The effect of financial crises on air pollutant emissions: an assessment of the short vs. medium-term effects

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***Highlights (for review : 3 to 5 bullet points (maximum 85 characters including spaces per bullet point)**

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Highlights

- Impact of financial crises on air pollutant emissions, 150 countries over 1970-2014.
- 1.4-6.2% fall in CO_2, SO_2 and NO_x emissions shortly after the crisis breakout.
- Crisis effect disappears or reverses (1-2% increase) one or two years after the start of crisis.
- No short-term fall in $PM_{2.5}$ emissions; in contrast, 0.9-1.8% medium term increases.
- 'Punctuated degrowth' caused by financial crises offers no long-term solution to air pollution.

The effect of financial crises on air pollutant emissions: an assessment of the short vs. medium-term effects

Abstract: This paper empirically investigates the impact of financial crises on air pollutant emissions (CO_2, SO_2, NO_x and $PM_{2.5}$). A panel data approach is used, including 419 financial crisis episodes in more than 150 countries over the period 1970-2014. The short- and medium-term effects of crises are estimated, using a GMM specification (for short-term) and the estimation of impulse response functions (for medium-term). Results show that in the short-term, as a consequence financial crises, emissions decrease for all gases except for $PM_{2.5}$. In particular, emissions of CO_2, SO_2 and NO_x decrease by 2.6, 1.8, and 1.7% respectively. However, in the medium-term, financial crises cause insignificant effect on emissions, or in some cases even lead to a 1-2% increase, cancelling out the initial benefit. Our analysis also shows that the effect of crises is larger in high income and upper-middle income countries. Moreover, recent crises had a larger short-term impact on air pollutants than crises in previous decades. Our results suggest that the beneficial impact of financial crises on air quality is short-lived. To preserve this beneficial impact in the long run and avert new negative post-crisis emission patterns and dynamics, policy responses to financial crises should encompass tighter environmental regulations and green investments.

Keywords: Economic crises, air pollution, environmental quality, economic growth, income groups, GMM specification.

1. INTRODUCTION

The intensity and frequency of financial crises have significantly increased over the last decades. In less than ten years after the 2008 Great Recession, financial vulnerabilities have been again on the rise across the globe, and almost 40% of the low income countries are already facing significant challenges in servicing their debt (IMF, 2018a, 2018b; Antoniades and Griffith-Jones, 2018). Given the strong interdependence between the economy and the environmental (see, for example, Ang, 2008; Apergis and Payne, 2010; Omri, 2013), it follows that a shock in the former should affect the latter. The direction and the size of the impact, however, has not been well defined. On one side for example, crises can be opportunities for environmental improvements where the immediate reduction in industrial output might lead countries towards more sustainable resource use (see, Bowen and Stern, 2010). On the other side, crises might have negative effects, if balancing budgets takes precedence over governments' social and environmental aims. Thus, instead of reaping the benefits of blue skies due to reduced economic activity, countries may end up with weaker environmental legislation or policy enforcement, and as a result greater environmental degradation. The existing literature has focused on whether environmental sustainability is compatible with economic growth (e.g. Daly, 1985; Jackson, 2009). We have much less systematic evidence on how financial crises impact on the environment.

To address this gap, we focus our analysis on the relationship between financial crises and environmental quality, concentrating in particular on a range of air pollutants: carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x) and particulate matter ($PM_{2.5}$). The significance of ambient air pollution as a critical, global public health issue is hard to overstate. According to a recent WHO (2018) report, air pollution kills 7 million people a year and harms billions of others, especially children, as 91 percent of the world's population live in areas with air pollution above WHO limits. We advance the existing state of the art in four ways. First, while the existing literature is mostly based on single country analyses, our analysis investigates the effect of crises on air pollutant emissions across countries and over a longer time period. In particular, we use data on CO_2, SO_2, NO_x and $PM_{2.5}$ emissions, exploiting a 40-year time series (1970-2010 or 2014) and including 419 instances of financial crises in more than 150 countries. This has the advantage of encompassing several crisis episodes, and allows drawing generalizable evidence rather than results linked to single countries' specificities. Second, our dataset enables comparing different country income groupings, and understanding whether and how the environmental effects of crises relate to different income-levels and stages of economic development. Similarly, our dataset enables us to disentangle the effect of those financial crises that have coincided with a decrease in GDP, thus enriching our understanding of the interplay among economic growth, financial crises and air pollutant emissions. Third, we provide results on how the nature of the environmental impact of financial crises has changed over the last forty years. Fourth, we distinguish between the short run versus the medium run effects of financial crises, whereas previous research is mostly based on short-term evidence and projections of future scenarios rather than empirical data.

Our results tell us that financial crises contemporaneously lead to a reduction in the emissions of CO_2, SO_2 and NO_x. The magnitude of this reduction is between 1 and 3 percent (this increases to 4-5 percent if focusing only on crises coinciding with a GDP decrease). However, the effect on $PM_{2.5}$ is smaller and less robust. Overall, in the short run, financial crises turn out to have a beneficial, if small, impact on air pollutant emissions. Yet, we find very little evidence on the persistence of this effect in the medium run, suggesting the existence of no long-lasting effect on air pollutant emissions. This finding is in line with scenarios projected by previous, mostly case-study based, literature (Siddiqi, 2000; Lekakis and Kousis, 2013), which predicted that the environmental benefits of crises would only be short-lasting. Moreover, we find some heterogeneity across country groups and time periods. The aforementioned short-term beneficial impact is stronger in high income and middle income countries, whereas no (beneficial) impact is observed in low income countries. Furthermore, the environmental impact of financial crises is overall higher in the years after 1990 than in those before.

The structure of the paper is organized into seven sections. Section 2 reviews the environmental economic literature on the effect of growth and crises on environmental quality. Section 3 illustrates the sources of our data, while section 4 focuses on the empirical strategy. Section 5 presents our main results, as well as some additional tests to account for the robustness of our results. Finally, sections 6 and 7 discuss our results and present our conclusions.

