)	(0.287)
Nonim	2.687*	2.691*	0.111	-0.498
	(1.502)	(1.498)	(0.771)	(0.590)
Concen	-0.638	-0.674	0.058	0.671
	(1.219)	(1.224)	(0.701)	(0.496)
Foreign	0.098	0.113	0.985**	0.271
	(1.170)	(1.165)	(0.472)	(0.415)
Inflation	1.356	1.358	-1.936**	-2.530***
	(1.431)	(1.427)	(0.889)	(0.717)
R^2	0.94	0.94		
Obs.	1221	1221	1345	1345
No. of countries	110	110	121	121
Threshold	N.A	N.A	N.A	40
Country FE	Yes	Yes		
Year FE	Yes	Yes		
AR(2)			0.68	0.73
Hansen J *p*-value			0.19	0.20

NOTE: Robust standard error in parenthesis. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

The GMM model considers the issue of endogeneity likely to be caused by omitted variable bias. As our data exhibited relatively large cross-sectional units compared to time-series periods, we use the system GMM method: this method combines both the difference and level regressions in a system making it suitable for the study's dataset. We follow Roodman (2009) and use the lags of the independent variables as instruments. Because this reduces the number of observations, we limit the number of instruments by employing the collapsing method of Holtz-Eakin et al. (1988) and the forward orthogonalization procedure of Arellano and Bover (1995).

Here, the satisfaction of the assumption of exclusion restriction, $E(X'\mu) = 0$, would show the validity of the GMM estimates. This means that, we treat the independent variables are exogeneous and hence uncorrelated with the error term. We use two tests to check the validity of this assumption. The Hansen test of over-identifying restrictions is the first test used. This test analyses the entire set of moment conditions by examining whether the instruments are valid in order to satisfy the exclusion restriction. Our model is supported when we fail to reject the null-hypothesis that the instruments are valid.

As a second test, we use the second-order autoregressive, AR(2), test. Here, the null hypothesis is that there is no second-order serial correlation in the differenced error term. As can be seen in Table 3, the *p*-value of the AR(2) and the Hansen J shows failure to reject the null hypothesis of no second-order serial correlation and the validity of the over-identifying restrictions, respectively. Hence, we conclude that our sys-GMM results are consistent and efficient. The estimate also indicates that the lag of the dependent variable is significant at the 1% level in all the regressions. This suggests that banking stability persists.

Using Z-score as a banking stability measure, column (3) of Table 3 shows that the coefficient of carbon emissions is positive and statistically significant at the 1% significance level. Specifically, 1 unit rise in per capita CO2 emissions leads to banking stability increasing by almost 0.01 units. We test for nonlinearity in the emissions-stability nexus by introducing a quadratic term of the CO2 coefficient. The intuition, as discussed earlier, is that excessive pollution can destabilize the financial system through physical and transition risks. This would suggest that too much per capita CO2 emissions would worsen climate change and threaten banking stability. It is therefore plausible to argue that CO2 emissions harm banking stability when it is excessive. Column (4) of Table 3 shows that the effect of per capita CO2 emissions on banking stability is nonlinear. Specifically, the coefficient of the quadratic term is negative and statistically significant, while the coefficient on the level of CO2 emissions is positive. This suggests that CO2 emissions may have a positive effect at a low emission level, and an adverse effect on banking stability at a higher level of emission. This is because low levels of CO2 emissions suggest an industrializing country. Thus, an increase in industrialization would lead to firms and economic agents being in a better position to pay loans to banks for example.

Further, at low levels of emission, the damage from climate change is unlikely to be high. Thus, in an environment of low pollution, we do not expect the stability of the banking system to be threatened. Further, economic agents can begin to invest in the technologies and infrastructure to reduce their carbon footprint. However, at very high levels of emission the physical and transition costs of climate change may occur abruptly and threaten the stability of the banking system. Further, excessive pollution would suggest that firms and economic agents may not have invested in the technologies and infrastructure necessary to reduce their carbon footprint. Our findings thus suggests that there exists an inverted U-shaped relationship between CO2 emissions and banking stability. Thus, in a sense, CO2 emissions could be seen to have a nonlinear effect on bank stability with respect to time. Here, the threshold per capita CO2 emissions after which banking stability begins to fall is 40. This threshold value is within the global per capita CO2 emissions levels indicating that CO2 emissions will have a negative impact on banking stability, when the emission levels exceed 40. Other control variables have the expected sign and are statistically significant in most specifications.

5.3 Instrumental variable (IV) estimation

A proper identification of the causal effect of CO2 emissions on banking stability requires an exogenous source of variation in carbon dioxide emissions. Our main empirical strategy to identify the causal effect of per capita CO2 emissions on banking stability is the IV method. In particular, we use variation in energy consumption across countries as the primary instrument for CO2 emissions. Energy use is a natural instrument for CO2 emissions because it is theoretically rooted, is highly correlated with CO2 emissions and plausibly satisfies the exclusion restriction.

Table 4 reports the results from the two stage least square estimation together with the first stage results and diagnostic tests. In column (1), we regress Z-score on only the per capita CO2 emissions, while other columns increasingly add more variables concluding with column (9) which includes the full set of control variables. The first-stage regression outcome indicates that the coefficient of GDP per unit of energy use is statistically significant at the 1% level and the first stage F-test is well above 10. These results suggest that energy use is sufficiently correlated with CO2 emissions variable to serve as a potentially good instrument.

We also use GDP per unit of energy as an instrument for the exclusion restriction in our IV estimates. Here, we assume that this instrument is not correlated with the second stage regression which is another important identifying assumption. We are unable to calculate the Sargan test of over-identification restrictions given that our model is exactly identified. We therefore test the endogeneity assumption by follow the approach of Altonji et al. (2005): this approach tests the sensitivity of the estimates to the exclusion and inclusion of control variables. The incremental addition of control variables across column (1) to (9) show that our 2SLS estimate are not sensitive to the inclusion and exclusion of control variables.