2. ECONOMY, FINANCIAL CRISES AND ENVIRONMENT

The relationship between economic growth and environmental sustainability has been widely studied and debated in the economic literature. One of the most popular branches of research analyzing the relationship between *per capita* GDP growth and environmental quality is referred to as the "environmental Kuznet's curve" hypothesis (hereafter "EKC"): the environment tends to deteriorate as economic growth increases, up to a certain level of income, where the relationship is reversed and environmental quality starts to improve. This is graphically represented by an inverse U-shaped curve, similar to the one found by Kuznets (1955) regarding the relationship between income growth and inequality. There are several channels underlying the EKC relationship (Dinda, 2004). On the side of production, economic growth brings about an increase in activity and, consequently, emissions and waste generation. Subsequent growth then leads to a change in the composition of the economy, with a gradual increase in cleaner activities. Through the introduction of new standards and higher R&D spending, cleaner technologies might be developed that bring significant socio-economic and environmental benefits (see for instance Kurgankina et al, 2019). Meanwhile, on the side of consumption, economic growth and increasing incomes potentially have impacts on consumers' preferences, inducing demand for greener products, cleaner and healthier environments (McConnell, 1997; Shafik, 1994). Brasington and Hite (2005), for example, find that income is positively correlated to environmental quality regarding housing characteristics, and Jalan and Somanathan (2008), using data on households from an Indian city, show a positive and statistically significant relationship between the increase in wealth and the money spent on water purification. International trade, which is closely linked to economic growth, also affects the environment in variegated ways; one country or group of countries may see benefits by shifting polluting activities towards other countries, which will become “pollution havens” (Cole et al., 2002; Janicke et al., 1997; Stern et al., 1996; Peters et al., 2011). Empirical findings on EKC are inconclusive, with some studies confirming the EKC hypothesis (e.g. Grossman and Krueger, 1995; Shafik, 1994; Panayotou, 1995; Selden and Song, 1994; Galeotti et al., 2006), and others challenging it (e.g. Harbaugh et al., 2002; Sirag and Matemilola, 2017; Dinda et al, 2000; Martínez-Zarzoso and Bengochea-Morancho, 2004; Perman and Stern, 1999).

The literature on the environmental effects of financial crises is rather scarce. Among the existing evidence, Siddiqi (2000) finds that the 1997 Asian crisis led to a slowdown in energy use and in the associated CO_2 emissions. However, the author points out that these short-term benefits could be neutralized by deferment of clean energy investments, as well as a negative impact on forest use and water pollution. These predictions are confirmed by Elliott (2011), who studies the effect of both the 1997 and 2008 financial crises in East Asia. She finds that any positive impacts from the crises were short-lived, while negative impacts endured. The latter include pressures for ‘further deforestation, agricultural expansion at the expense of water and soil quality, and lax enforcement of pollution regulations’ (ibid. 179). Moreover, the priority for both government and the private sector in the post-crisis environment was investments that would generate ‘quick returns to compensate for losses rather than pursuing longer-term environmental and financial sustainability’ (ibid. 180). Similarly, Lekakis and Kousis (2013) discuss short vs. long run environmental effects of the Greek 2008 crisis. After pointing out that the crisis has brought some short run benefits, consisting in lower air and water pollution intensities, the authors anticipate that, in the longer run, the pro-growth policies and the austerity measures might weaken environmental standards and protection. Monteiro et al. (2018), studying air pollution in the cities of Lisbon and Porto, find a reduction in energy consumption following the 2007 crisis, a positive correlation between energy use and PM_{10} and NO_2

emissions, and a negative trend of pollution concentration in the 5 years following the crisis. In contrast to Siddiqi (2010) and Lekakis and Kousis (2013), Monteiro et al. (2018) find that crises have a significant medium-term impact on pollutant gases' emissions, suggesting that the recession might have induced changes in consumers' behavior. Other studies, limited to short-term effects considerations, see a reduction of anthropogenic activities, such as traffic and polluting gases' emissions, in several countries as a consequence of the 2008 great recession. Most of these contributions focus on single countries: for instance, Markaki et al. (2013) and Karagiannidis (2015) study environmental quality in Greece, while Sobrino and Monzon (2014) and Querol (2014) observe pollution in Spain. An exception is a study by Botetzagias et al. (2018), which finds that, for the period 2000-2015, a negative GDP growth causes positive to non-significant effects on environmental quality and policy indicators across all European countries. However, whenever a country is recipient of a "troika rescue package" while experiencing a recession, the effect on the environment is detrimental. We summarise key points and assumptions from the above literature in Table 1.

Table 1: Environmental Kuznet's curve and financial crises

To sum up, existing evidence suggests that, in the short run, environmental degradation tends to decrease in response to financial crises. Findings on the medium and long run effects are weaker, and lack evidence from data-based studies, large countries' samples and extended time periods.

3. DATA

Data on financial crises come from Laeven and Valencia (2018). The authors distinguish between three different types of economic crises occurring between 1970 and 2017: systemic banking crises, sovereign debt crises and currency crises. Banking crises are defined as systemic if two conditions are met: signs of financial distress in the banking system, and significant banking policy interventions. Currency crises are defined as a nominal depreciation of the country's currency *vis-à-vis* the U.S. dollar of at least 30 percent, that is also at least 10 percentage points higher than the rate of depreciation in the year before. As for sovereign debt crises, these include episodes of sovereign default or debt restructuring. Table 2 shows crises' occurrence in our database. According to Leaven and Valencia (2018), the database includes 143 banking crises, 65 sovereign debt crises and 211 currency crises. All income groups have experienced all three different types of crises, giving us room for comparison between crisis and non-crisis years.

Table 2 – Financial crisis occurrence, 1970-2017, according to Laeven and Valencia (2018)

Data on gases' emissions come from the World Bank. We consider CO_2, SO_2, NO_x and $PM_{2.5}$ emissions. CO_2 data are available until 2014, while the other pollutants' data are only available until 2010. The reasons why we use these gases as air quality and emissions indicators are the following. CO_2 is the most abundant greenhouse gas after water vapor; it is mostly produced by fossil fuel use and industrial activities and, to a lesser extent, by forestry and land use. SO_2 and NO_x are also mostly produced by fossil-fuel-fired power plants, biomass burning, transport, and agricultural soils, and cause harmful health effects by creating respiratory problems, which are worsened by the fine particles that these gases produce through chemical reactions in the air (e.g. NO_x is a major precursor of ozone). Finally, particulate matter ($PM_{2.5}$) is largely produced by vehicles, as well as household and industrial activities. Prolonged exposure to these particles is found to increase mortality risk.

As for our control variables, GDP (at constant prices), trade openness and urban population are taken from the World Bank's *World Development Indicators*. Data on total primary energy use come from the Energy Information Administration (EIA), and include the consumption of petroleum, dry natural gas, coal, and net nuclear, hydroelectric, and non-hydroelectric renewable electricity.

4. EMPIRICAL STRATEGY

Our econometric strategy consists of two different steps. As a first step, we estimate the short-term effect of financial crises on air pollution, using a GMM specification to assess how air pollution is affected in the years when economic crises happen. As a second step, we infer the medium-term effect of crises by using impulse response functions (IRF). Specifically, we estimate CO_2, SO_2, NO_x and $PM_{2.5}$ emissions from 1 to 10 years after the onset of crises. We choose the GMM model for the analysis of short-term effects because it allows correcting for the bias coming from potentially endogenous relationship between economic crises and emissions by instrumenting endogenous variables with their own lags. In this way, we do not have to look for valid external instruments, which can be very difficult. For the medium-term analysis, the impulse-response function is useful to assess how emissions react to the occurrence of a crisis over time, which would not be possible with a GMM model.

In order to measure the short-term effect of financial crises on emissions, we employ the following specification:

$$y_{it} = y_{it-1} + crisis_{it} + L.pcGDP_{it} + X_{it} + \varepsilon_{it} \qquad \textbf{(1)}$$

Where *y*, our dependent variable, represents pollutant gases' emissions (CO_2, SO_2, NO_x and $PM_{2.5}$) in country *i* and year *t*. All dependent variables are computed in *per capita* terms. $Crisis$ is an indicator variable, equal to 1 in those years when a country is experiencing a banking, currency or debt crisis, and to 0 in all other years. $pcGDP$ indicates *per capita* GDP at constant prices, which is included in lagged form to attenuate potential multicollinearity bias, which might arise by incorporating gross domestic product and the crisis indicator in the same year. *X* is a vector of control variables which include the percentage of urban population over total population, the level of trade openness and per *capita* energy consumption. Finally, ε

is the error term. The selection of the control variables to be included in our model was based on a review of the literature that focuses on the determinants of emissions (see, in particular, Sharma, 2011), as well as on data availability (given the lack of solid time series for many variables). The limited number of covariates in our models is balanced by the inclusion of the lagged dependent variable, which captures dynamic relationships between financial crises and emissions. Thus, in equation (1), the first lag of the dependent variable is incorporated among the predictor variables. The inclusion of the lagged dependent variable has the advantage of capturing dynamic and temporal dependence of our *y* variable, attenuating the omitted variables bias. However, the lagged term generates autocorrelation between the independent variables and the error term, violating one of the fundamental OLS assumptions. To solve this issue, Arellano and Bond (1991) have suggested using the Generalized Method of Moments, where all available lags (second lag and deeper) can be used as instruments for the first lag of the dependent variable. We choose to use the GMM, instrumenting y_{it-1} with its second and further lags. In particular, we choose to implement the two-step system GMM estimator.[1]

In order to precisely assess the medium- and long-term effects of banking crises, we employ the impulse response function (IRF) methodology introduced by Jordà (2005) and used by Teuling and Zubanov (2010) and Furceri and Zdzienicka (2012). The method, initially proposed as an alternative to a VAR model, consists in estimating, for a chosen number of future periods, impulse response functions from local projections. This translates, in our case, into running sequential regressions where air quality variables are estimated as a function of the lagged dependent variable and a dummy variable indicating the occurrence of a financial crisis. The specification we use is similar to the one used by Teuling and Zubanov (2010), and takes the following form:

$$y_{i,t+k} = \alpha_i^k + t_i^k + \sum_{l=0}^{l=2} \gamma_{lk}\, y_{i,t-l} + \sum_{l=0}^{l=2} \beta_{lk}\, crisis_{i,t-l} + \sum_{l=0}^{k-1} \theta_l\, crisis_{i,t+k-l} + \varepsilon_{i,t}^k \qquad \textbf{(2)}$$

Where *y* is our dependent variable, corresponding to CO_2, SO_2, NO_x and $PM_{2.5}$ emissions, alternatively. Each future period is indicated by *k*; in our case, we use future periods that go from 1 to 10. This allows estimating the effect of financial crises that occur up to ten years after the start of the crisis itself. Lagged terms of the dependent variable are included as controls. We use up to two lags in the main specification; we also try to use a higher number of lags (3 and 4), finding that results are robust across lag choice. α represents country-level fixed effects, while *t* indicates country-specific time trends. We also run an alternative specification, where we include time fixed effects instead of trends. The *crisis* variable, in this case, is equal to one in the year of start of a financial crisis, and equal to zero in all the other years. The coefficient β_0, in front of the *crisis* dummy variable, represents, for each period *k*, the estimated impulse-response function. Two lags of the financial crisis variable are also included. We employ the methodology proposed by Teuling and Zubanov (2014), which consists in incorporating, in equation (2), the financial crisis variable between *t* and *t+k*. According to the authors, the inclusion of intermediate observations has the double advantage of improving efficiency and, at the same time, reducing the bias in the estimator.