From Table 4, we see that the coefficient on CO2 emissions is positive and statistically significant at the 5% level or better in all regressions, suggesting that rising CO2 emissions has a significant positive impact on banking stability. In particular, on average, 1 unit increase in CO2 emissions can result in a rise in Z-score in the range of 0.62 to 1.55 units depending

Table 4: Main (IV) results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
CO2	0.623**	1.551**	1.490**	1.437**	1.444***	1.255**	1.241**	1.234**	1.236**
	(0.275)	(0.705)	(0.688)	(0.682)	(0.550)	(0.525)	(0.510)	(0.501)	(0.497)
CO2sq		-0.018**	-0.017**	-0.017**	-0.017**	-0.014**	-0.014**	-0.014**	-0.014**
		(0.008)	(0.008)	(0.008)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)
Nim			32.678***	30.636***	30.695***	35.034***	35.007***	35.029***	35.006***
			(7.087)	(7.050)	(6.699)	(6.881)	(6.861)	(6.868)	(6.899)
Boone				-2.656***	-2.656***	-2.776***	-2.770***	-2.774***	-2.773***
				(0.743)	(0.745)	(0.730)	(0.730)	(0.729)	(0.729)
Quality					0.023	0.296	0.315	0.352	0.353
					(0.592)	(0.572)	(0.564)	(0.549)	(0.551)
Nonim						2.418***	2.402***	2.382***	2.375**
						(0.907)	(0.908)	(0.907)	(0.917)
Concen							0.147	0.146	0.143
							(0.774)	(0.773)	(0.775)
Foreign								-0.334	-0.339
								(1.220)	(1.218)
Inflation									0.073
									(1.201)
First-stage regressions									
Energy	2.414***	0.978***	0.987***	0.986***	1.250***	1.293***	1.344***	1.367***	1.381***
	(0.368)	(0.180)	(0.180)	(0.180)	(0.180)	(0.182)	(0.183)	(0.183)	(0.183)
1st stage F-test	43.10	29.47	30.13	30.04	47.97	50.56	53.70	55.83	56.78
Threshold (CO2)	N.A	43	44	42	42	45	44	44	44
R^2	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
Obs.	1330	1330	1330	1330	1330	1330	1330	1330	1330
No. of countries	111	111	111	111	111	111	111	111	111

NOTE: To conserve space, the lagged dependent variable is not reported. Robust standard errors in parenthesis. ** and *** indicate significance at the 5% and 1% level, respectively.

on the exact specification. These results affirm our use of the 2SLS over the FE regression which saw a downward bias resulting from the issue of endogeneity. Again, the coefficient of quadratic term is negative and statistically significant at the 5% level, suggesting that an inverted U-shaped relationship between per capita CO2 emissions and banking stability. Our IV findings confirm the hypothesis that CO2 emissions is positively related to banking stability below a threshold level of CO2 emissions. Here, the average threshold of per capita CO2 emissions after which banking stability begins to fall is 44. This threshold is closer to the level (40) recorded when we use the GMM approach and it is within the global emissions level even though above the global average of 6.

5.4 Robustness checks

In this section, we perform three types of robustness checks. First, we split our sample into multiple sample periods to investigate whether business cycle shocks may affect the influence of CO2 emissions on banking stability. Second, we divide our sample countries into five regional groups based on the World Bank's classification. Third, we use an alternative measure of banking stability.

5.4.1 Dividing sample into multiple time periods

To examine whether the effect of CO2 emissions on banking stability will vary when global economic conditions have changed, we divide the data sample into multiple time periods. In our sample, there are at least three global external shocks that are likely to result in significant changes in banking stability: the 2000 Dotcom bubble, the 2007-2009 Global Financial Crisis (GFC) and the 2010-2012 European Debt Crisis. We therefore divide our sample into two periods: non-crisis period (2001-2006, 2013) and volatile period (2000, 2007-2012). Tables 5 presents the regression results. Columns (1) and (3) show that when we split our data sample into different time periods, we also find a significant positive effect of CO2 emissions on banking stability. In fact, the scales of the coefficients are quite similar as in

Table 5: System GMM results (divide sample into multiple periods)

	Non-crisis period		Volatile period	
	(1)	(2)	(3)	(4)
L.dependent	0.969***	0.964***	0.953***	0.955***
	(0.008)	(0.008)	(0.004)	(0.004)
CO2	0.008**	0.031***	0.008**	0.037***
	(0.003)	(0.009)	(0.004)	(0.010)
CO2sq		-0.0003***		-0.0007***
		(0.0001)		(0.0002)
Nim	2.083	7.513***	-0.011	-0.223
	(1.696)	(2.479)	(2.214)	(1.866)
Boone	-0.605	-0.717	-0.121	0.031
	(0.387)	(0.436)	(0.182)	(0.175)
Quality	0.085	0.100	-0.208***	-0.247***
	(0.057)	(0.066)	(0.065)	(0.054)
Nonim	0.139	-0.039	-1.108***	-1.259***
	(0.427)	(0.411)	(0.298)	(0.281)
Concen	-0.003	-0.088	-0.647***	-0.384**
	(0.270)	(0.311)	(0.192)	(0.183)
Foreign	-0.301*	-0.479***	0.088	0.068
	(0.157)	(0.154)	(0.143)	(0.110)
Inflation	-1.492***	-1.876***	-1.633***	-1.692***
	(0.402)	(0.653)	(0.492)	(0.463)
Obs.	663	663	804	804
No. of countries	121	121	122	122
Threshold (CO2)	N.A	52	N.A	26
AR(2)	0.94	0.93	0.82	0.82
Hansen J *p*-value	0.57	0.42	0.48	0.23

NOTE: Non-crisis period includes the year 2001-2006 and 2013, crisis period covers the year 2000, 2007-2012. *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

our benchmark regressions. Moreover, columns (2) and (4) indicate that there is a nonlinear impact of CO2 emissions on banking stability, and such impact is stronger during the volatile periods. Overall, we can see the main results on how CO2 emissions affect banking stability still holds, that is CO2 emissions exhibit a positive relationship with banking stability at low levels and a negative relationship with banking stability at high levels of emission. Thus, our findings indicate that the influence of CO2 emissions on stability of the banking system is not affected by short-run business cycle characteristics. Here, the per capita CO2 emissions threshold of volatile periods is 26 lower than the threshold of 52 in non-volatile periods. This shows that the negative effect of CO2 emissions on banking stability happens earlier and is more pronounced during volatile periods than when in normal times. This is economically intuitive given that during crises periods, banks are already exposed to higher risk as was seen in the GFC and the European Debt Crisis, hence, the consequences of climate change further worsen the effects of volatile periods on the banking system.