5. MAIN RESULTS

5.1 Short-term effect

Results from equation (1) are presented in Table 3 for all considered polluting gases. Columns (1)-(4) present results from a system, two-step GMM specification, where the key explanatory variable is the dummy variable accounting for the occurrence of a financial crisis. Drawing from the analysis by Sharma (2011), we include, as control variables, lagged *per capita* GDP at constant prices, trade openness, and the percentage of urban population. In columns (5)-(8), we also add *per capita* energy consumption, which, however, leads to a reduction in the sample size, since data from the EPA are only available from 1981. By running the Im-Pesaran-Shin (2003) unit root test[2] on both dependent and explanatory variables, we find that many of the variables included in our model are nonstationary. Therefore, we include them in growth form to avoid bias coming from spurious regressions. This also has the advantage of having easily interpretable results, since the coefficients indicate how much independent variables affect the dependent variable in percentage terms.

Overall, results in Table 3 show that financial crises have a negative and statistically significant effect on *per capita* CO_2, SO_2 and NO_x, and no statistically significant effect on PM_{25} growth. Looking at columns (1)-(4), we can infer that on average, when countries experience a financial crisis, the growth of *per capita* CO_2 is 2.6 percent lower than in the years in which no financial crisis occurs. For SO_2 and NO_x, this effect is smaller, with a decrease of 1.6 and 1.7 percent, respectively. Interestingly, in columns (5)-(8), the coefficients on the financial crises variable are very similar to the ones presented in columns (1)-(4), showing that our results are robust to the inclusion of energy consumption as control and to the use of a different time period. Following Roodman (2009), who advises against the use of too many instruments, we only employ the second lag to instrument the variables that are treated as potentially endogenous. In columns (5)-(8), in addition to instrumenting the lagged dependent variable, we consider *per capita* energy consumption as potentially endogenous. Indeed, energy use and emissions could be simultaneously determined, as an effect, for example, of environmental laws or policies implemented by countries.

Table 3 – Effect of financial crises on polluting gases' emissions, GMM Specification

Table 4 displays results from equation (1), where the estimation method is a fixed effects model, rather than a GMM specification. Despite the GMM being the most appropriate model for estimating a dynamic panel, having a long time period (30-40 years) should attenuate the potential bias coming from the inclusion of the lagged dependent variable in the model (Nickell, 1981). Basing on this consideration, we would expect results from a fixed effect model not to deviate substantially from those of the preferred GMM specification. The coefficients on the financial crisis dummy variable presented in Table 4 support our hypothesis. Similarly to Table 3, columns (1)-(4) show results obtained by including trade openness, urban population and lagged *per capita* GDP as control variables, while columns (5)-(8) add per capita energy consumption. With the exception of column (1), where the *t* test gives a value that is slightly below the conventional threshold for statistical significance, we find that the occurrence of financial crises has a negative and statistically significant effect – at least at the 0.1 level – on CO_2, SO_2 and NO_x emission growth (with the exception of CO_2 in column (1), where the coefficient is slightly under significance level). The magnitude of this effect ranges between 1.5 and 2 percent, confirming findings from our GMM specification.

Table 4 – Effect of financial crises on polluting gases' emissions, Fixed Effects Specification

We then subdivide our results from Tables 3 and 4 into income groups to investigate heterogeneous effects of financial crises on the air pollutants. Table 5 shows results from equation (1), where the country sample is split into four sub-samples: high income, upper-middle income, lower-middle income and low income countries. The splitting has been done according to the World Bank Atlas Method that classifies countries basing on their GNI.[3] Two different estimation methodologies are presented, a system GMM specification and a fixed-effects specification. When implementing the GMM specification, given the small number of countries in each income group, we reduce the number of instruments.[4] Table 5 displays the coefficients and significance concerning the effect of financial crises on air pollutants. The lagged dependent variable and the usual control variables –trade openness, urban population and GDP– are included in both specifications. The results indicate that financial crises have a negative and statistically significant impact on CO_2 emissions only for high income and upper-middle income countries (3.1 and 5.7 percent reduction, respectively); SO_2 and NO_x are negatively and significantly affected by crises in high income and lower-middle income countries, while none of the income groups shows any statistically significant effect of economic crises on $PM_{2.5}$. Overall, our results show that crises –at least in the short-term–effect air pollutant emissions in high and middle income countries, but not in low income countries.

Table 5 – Effect of financial crises on polluting gases' emissions for different income groups

Beyond differences in income level, it is also important to examine whether the nature of the environmental impact of the financial crises has changed during the last forty years. Table 6 presents results from our preferred GMM specification, where our time period is split into four different sub-periods: 1970-1979, 1980-1989, 1990-1999 and 2000-2010 (or 2014 for CO_2 emissions). Overall, our results are heterogeneous across decades. For CO_2, results on the full sample are driven by the most recent period, during which economic crises caused a 4 percent reduction of *per capita* emissions. *Per capita* SO_2 emissions turn out to be significantly affected by crises only in the 90s, while NO_x displays negative and statistically significant coefficients on all four periods; however, the magnitude of the coefficient on the most recent period is considerably larger than the one on previous years.

Table 6 – Effect of financial crises on polluting gases' emissions across different time periods

Finally, considering the centrality of economic growth in environmental debates, and the fact that not all financial crises lead to an output loss (i.e. a fall in GDP), it would be important to account separately for the environmental impact of those financial crises that coincided with an output loss. In Table 7, results from our main specification are displayed, where we have only selected financial crises that coincided with a negative GDP growth. Using both a GMM and a fixed effects specification, we find that, when there is a reduction of *per capita* GDP, the effect of financial crises is almost double in magnitude with respect to our baseline specification. The pollutant with the highest coefficient is SO_2, whose emissions' growth is 5% higher when countries are experiencing a crisis together with a GDP reduction as compared to all the other years. Moreover, when a GDP reduction occurs, crises have a negative and significant impact on $PM_{2.5}$ too.