5.4.2 Dividing sample into different regional groups

One main concern of our analysis is that differences in regional performance may reflect differences in the stability of the banking system. It is in fact a stylised fact that there are substantial regional differences in banking sector fragility. For instance, De Haas and van Lelyveld (2006, 2010) find that, due to the presence of foreign banks, the financial stability in Eastern Europe is enhanced during the periods of financial distress. In contrast, according to Arena et al. (2007), the stabilising effect is more subdued and diverse in Latin America and Asia. Hence, without considering such potential difference in regional disparities, the baseline estimation results may not be precise. To address this concern, we divide our sample into five regional groups according to the World Bank's classification: European and Central Africa (ECA), Latin America (LAC), Middle East and North Africa (MENA), Sub-Saharan Africa (SSA) and East Asia and Pacific (EAP).[6]

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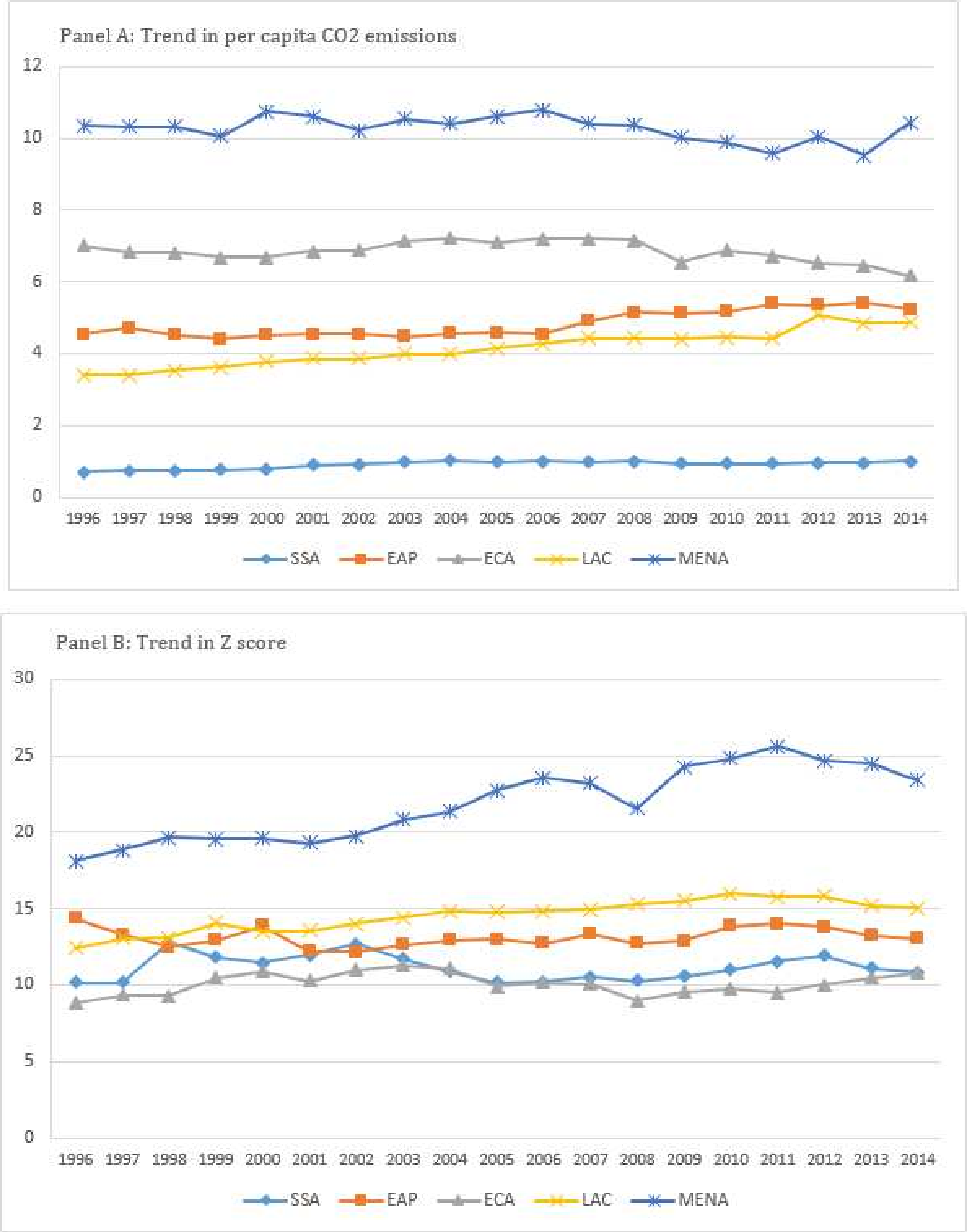
[6] Summary statistics for all five regional groups are presented in Appendix.

Fig.2: Trends in per capita CO2 emissions and Z-score by regional groups

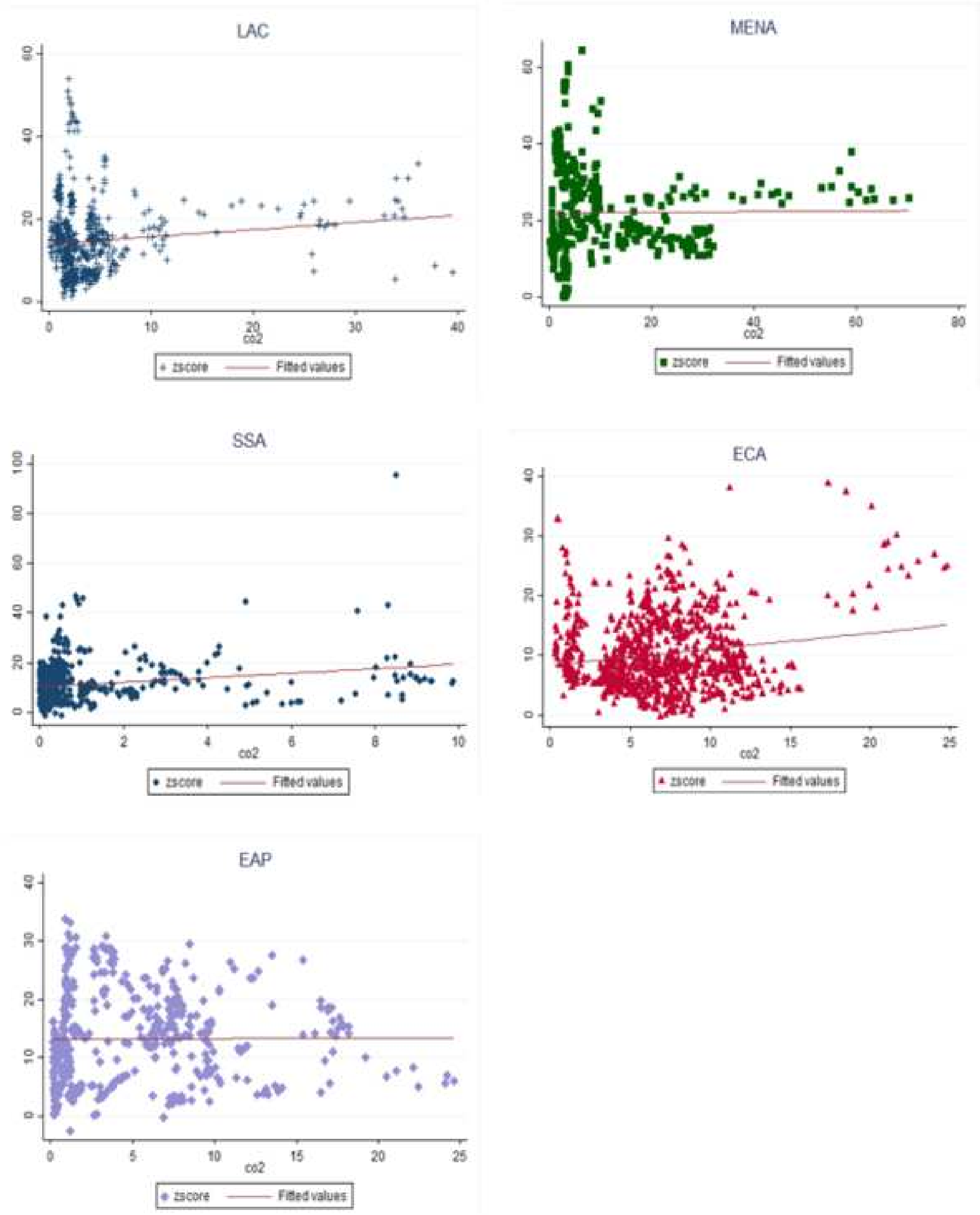


The paths and patterns of CO2 emissions and banking stability over time differ across regions. As can be seen from Panel A of Figure 2, MENA region has the highest per capita CO2 emissions. This is not surprising as the region has a lot of oil deposits hence having the highest emissions of fossil fuels. The region has had emissions hovering around 10 metric tons per capita over the sample period. ECA is the next region with the second highest per capita CO2 emissions. The region has had quite a stable CO2 emission per capita from 1996 to 2008 hovering around 7 metric tons per capita after which the trend begun to decline to around 6 metric tons per capita. The EAP region follows with CO2 emissions hovering around 4 metric tons per capita from 1996 to 2007 after which the region saw an increasing trend of CO2 emissions to around 5 metric tons per capita. The LAC region follows with CO2 emissions, also seeing an increasing trend over the years. The early part of the sample period (i.e. from 1996 to 2004) saw per capita CO2 emissions was very close to 4 metric tons but exceeded 4 metric tons from 2005. It reached a peak of 5 metric tons per capita in 2012 and has been around that value afterwards. The region with the lowest CO2 emissions per capita is the SSA region with emissions less than 1 ton per capita for most years.

In regard to the trend of Z-score, Panel B of Figure 2 shows that the MENA region has the most stable banking system. This is as expected because the region has abundant oil resources which is the most likely to support their banking system. The LAC region follows as the second most stable banking system and then closely followed by the EAP region. The SSA region has the second least stable banking system, and the ECA region being the region with the least stable banking system.

To evaluate the role of regional heterogeneity, we first show some scatter diagrams of Z-score against per capita CO2 emissions by regional groups. The plots show that CO2 emissions have a positive influence on Z-score, and such influence is stronger at lower CO2 emissions level. Therefore, per capita CO2 emissions is helpful for improving banking stability below a certain threshold.

Fig.3: Trends in per capita CO2 emissions and Z-score by regional groups



Results are reported in Tables 6a and 6b. We can see that, in most of our regressions, the coefficients of carbon dioxide emissions are positive and statistically significant at 10% significance level or better, indicating that a rise in per capita CO2 emissions leads to higher banking stability. As discussed earlier, initial increase in CO2 emissions may suggest indus-

Table 6a: System GMM results (SSA, MENA and EAP regions)

	SSA		MENA		EAP	
	(1)	(2)	(3)	(4)	(5)	(6)
L.dependent	0.821***	0.586***	0.947***	0.718***	0.792***	0.403**
	(0.057)	(0.050)	(0.054)	(0.046)	(0.096)	(0.177)
CO2	0.201***	0.887***	0.093***	0.291**	-0.269	3.701**
	(0.071)	(0.211)	(0.023)	(0.126)	(0.213)	(1.596)
CO2sq		-0.048**		-0.002*		-0.211***
		(0.021)		(0.001)		(0.072)
Nim	33.819***	42.429***	215.459***	247.874***	433.415***	131.509
	(4.201)	(4.825)	(61.420)	(91.503)	(118.813)	(162.019)
Boone	18.194***	28.026***	-18.210	44.749*	-5.817	-7.836*
	(4.017)	(2.025)	(14.481)	(24.283)	(4.365)	(4.350)
Quality	0.585*	0.273	-0.395	-3.142	7.851***	9.465**
	(0.345)	(0.370)	(0.751)	(2.102)	(2.575)	(4.763)
Nonim	6.271***	10.510***	13.180**	33.716***	32.766***	-10.857
	(1.126)	(1.118)	(6.165)	(10.727)	(8.729)	(21.608)
Concen	-2.203***	-2.118**	-15.364***	-18.723**	-17.440***	-6.588
	(0.769)	(0.922)	(4.431)	(8.052)	(5.652)	(6.131)
Foreign	-0.267	-0.345	0.430	4.030	-27.104***	-21.060
	(0.665)	(0.995)	(3.779)	(2.857)	(6.208)	(17.459)
Inflation	-1.248*	-1.495**	-12.077**	-26.102***	-47.794***	62.078
	(0.640)	(0.686)	(5.612)	(8.893)	(17.616)	(44.985)
Obs.	333	333	179	179	156	156
No. of countries	29	29	15	15	13	13
Threshold (CO2)	N.A	9	N.A	61	N.A	9
AR(2)	0.23	0.16	0.35	0.35	0.13	0.13
Hansen J *p*-value	0.29	0.31	0.86	0.94	0.38	0.95

NOTE: *,** and *** indicate significance at the 10%, 5% and 1% level, respectively.

Table 6b: System GMM results (ECA and LAC regions)

	ECA		LAC	
	(1)	(2)	(3)	(4)
L.dependent	0.756***	0.847***	0.692***	0.867***
	(0.037)	(0.018)	(0.128)	(0.070)
CO2	0.070**	0.189***	0.059*	0.617***
	(0.034)	(0.038)	(0.033)	(0.219)
CO2sq		-0.012***		-0.014***
		(0.002)		(0.005)
Nim	20.337**	7.793***	36.851*	49.485**
	(8.689)	(2.733)	(19.280)	(24.034)
Boone	-0.677	2.606***	-0.457	0.223
	(0.449)	(0.582)	(3.497)	(3.554)
Quality	0.936***	0.659***	1.817***	1.062**
	(0.250)	(0.146)	(0.674)	(0.447)
Nonim	-0.082*	3.308***	8.394***	8.461***
	(0.050)	(0.739)	(2.344)	(2.280)
Concen	-1.773*	-1.491***	-1.608	-3.754**
	(1.005)	(0.293)	(2.378)	(1.511)
Foreign	-0.001	0.295	2.173**	1.959
	(0.365)	(0.200)	(0.859)	(1.667)
Inflation	-3.340**	0.240	-3.353*	-9.023***
	(1.351)	(0.823)	(1.945)	(3.111)
Obs.	532	532	267	267
No. of countries	43	43	22	22
Threshold (CO2)	N.A	8	N.A	22
AR(2)	0.28	0.37	0.59	0.59
Hansen J *p*-value	0.40	0.30	0.75	0.46