In conclusion, our results suggest that growth is an important channel through which our relationship of interest takes place.

Table 7 – Effect of financial crises coinciding with output loss on polluting gases' emissions

5.2 Medium-term effect

In Table 8, we present results from equation (2), where the medium-term effect of financial crises has been estimated for our four pollutants of interest. The number on top of each column indicates each period (from year 0 to year 10), and the coefficients shown in the Table correspond to the estimated impulse-response functions from the starting year of a financial crisis to 10 years after the crisis' start. The impulse response functions have been estimated using a fixed effects regression and including time fixed-effects. Looking at coefficients in year 0, we can notice that the IRF results confirm findings from our GMM specification. For all four pollutants, coefficients are negative and statistically significant, with a magnitude that ranges between 0.014 (for $PM_{2.5}$) and 0.034 (for SO_2). Differently from the GMM results, the coefficient on $PM_{2.5}$ is statistically significant, despite the effect of crises being smaller for $PM_{2.5}$ than for CO_2, SO_2 and NO_x. By contrast, there are very few future periods when the occurrence of crises is negatively correlated with and has a statistically significant effect on pollutant gases' emissions. For CO_2, we detect a negative statistically significant coefficient in the 4th, 6th and 10th year from the beginning of the crisis, with a 2-3 percent emission reduction. For both SO_2 and NO_x, after a reduction in emissions in year 1, medium-term coefficients are either null or positive. For $PM_{2.5}$ coefficients after year 1 are often positive, and indicate 0.9 to 1.8 percent increases in emissions.

Table 8 – Medium-term effect of financial crises on polluting gases' emissions, Impulse-Response Functions

To complete our analysis on the medium-term effect of financial crises on air pollutant emissions, we estimate impulse response functions for the 10-year crises horizon for different income groups in Table 9. For none of the groups did we find robust evidence of a beneficial medium-term environmental effect. High income countries display negative and, on average, higher magnitude coefficients for CO_2, SO_2, NO_x and $PM_{2.5}$ in years 0 and 1, with a pollution reduction effect that goes from 3.6% to 6.2%. However, in the following years, we find no consistent evidence that this positive impact on air pollutant emissions continues. In contrast, we find an increase in particulate matter emissions in years 4 and 6 (2.5 and 3.5 percent, respectively). Upper-middle income countries display a negative effect on pollution mostly in year 0, and in year 1 only for SO_2. In the medium-term, most statistically significant coefficients carry a positive sign, signifying increases in air pollution. Finally, lower-middle income and low income countries seem to benefit less from financial crises in the short run, and show no robust effect of crises in the medium run.

Table 9 – Medium-term effect of financial crises on polluting gases' emissions for different income groups, Impulse-response functions

Overall, we can conclude that we do not find a strong medium- or long-term effect of financial crises on air pollutant emissions: with few exceptions, most of the coefficients on future periods are statistically insignificant. As shown in Table A1, presented in the Appendix of the paper, this finding holds when considering only crises that coincided with a GDP reduction. Interestingly, when a statistically significant effect is detected, the coefficients often carry a positive sign, signifying increases rather than decreases in air pollution. This is particularly true for $PM_{2.5}$, whose emissions show some increases after year 1 from the start of a crisis for all income categories.

5.3 Robustness Checks

In order to assess the consistency of our results across different specifications, we present some robustness tests for the short run and medium run results. Table 10 shows two alternative GMM specifications, where different variables are treated as endogenous with respect to our main specification. Indeed, one advantage of the GMM model is that it does not only allow instrumenting the lagged dependent variable to account for first-order autocorrelation issue, but it also gives the possibility to instrument some additional model variables that are suspected to be endogenous. While in Table 1 we only instrumented the lagged dependent variable, in Table 10 we alternatively treat financial crises (columns (1)-(4)) and GDP growth (columns (5)-(8)) as endogenous. The logic behind this potential endogeneity is that there could be some factors, such as the increase in countries' debt, or the change of governments, that contribute to determining financial crises and a change in environmental policies at the same time. Looking at Table 10, we note that, although the magnitude of coefficients on the crisis indicator changes in some of the specifications (in particular, they tend to increase when the financial crisis variable is treated as endogenous), their sign and significance does not vary. We also try specifications where the other model variables are treated as endogenous, always finding that our results on the effect of financial crises on gases' emissions is robust.

Table 10 – Robustness Checks, GMM Specification

We have also tested whether our results are robust across different definitions of financial crises. For this, we used the Reinhart and Rogoff (2011) database on financial crises. Similarly to what we did with the Leaven and Valencia (2018) database, in our main specification we created a combined dummy variable including banking crises, sovereign debt crises and currency crises. The Reinhart and Rogoff (2011) database only includes 70 countries; therefore, the final sample is substantially smaller with respect to our main specification. We also applied both a fixed effects and a system GMM specification. Overall, our results prove to be robust to the use of this different database. Financial crises turn out to have a negative effect on CO_2, SO_2 and NO_x emissions, and a smaller (or statistically insignificant) effect on $PM_{2.5}$ emissions (see Table A2 in the Appendix)

Finally, regarding the medium-term effects, we ran an alternative specification, where a time trend is included instead of year-fixed effects. The results confirmed evidence from Table 8, showing that the medium-term effect is insignificant for most of the future periods.[5]