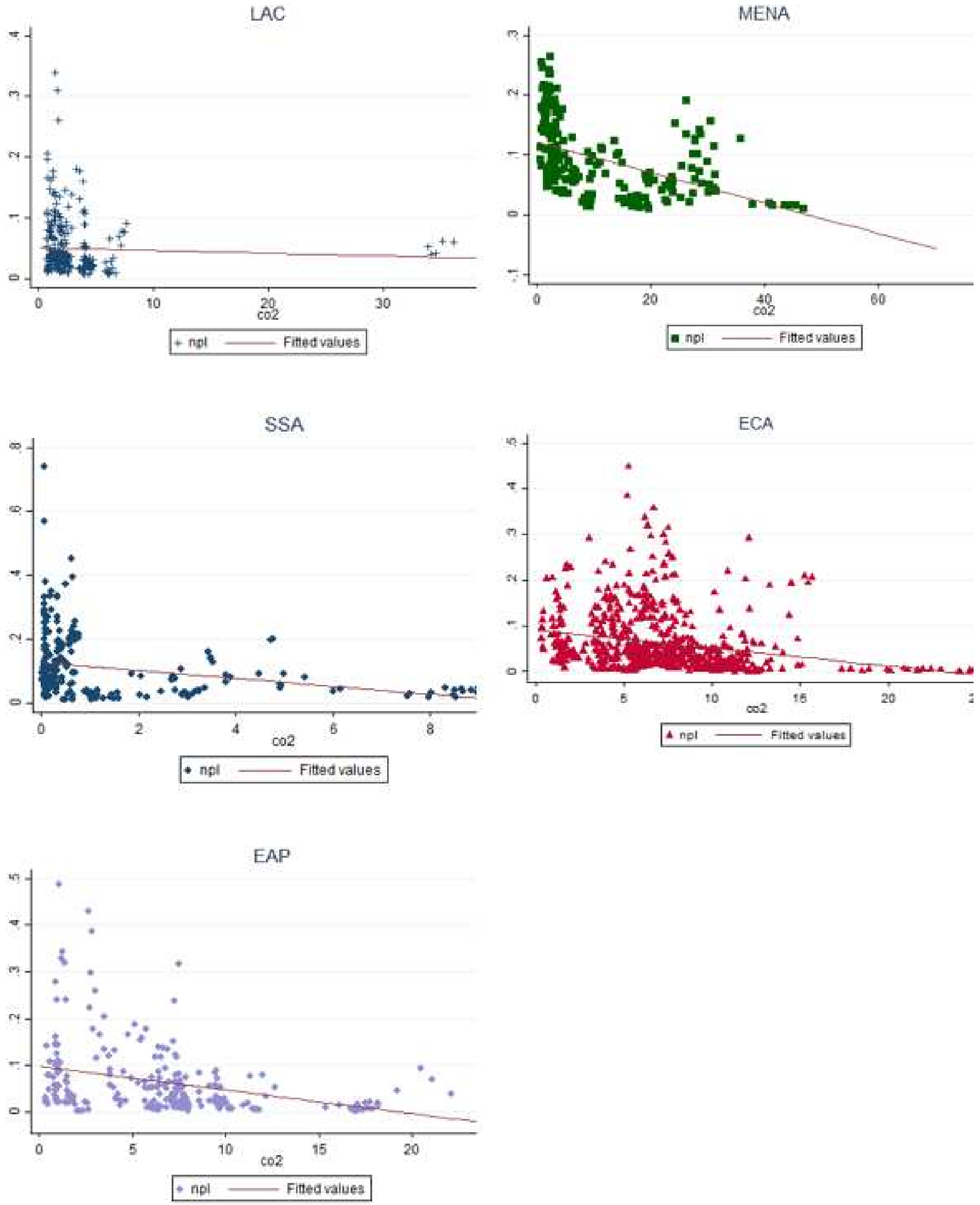
NOTE: *, ** and *** indicate significance at the 10%, 5% and 1% level, respectively.

trialization in the country which would mean borrowers are able to grow their businesses from the loans and consequently their ability to repay their loans. In both of the two tables, coefficients on the quadratic term are all negative and statistically significant at the 10% significance level or better. This suggests that a nonlinear relationship exists between CO2 emissions and banking stability. This is consistent with our baseline estimation results. Looking at the turning points of per capita CO2 emissions, we see that the MENA region has the highest turning point of 61 followed by the LAC region with a turning point of 22. The SSA and EAP regions have the same turning point of 9 while the ECA region had a turning point of 8. These results present an interesting outlook given that MENA being the highest emitter of CO2 emissions requires the highest emissions level to affect the stability of the banking system. Thus, even though all countries are vulnerable to the negative effect of climate change, the impact is largely dependent on the levels of emissions in that country.

5.4.3 Using alternative proxy for banking stability

In the third robustness check, we use the ratio of non-performing loans to gross loans (*NPL*) as an alternative measure of banking stability; higher NPL values suggest lower banking stability. We first show scatter diagrams of NPL against per capita CO2 emissions by regional groups as seen in Figure 4. The plots show that CO2 emissions have a negative influence on NPL, and such influence is stronger at lower CO2 emissions level. Hence, consistent with the earlier observations, per capita CO2 emissions is helpful for improving banking stability below a certain threshold. To test the impact of per capita CO2 emissions on NPL, we use the sys-GMM approach and present the results in Tables 7a and 7b.

Fig.4: Scatter plots of NPL and per capita CO2 emissions by regional group



Since higher NPL indicates lower banking stability, the results are generally consistent with the earlier results when Z-score is used as stability indicator. When CO2 emissions alone are used without the squared term, the results show a negative but insignificant impact of CO2 emissions on NPL for the full sample. However, the results for the regional groupings

Table 7a: System GMM results, using NPL as proxy for banking stability (full sample, SSA and MENA regions)

	Full Sample		SSA		MENA	
	(1)	(2)	(3)	(4)	(5)	(6)
L.dependent	0.656***	0.517***	0.780***	0.781***	0.798***	0.897***
	(0.062)	(0.130)	(0.074)	(0.076)	(0.057)	(0.062)
CO2	-0.0003	-0.0005	-0.006**	-0.013***	-0.0005*	-0.001*
	(0.0003)	(0.001)	(0.003)	(0.005)	(0.0002)	(0.0007)
CO2sq		0.000002		0.0008*		0.00003*
		(0.00003)		(0.0004)		(0.00001)
Nim	-0.244**	-0.273**	-1.128***	-1.435***	-1.577*	0.408
	(0.100)	(0.120)	(0.242)	(0.247)	(0.826)	(0.481)
Boone	0.0007	0.002	-0.137*	0.076**	-0.319**	0.042
	(0.010)	(0.012)	(0.079)	(0.031)	(0.157)	(0.081)
Quality	-0.012***	-0.017**	-0.010*	-0.019*	-0.004	0.0001
	(0.004)	(0.007)	(0.005)	(0.010)	(0.004)	(0.003)
Nonim	0.003	0.011	0.047	0.033	-0.138*	0.063***
	(0.015)	(0.018)	(0.062)	(0.063)	(0.080)	(0.022)
Concen	0.007	0.009	0.045***	0.082***	0.148**	-0.027
	(0.009)	(0.011)	(0.015)	(0.027)	(0.074)	(0.020)
Foreign	0.015**	0.016**	0.048**	0.076**	-0.003	-0.018*
	(0.007)	(0.008)	(0.022)	(0.031)	(0.011)	(0.011)
Inflation	-0.021	-0.036	0.209***	0.026	0.003	0.053
	(0.026)	(0.032)	(0.079)	(0.137)	(0.079)	(0.085)
Obs.	889	889	117	117	127	127
No. of countries	102	102	17	17	14	14
Threshold (CO2)	N.A	N.A	N.A	8	N.A	28
AR(2)	0.11	0.26	0.90	0.80	0.67	0.47
Hansen J *p*-value	0.55	0.23	0.51	0.66	0.86	0.71

NOTE: *,** and *** indicate significance at the 10%, 5% and 1% level, respectively.

Table 7b: System GMM results, using NPL as proxy for banking stability (EAP, ECA and LAC regions)

	EAP		ECA		LAC	
	(1)	(2)	(3)	(4)	(5)	(6)
L.dependent	1.021***	1.006***	0.971***	0.989***	0.929***	0.834***
	(0.035)	(0.073)	(0.036)	(0.034)	(0.060)	(0.034)
CO2	0.001	-0.009**	-0.003***	-0.008***	-0.0006***	-0.011***
	(0.0007)	(0.004)	(0.001)	(0.002)	(0.0002)	(0.003)
CO2sq		0.0007***		0.0002***		0.0003***
		(0.0002)		(0.0001)		(0.003)
Nim	-0.652***	-0.671	-0.912***	-1.176***	-0.278*	-0.677***
	(0.122)	(0.471)	(0.084)	(0.184)	(0.143)	(0.205)
Boone	0.053**	0.021	0.008	-0.003	0.136***	0.222**
	(0.025)	(0.030)	(0.006)	(0.012)	(0.053)	(0.089)
Quality	-0.010	-0.030**	-0.018***	-0.018***	0.007	0.002
	(0.006)	(0.016)	(0.003)	(0.007)	(0.005)	(0.008)
Nonim	0.036	0.132***	-0.039***	-0.082***	-0.082**	-0.060***
	(0.025)	(0.051)	(0.013)	(0.017)	(0.034)	(0.261)
Concen	-0.014	-0.022*	-0.005	-0.015	-0.012	-0.061***
	(0.014)	(0.013)	(0.008)	(0.016)	(0.023)	(0.021)
Foreign	0.061***	0.123*	0.027***	0.019**	-0.015	-0.062*
	(0.021)	(0.064)	(0.005)	(0.008)	(0.019)	(0.034)
Inflation	-0.324	-0.616**	-0.098***	-0.054**	0.027	0.055
	(0.200)	(0.283)	(0.016)	(0.022)	(0.028)	(0.046)
Obs.	130	130	468	468	191	191
No. of countries	12	12	42	42	17	17
Threshold (CO2)	N.A	6	N.A	21	N.A	18
AR(2)	0.17	0.19	0.12	0.10	0.37	0.41
Hansen J p-value	0.74	0.57	0.26	0.18	0.45	0.43

NOTE: *,** and *** indicate significance at the 10%, 5% and 1% level, respectively.

show a significant negative impact of CO2 emissions on NPL with at least 10% significance level indicating that a rise in per capita CO2 emissions improves banking stability. This is consistent for all the regions. After we add the squared term (CO2sq) in the models, CO2sq shows a positive but insignificant impact on NPL for the full sample but for the regions, the results show a significant positive impact on NPL while the level impact of CO2 emissions remains negative. This indicates a U-shaped relationship between CO2 emissions and NPL indicating that initial rise in per capita CO2 emissions benefits banking stability up to a point after which stability begins to fall. The threshold of per capita CO2 emissions after which this occurs is 28 for MENA, followed by 21 for ECA, 18 for LAC, 8 for SSA and 6 for EAP. Overall, our results suggest that it takes less CO2 emissions to reduce bank stability when NPL is used compared to when Z-score is used except for the ECA region where more CO2 emissions is required.

6 Channel Analysis

In this section, we explore whether manufacturing value added (MVA) as percent of GDP (MVA/GDP ratio) can be a potential channel through which CO2 emissions affect banking stability. The data for MVA/GDP ratio is obtained from the World Development Indicators (WDI). As we mentioned earlier, higher CO2 emissions may indicate the level of industrialization in a country. Higher MVA show the increasing capacity and manufacturing level of a country hence the corresponding financing for this expansion. If banks finance these expansions, most of these firms will have their loans on the books of the banks. Therefore, the physical risk of climate change to these manufacturing firms and their products would affect their ability to service their loans as they fall due. This will likely increase the non-performing loans of banks hence their stability. MVA is therefore a plausible channel to explore how climate change can affect banking stability.

To examine whether MVA/GDP ratio is a channel, we follow the method in the existing studies such as Alesina and Zhuravskaya (2011) and Awaworyi Churchill et al. (2019). Two conditions need to be satisfied for MVA/GDP ratio to qualify as a potential channel. First, MVA/GDP ratio is required to be correlated with CO2 emissions. Table 8 presents results for the relationship between per capita CO2 emissions and MVA/GDP ratio. We can see that CO2 emissions raises MVA/GDP ratio. More specifically, MVA/GDP ratio is associated with a 0.004 unit increase in per capita CO2 emissions.

Table 8: Effect of per capita CO2 emissions on MVA/GDP ratio

Dependent Variable	MVA/GDP
CO2	0.004***
	(0.0004)
Controls	Yes
R^2	0.18
Obs.	1565

NOTE: *** indicates statistical significance at the 1% level.