6. 6. DISCUSSION

7. 6.1 – Discussion of Main Results

The findings of our analysis show that financial crises lead to a decrease in global emissions of CO_2, SO_2 and NO_x in the short run, with average reductions of 2.6, 1.8, and 1.7%, respectively (Table 3). Results on particulate matter emissions (PM_{25}) are less robust, and differ across specifications, suggesting that this pollutant is less sensitive to the occurrence of crises. Separating our analysis into income groups, our results show (Table 5) that financial crises have a significant short run beneficial effect on all three air pollutants only in high income countries (3.1, 2.0, 2.6% decrease in CO_2, SO_2, and NO_x). This effect is less comprehensive in upper-middle income countries (5.7% decrease in CO_2) and lower-middle income countries (2.8, 3.2% decrease in SO_2, NO_x), with no effect for low income countries. Moreover, the financial crisis effects have become more pronounced and significant in the recent decades, with a reduction in CO_2 and NO_x global emissions of 4.1 and 3.8% between 2000-2010 (Table 6). Yet this beneficial impact is short-lived. We find no evidence that environmental improvements continue in the medium- or long-term (Tables 8 and 9). Overall, our results suggest that the medium- to long- term reduction in growth and output capacity due to financial crises and economic recessions (Ollivaud and Turner, 2015; Cerra and Saxena, 2017; IMF, 2018c) does not translate into an equal medium-term reduction in air pollutants; instead it may give rise to new or renewed forms of pollution that neutralize or reverse any positive gains made in the first years of a crisis. These outcomes come to support existing evidence from case studies, finding that the beneficial environmental effects that appear shortly after the onset of a financial crisis are consistently attenuated as years go by (Siddiqi, 2000; Berghäll and Perrels, 2010; Lekakis and Kousis, 2013).

The existence of a short-term pollution reduction could result from several mechanisms. Financial crises bring about a reduction in GDP and industrial production. According to the Bureau of Labor Statistics (2012), for example, the 2008 crisis caused, in the United States, declines in manufacturing and construction of 13.7 and 10 percent, respectively. Siddiqi (2000) shows that, after the 1997 financial crisis, industry value-added consistently decreased in the automotive, manufacturing, transportation and metal production industries in Thailand, Indonesia and Korea, with drops often higher than 50%. Financial crises also coincide with a reduction in trade between countries, and, as a consequence, of transportation of goods. As pointed out by several authors, these dynamics led to a decrease in energy consumption, which in turn results in lower emissions. Siddiqi (2000) and Monteiro (2018) find a high correlation between the occurrence of crises and energy use, mostly due to this drop in industry. Elliott (2011) stresses too that crises lead to an overall reduction in energy consumption, mostly due to a contraction in energy-intensive sectors. Furthermore, energy use can also decline due to changing consumption habits. With declining income and higher uncertainty, crises often lead to a decrease in purchase of appliances, as well as in the use of vehicles and domestic heating (Querol, 2014). This dynamic is further exacerbated by the fact that financial crises have a stronger adverse impact on labour-income depended households, which have the highest propensity to consume (Mian and Sufi, 2015).

The above emissions dynamics, however, do not persist in the medium-term. The reversal of the beneficial environmental effects of a crisis only a few years after its start suggests the existence of additional forces acting as time goes on. Emissions might go back to their pre-crisis level partly because of a recovery of the economy. Peters et al. (2012) showed that global CO_2 emissions rebounded within 1-2 years after the 2008 global recession. They attributed these 'burst-like dynamics' to three different factors: (a) A strong emissions growth in emerging economies. A decade of high economic growth in these economies, prior to the crisis, provided a solid foundation for their quick recovery from the crisis. Thus, at a global level, the reduction of CO_2 emissions in developed economies right after the 2008 crisis, was counterbalanced by increasing emissions in emerging economies. (b) A quick return to emissions growth in developed economies, based on government policies that promoted economic recovery (e.g. quantitative easing). (c) An increase in the fossil-fuel intensity of the world economy, partly due to the rapid easing of energy prices that relieved pressure on energy consumption. Yet, several studies exist, showing that the negative effects of financial crises on GDP growth are long-lasting, and still persist after 10 years from the beginning of crises (e.g. Furceri and Zdzienicka, 2012; Teuling and Zubanov, 2014; IMF, 2018c). Therefore, the attenuation of the beneficial effect of air pollutant reduction should be explained by other mechanisms. Of course, the medium- and long-term impact of financial crises on air pollutant emissions depends on how the involved countries respond to the crisis. In this sense, financial crises may present an opportunity for environmental policy. For instance, Bowen and Stern (2010) highlight how, in the period immediately after the 2008-9 downturn, decision-makers were presented with new opportunities to undertake a necessary step change in the public spending component of environmental policies. The authors make a strong case that public investment and economic stimulus packages can be used to improve the environment (see also Berghall and Perrels, 2010). However, our results on the medium-term effect of crises shown in Table 9 suggest no beneficial impact from longer term initiatives or stimuli for environmental policies. Our results confirm Elliott’s (2011) pessimism on the potential impact of green stimulus packages in East Asia, where financial crises have led to a decrease of “green” investments, such as the adoption of energy efficient technologies, renewable energy use, waste reduction and recycling, emission control programs. Similarly, Lekakis and Kousis (2013) and Botetzagias et al. (2018) illustrate how crisis-related austerity policies and structural adjustment programmes pose a threat for environmental quality and protection. Second, consumption habits may again play a role. In the medium-term, people might further adapt their standard of living to a crisis situation, and rely on cheaper means of transportation and heating systems. Saffari et al. (2013), conducting a sampling on $PM_{2.5}$ emissions in Greece, found that the concentration of particulate matter in the air increased in the winters of 2012 and 2013 due to the replacement of fuel oil with inexpensive wood for burning. Similarly, Santamouris et al. (2013), who conducted a survey on Greek households, found that crises led to a 14% decrease in average household income in the years 2009-2011, as well as to a change in the sources of energy used. Our empirical results support these findings. This is particularly true for $PM_{2.5}$ emissions, which not only display a lower decrease in the short run with respect to the other emissions, but also show the highest number of positive coefficients in the medium run, indicating an increase in the level of particulate matter after two years from the beginning of crises.