Table 9: Effect of per capita CO2 emissions and the channel on banking stability

	(1)	(2)	(3)	(4)
CO2	0.009***	0.003***	0.016***	0.004***
	(0.003)	(0.001)	(0.004)	(0.001)
CO2sq			-0.0001**	-0.00001
			(0.00007)	(0.00002)
MVA/GDP		1.826***		1.854***
		(0.112)		(0.062)
Controls	Yes	Yes	Yes	Yes
Obs.	1345	1387	1345	1387
No. of countries	121	119	121	119
AR(2)	0.81	0.13	0.82	0.14
Hansen J *p*-value	0.30	0.50	0.22	1.00

NOTE: Robust standard error in parenthesis. ** and *** indicate significance at the 5% and 1% level, respectively.

The second condition is that the inclusion of MVA/GDP ratio as an additional control variable in the regression that relates per capita CO2 emissions and banking stability should decrease the magnitude of the coefficient on CO2 emissions or render it insignificant. Table 9 reports the results. Column (2) shows that when MVA/GDP ratio is included as an additional control, the scale of the coefficient on per capita CO2 emissions falls. Furthermore, column (4) suggests that when assessing the nonlinear effect of CO2 emissions on banking stability, adding MVA/GDP ratio as an extra control variable makes the coefficient of the quadratic term insignificant. Our findings imply that MVA/GDP ratio serves as a potential channel through which per capita CO2 emissions affect banking stability.

We then test whether the impact of per capita CO2 emissions on banking stability through MVA/GDP is dependent on the level of MVA/GDP. We provide estimates for MVA/GDP below and above the 50th percentile. The results in Table 10 further confirm the inverted U-shaped relationship between CO2 emissions and banking stability. We however observe the same per capita CO2 emissions of 20 as a turning point for both sub-samples. This shows that at a per capita CO2 emission of 20, banking stability begins to fall in countries with MVA/GDP up to the 50th percentile and above the 50th percentile.

Table 10: Effect of per capita CO2 emissions and the level on MVA/GDP, system GMM

	Low MVA		High MVA	
	(1)	(2)	(3)	(4)
CO2	0.034***	0.121***	0.040**	0.079*
	(0.013)	(0.025)	(0.016)	(0.042)
CO2sq		-0.003***		-0.002**
		(0.0003)		(0.001)
Controls	Yes	Yes	Yes	Yes
Obs.	648	648	818	818
No. of countries	77	77	87	87
Thereshold (CO2)	N.A	20	N.A	20
AR(2)	0.82	0.84	0.52	0.51
Hansen J p-value	0.23	0.24	0.25	0.22

NOTE: Robust standard error in parenthesis. ** and *** indicate significance at the 5% and 1% level, respectively.

7 Conclusion and Policy Recommendations

The issue of climate change has gained a lot of attention from various stakeholders in recent years due to its adverse effects. For governments, there is an increasing need and pressure to implement climate friendly regulations to limit greenhouse gas emissions as they seek to work towards Goal 13 (Climate Action) of the Sustainable Development Goals (SDGs) and the Paris Agreement to limit global warming to 2°C or even 1.5°C. For firms, the issue of being environmentally responsible is gradually affecting their assessment by consumers and equity investors alike. Consequently, green finance is gaining some traction as investors become environmentally conscious. While a number of studies have looked at the growth impact of climate change, this study is unique as we look at the impact of CO2 emissions on banking stability at various levels of emissions, across volatile and non-volatile time periods and across different regions. The results consistently show that there is an inverted U-shaped relationship between CO2 emissions and banking stability. This suggests that, initial levels of CO2 emissions may show initial levels of industrialization in an economy. As countries industrialize, firms rely on banks to finance their growth and expansion. At this stage firms need to reinvest into their business, and remain profitable to be able to meet their loan obligations as they fall due. It may therefore be costly for industries especially young firms to adapt new technologies that will minimize or limit their emissions of greenhouse gases while staying profitable in other to repay their loans.

However, the results showed that after a certain threshold of CO2 emissions, banking stability starts to reduce. Here, regulatory capacity of the government is key in ensuring that the negative impact of CO2 emissions on banking stability after the threshold is mitigated. Particularly, governments are to identify the right balance by ensuring that on one side firms industrialize and on the other side the environment is protected by limiting CO2 emissions. Therefore, governments in different markets should examine their own realities and fashion out climate related policies that can help mitigate any adverse effects of CO2 on banking stability. Firms on the other hand should also prepare to invest in green technology as they grow. Especially, high emitting firms can create a green fund into which they can contribute a certain portion of their profits for future investment in green technology. This would avoid the huge initial outlay of investment into adaptive green technologies that otherwise would be needed for productive capital. The government can also encourage the firms to invest in these technologies by offering tax cuts through carbon credits. This will encourage firms to invest these reliefs in green technologies that can limit their greenhouse gas emissions.

At the international level, development agencies like the World Bank with commitment from developed countries can institute incentives for countries especially those in developing countries to help in their commitment to invest in low-carbon technologies. Given that most advanced economies emit higher greenhouse gases compared to other economies, it would not be out of place for these developed countries to provide support to the developing counterparts to help them invest in climate friendly technologies as they are exposed to the vestiges of climate change. The developing countries even though have a lower share of global emission compared to developed countries, are more exposed to the vagaries of climate change. The move towards reducing global warming and hence climate change would need the efforts from both the government, private sector and development organizations.

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Appendix A: Data Appendix

This appendix provides the list of countries used in the study.

Table A1: List of countries

Country	World Bank Country code	Country	World Bank Country code
Albania	ALB	Algeria	DZA
Armenia	ARM	Angola	AGO
Antigua and Barbuda	ATG	Australia	AUS
Austria	AUT	Azerbaijan	AZE
Bahrain	BHR	Barbados	BRB
Belarus	BLR	Belgium	BEL
Benin	BEN	Bolivia	BOL
Bosnia and Herzegovina	BIH	Botswana	BWA
Brazil	BRA	Bulgaria	BGR
Burkina Faso	BFA	Burundi	BDI
Cambodia	KHM	Cameroon	CMR
Chile	CHL	China	CHN
Colombia	COL	Congo, Rep.	COG
Costa Rica	CRI	Cote d'Ivoire	CIV
Czech Republic	CZE	Denmark	DNK
Dominican Rep.	DOM	Ecuador	ECU
Egypt	EGY	El Salvador	SLV
Ethiopia	ETH	Estonia	EST
Finland	FIN	France	FRA
Georgia	GEO	Germany	DEU
Ghana	GHA	Greece	GRC
Guatemala	GTM	Haiti	HTI
Honduras	HND	Hong Kong SAR	HKG
Hungary	HUN	Iceland	ISL
Ireland	IRL	Indonesia	IDN
Israel	ISR	Italy	ITA
Jamaica	JAM	Japan	JPN
Jordan	JOR	Kazakhstan	KAZ
Kenya	KEN	Korea, Rep.	KOR
Kuwait	KWT	Kyrgyz Republic	KGZ
Latvia	LVA	Lebanon	LBN
Libya	LBY	Lithuania	LTU
Luxembourg	LUX	Madagascar	MDG
Malawi	MWI	Malaysia	MYS
Mali	MLI	Mauritania	MRT
Mauritius	MUS	Mexico	MEX