Lastly, our results point to differences between income groups and between time periods. In particular, despite some differences across pollutants, a reduction in emissions was experienced by high income and middle income countries, but not by low income ones. A possible explanation for this pattern might be found in the different structure of production sectors across countries: low income countries are characterized by a prevalent primary sector and light industry, as opposed to heavy industry. Since the latter makes a much bigger contribution to emissions than the former, it is reasonable to think that, where heavy industry is less developed, the impact of crises on emissions will be more moderate. Shifts in the nature and structure of the global economy could also in part explain why the short-term effect of crises is, on average, stronger in the more recent time period (1990-2014) in comparison to previous decades. The intensification of global economic integration processes, including the liberalization of capital flows and global integration of capital markets, the rise of China and the relocation of industrial facilities in developing countries, and the associated increase in global trade, should be factors contributing to stronger crises and effects in the most recent period.

In terms of the wider discussion on economic growth and environmental sustainability, our analysis indicates that growth is an important channel through which economic activity impacts on the environment, but achieving environmental sustainability requires policies and action that goes beyond controlling growth. As suggested by our results, as well as by Mardani et al. (2018), the relationship between growth and emissions gives reasons for policies aiming at reducing emissions through limiting growth. Yet, to avoid undesired and unexpected outcomes, any such measures would need to be carefully designed and implemented as a comprehensive policy package with considerations on environmental protection, local and national fuel pricing, incentives for cleaner technologies, and impacts on employment and income. Based on our findings, we can safely conclude that we cannot rely on the punctuated degrowth and output-capacity-reduction effects of financial crises and economic recessions to deal with the problem of air quality. On the contrary, financial crises may lead to regressive shifts in the priorities of governments, businesses and households, with significant negative effects on the environment.

6.2 Main Limitations of the study and recommendations for future research

By focusing on air pollutant emissions, our study has the limitation of only partially addressing the impact of financial crises on environmental sustainability. As pointed out by Bell and Morse (2008), measuring sustainability and environmental quality requires taking a holistic approach. There are, indeed, other variables that can be looked at in order to draw conclusions on whether financial crises have a detrimental or beneficial effect on environmental quality, such as land use, forest coverage, water pollution, waste management and biodiversity, as well as examine the complex ways in which these aspects interact. For instance, during financial crises, environmental protection and climate initiatives may be weakened (Lekakis and Kousis, 2013; Gaveau et al., 2009; Botetzagias et al., 2018; Finish Environmental Institute 2014). This may lead to financial crises being positively linked to furthering deforestation (Gaveau et al., 2009; Elliot 2011) and increasing illegal logging (Lekakis and Kousis, 2013), although may decrease national and international timber demand (Dauvergne, 1999; Elliott, 2011). Financial crises may have an effect on agriculture, expanding agricultural land (Pagiola, 2000; Elliott, 2011), both commodity-driven and slash-and-burn agriculture (Sayer et al., 2012). Furthermore, they may affect land use through adverse effects on regional or global food security (IFPRI, 2008; Helleiner et al., 2009), influenced by a decrease in available capital for agriculture, and volatility in food prices and food imports. Waste management may also be affected by financial crisis, both positively, e.g. household waste reductions, (e.g. Shields, 2009) and negatively, e.g. increases in untreated waste (e.g. Afsah, 1998). Given the lack of global longitudinal data about many of these indicators, our quantitative approach will have to be complemented by qualitative analysis and case-studies. Furthermore, our analysis is not well-placed to capture feedback-loops between the environment and the economy. For instance, over-extraction of environmental resources may also be a cause rather than just a consequence of future economic crises (e.g. see Harvey, 2011).

Another limitation of our paper is that it does not capture changes in the drivers of pollutant emissions such as changes in the energy sector due to increases in renewable energy (Le Quéré et al., 2019), use of alternative cleaner fuels (e.g. Kurgankina et al., 2019), or effects of clean air acts on transport, industry, households, and agriculture (Zheng et al., 2018). For instance, although in most cases CO2 emissions rebound a year after the outbreak of financial crises we cannot assess whether the drivers of this rebound are the same with those before the outbreak of the crisis. Thus, we capture how much pollution is there, but to understand changing pollution patterns and assess their long-lasting implications we need to further both qualitative and quantitative evidence and analysis.

7. CONCLUSION

- In this paper, we studied the impact on air pollutant emissions of 419 financial crises in more than 150 countries over the period 1970-2014. The adopted global panel data approach presents new evidence and insights that come to complement the existing literature that focuses on regional or single-country case studies.
- At a global level, our results suggest that financial crises have an immediate beneficial impact on emissions of *per capita* CO_2, SO_2 and NO_x, with an effect that ranges between 1.4% and 6.2%, depending on the considered pollutant and the used specification. For $PM_{2.5}$ emissions, the effect is closer to zero and does not hold for all econometric models used. A key driver in the magnitude of the observed impact is whether a financial crisis coincides with a decrease in GDP. When it does, the decrease in emissions is significantly enhanced (in our baseline specification: in CO_2 from 2.6 to 4.7%; in SO_2 from 1.8 to 5.1%; in NO_x from 1.7 to 3.9%).
- Yet, the above beneficial environmental impact of financial crises, on average, fades away after one year from the crises' start. Furthermore, in some cases, we find a 1-2% increase in emissions in the medium-term. This suggests that the medium-term reduction in growth rates due to financial crises

does not translate into an equal reduction in air pollutants; instead, it may give rise to new or renewed forms of pollution that neutralize or reverse any positive gains made in the first years.