Table A1: Continued

Country	World Bank Country code	Country	World Bank Country code
Moldova	MDA	Mongolia	MNG
Montenegro	MNE	Morocco	MAR
Namibia	NAM	Netherlands	NHL
New Zealand	NZL	Nicaragua	NIC
Niger	NER	Nigeria	NGA
Norway	NOR	Oman	OMN
Panama	PAN	Paraguay	PRY
Peru	PER	Philippines	PHL
Poland	POL	Portugal	PRT
Qatar	QAT	Russian Federation	RUS
Rwanda	RWA	Saudi Arabia	SAU
Senegal	SEN	Serbia	SCG
Seychelles	SYC	Singapore	SGP
Slovak Republic	SVK	Slovenia	SVN
South Africa	ZAF	Spain	ESP
Sudan	SDN	Sweden	SWE
Switzerland	CHE	Tanzania	TZA
Thailand	THA	Togo	TGO
Trinidad and Tobago	TTO	Tunisia	TUN
Turkey	TUR	Uganda	UGA
Ukraine	UKR	United Arab Emirates	ARE
United Kingdom	GBR	Uruguay	URY
Venezuela	VEN	Yemen, Rep.	YEM
Zambia	ZMB	Zimbabwe	ZWE

Appendix B: Summary statistics for each regional group

Table B1: Descriptive statistics by regional groups

	Obs.	Mean	Std.Dev.	Min	Max
Panel A: SSA region					
Z-score	740	11.119	7.456	-1.458	95.279
NPL	257	0.108	0.101	0.010	0.741
CO2 emissions per capita	833	0.900	1.796	0.017	9.871
Institutional quality	704	-0.655	0.610	-2.298	1.127
Net interest margin	691	0.072	0.035	0.0003	0.233
Non-interest income	715	0.446	0.144	0.014	0.905
Bank asset concentration	579	0.787	0.183	0.223	1.000
Foreign entry	536	0.495	0.274	0.000	1.000
Boone indicator	535	-0.050	0.108	-0.305	1.607
Consumer price index	745	0.119	0.373	-0.096	5.139
Panel B: MENA region					
Z-score	381	21.884	11.524	0.044	64.426
NPL	207	0.093	0.063	0.011	0.265
CO2 emissions per capita	397	10.269	10.269	0.146	70.136
Institutional quality	336	-0.205	0.836	-2.233	1.431
Net interest margin	379	0.033	0.018	0.0006	0.205
Non-interest income	372	0.317	0.121	0.034	0.813
Bank asset concentration	331	0.719	0.167	0.327	1.000
Foreign entry	304	0.189	0.210	0.000	0.710
Boone indicator	292	-0.042	0.107	-1.023	0.159
Consumer price index	454	0.092	0.314	-0.161	4.485
Panel C: EAP region					
Z-score	453	13.127	7.794	-2.619	33.721
NPL	245	0.064	0.077	0.010	0.486
CO2 emissions per capita	494	4.819	5.035	0.096	24.607
Institutional quality	411	0.222	1.030	-2.344	2.234
Net interest margin	442	0.038	0.021	0.002	0.110
Non-interest income	451	0.331	0.140	0.032	0.922

The summary statistics for each regional group are presented in Table B1. The MENA region has the most stable banking system with the highest average Z-score of 21.88 over the period 2000-2013 followed by the LAC region with Z-score value of 14.57. The region with least average Z-score is the ECA region. The SSA region has the highest NPL of 10.80%

Table B1: Continued

	Obs.	Mean	Std.Dev.	Min	Max
Bank asset concentration	332	0.681	0.213	0.289	1.000
Foreign entry	288	0.328	0.243	0.000	0.830
Boone indicator	249	-0.069	0.144	-0.770	0.320
Consumer price index	471	0.054	0.098	-0.040	1.253
Panel D: ECA region					
Z-score	941	10.108	6.077	-0.448	38.695
NPL	679	0.066	0.069	0.000	0.450
CO2 emissions per capita	893	6.841	3.843	0.292	24.825
Institutional quality	778	0.602	0.981	-2.133	2.098
Net interest margin	923	0.038	0.030	0.001	0.184
Non-interest income	940	0.423	0.140	0.071	0.929
Bank asset concentration	895	0.701	0.185	0.209	1.000
Foreign entry	810	0.370	0.274	0.000	0.960
Boone indicator	753	-0.096	0.207	-2.000	2.130
Consumer price index	857	0.070	0.134	-0.085	1.548
Panel E: LAC region					
Z-score	649	14.567	8.237	1.131	53.736
NPL	293	0.050	0.047	0.007	0.339
CO2 emissions per capita	668	4.145	6.155	0.130	39.446
Institutional quality	552	0.090	0.712	-1.815	1.543
Net interest margin	638	0.059	0.026	0.007	0.213
Non-interest income	640	0.347	0.144	0.025	0.937
Bank asset concentration	530	0.679	0.203	0.243	1.000
Foreign entry	432	0.398	0.244	0.000	1.000
Boone indicator	494	-0.067	0.121	-0.570	0.378
Consumer price index	550	0.071	0.098	-0.024	0.988

compared with the other regions. It is then followed by the MENA region. The LAC region is the most stable region with the least mean NPL of 5.00% followed by the EAP region with a mean NPL of 6.40%. We can also see that the region with the highest average per capita CO2 emissions is the MENA region with a mean of 10.27. This is followed by the ECA region with a mean CO2 emissions of 6.84. The region with the lowest per capita CO2 emissions is the SSA region. In regards to regulatory quality, the ECA has the highest mean value of 0.60 followed by the EAP region with a mean value of 0.22. The region with the lowest value of institutional quality is the SSA region with a mean value of -0.66.

In terms of the banking system variables, the SSA region has the highest mean net interest margin of 7.20% followed by the LAC region with 5.86%. The region with the lowest net interest margin is the MENA region with mean value of 3.30%. The mean non-interest income for SSA is 44.62% being the highest among the regions with the least recorded for the MENA region of 31.70%. The region with the highest mean bank asset concentration ratio is the SSA region with 78.60% and the least concentrated region is the LAC with a mean value of 67.90%. In terms of the Boone indicator, ECA is the most competitive banking market with a negative mean of -0.10. This is followed by the EAP region with a mean value of -0.07. The least competitive banking market is the MENA region with a negative mean value of -0.04. It can also be seen from Table B1 that the region with the most share of foreign banks in the banking system is the SSA region with a mean value of 49.50%. The region with the least foreign banks presence is 18.90%.