- Our findings indicate that financial crises have different environmental effects on different countries. The beneficial short-term impact is more comprehensive in high income countries, which, on average, experience reductions of 3.1, 2.0 and 2.6 percent in their CO_2, SO_2 and NO_x emissions respectively. In upper-middle income countries, crises coincide with a 5.7 percent reduction only in CO_2 emissions, whereas in lower-middle income countries there is a reduction only in the SO_2 and NO_x, emissions (2.8 and 3.2 percent respectively). There is no beneficial effect on pollutant emissions in low income countries. Thus, the impact of financial crises on emissions is contingent on the stage of economic development and the industrial, and broader economic structure of each country. Yet, more research is required to clearly map and understand the drivers of the above heterogeneity.
- The impact of financial crises on air pollutant emissions is not constant over the period 1970-2014. The crises in the 1970s and 1980s had mostly a beneficial impact on NO_x emissions; although, this impact decreased from 2.7 to 1.7 percent between these two decades. In the 1990s this impact is extended from NO_x (1.3 percent) onto SO_2 emissions (2.3 percent). In the 2000s, for the first time we observe a strong impact on CO_2 emissions (4.1 percent decrease), but also the impact on NO_x emissions (3.8 percent) is stronger than any of the previous three decades. The forces underlying these dynamics have to do with the different groups of countries experiencing crises in these different periods, as well as with the transformation of the global economy itself during that period.
- Overall, financial crises seem to be one step forward, two steps back for air quality. An initial reduction in pollutant emissions is soon counterbalanced by returning or newly emerged sources of pollution. Our results suggest that to deal effectively with the problem of air quality, countries need a policy framework that goes beyond economic growth and encompasses long-term environmental goals. In this context, the supporting role of international and regional institutions is critical.

Prioritizing short-term budgetary actions, as international economic institutions have often done in the past, does not seem to bring, let alone secure, long-lasting environmental benefits.

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Appendix A

[1] As explained by Roodman (2009), the Arellano‑Bover/Blundell-Bond estimator augments Arellano-Bond by adding one equation (the level equation in addition to the difference one). This allows employing more instruments, which can dramatically improve the efficiency of the estimator.

[2] Results from the unit root test are available from the authors upon request. Unlike the majority of unit root tests, which assume that you have a balanced panel, the Im–Pesaran–Shin (2003) allows for unbalanced panels, which makes it suitable for our data.

[3] The sub-samples include 48 high income countries, 44 upper-middle income countries, 39 lower-middle income countries and 27 low income countries, respectively.

[4] This is done on STATA by using the option *collapse*, which reduces the size of the instruments' matrix and avoids instrument proliferation.

[5] Results are available from the authors upon request.

Table
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Table 1: Environmental Kuznet's curve and financial crises

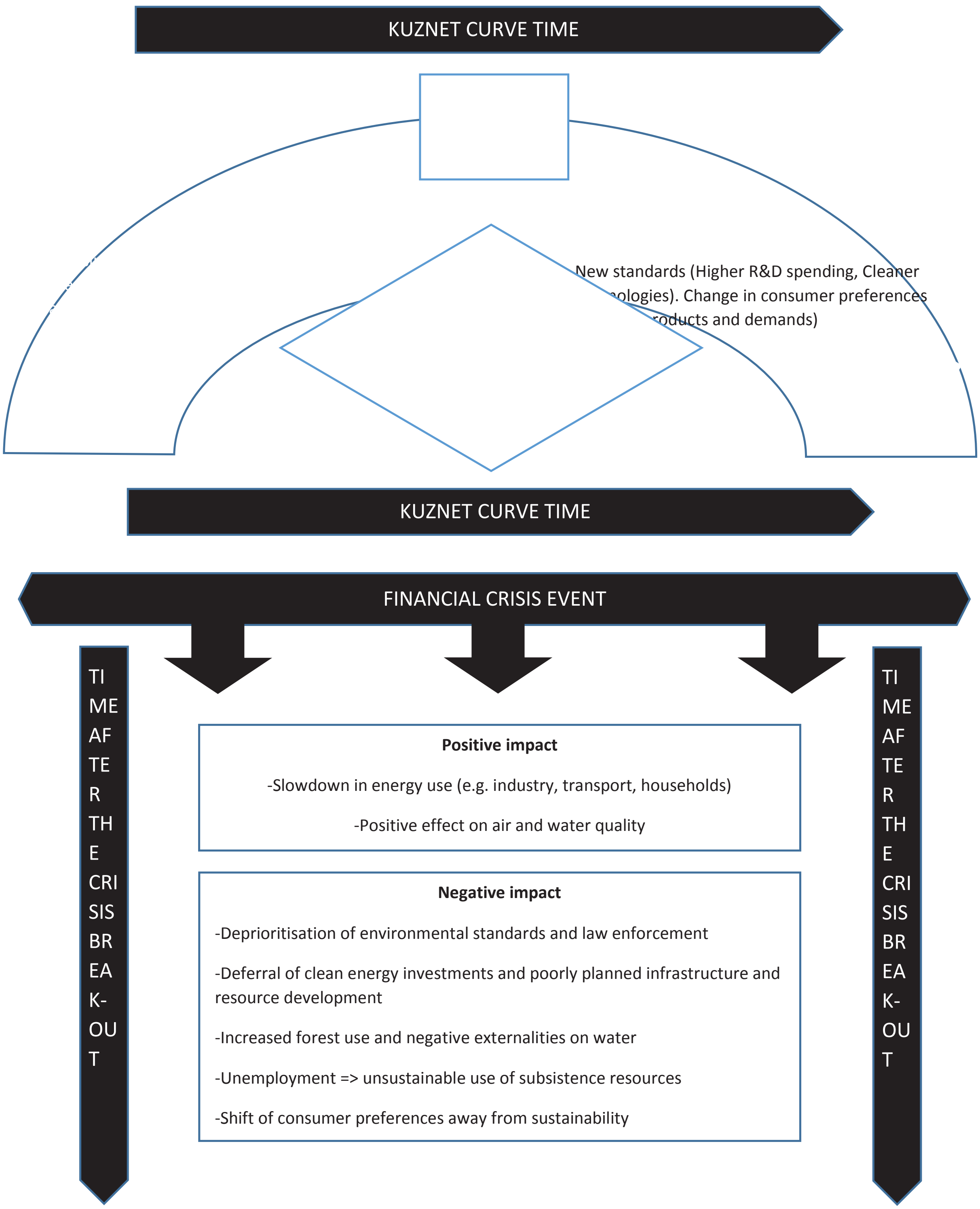

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Table 1: Environmental Kuznet's curve and financial crises

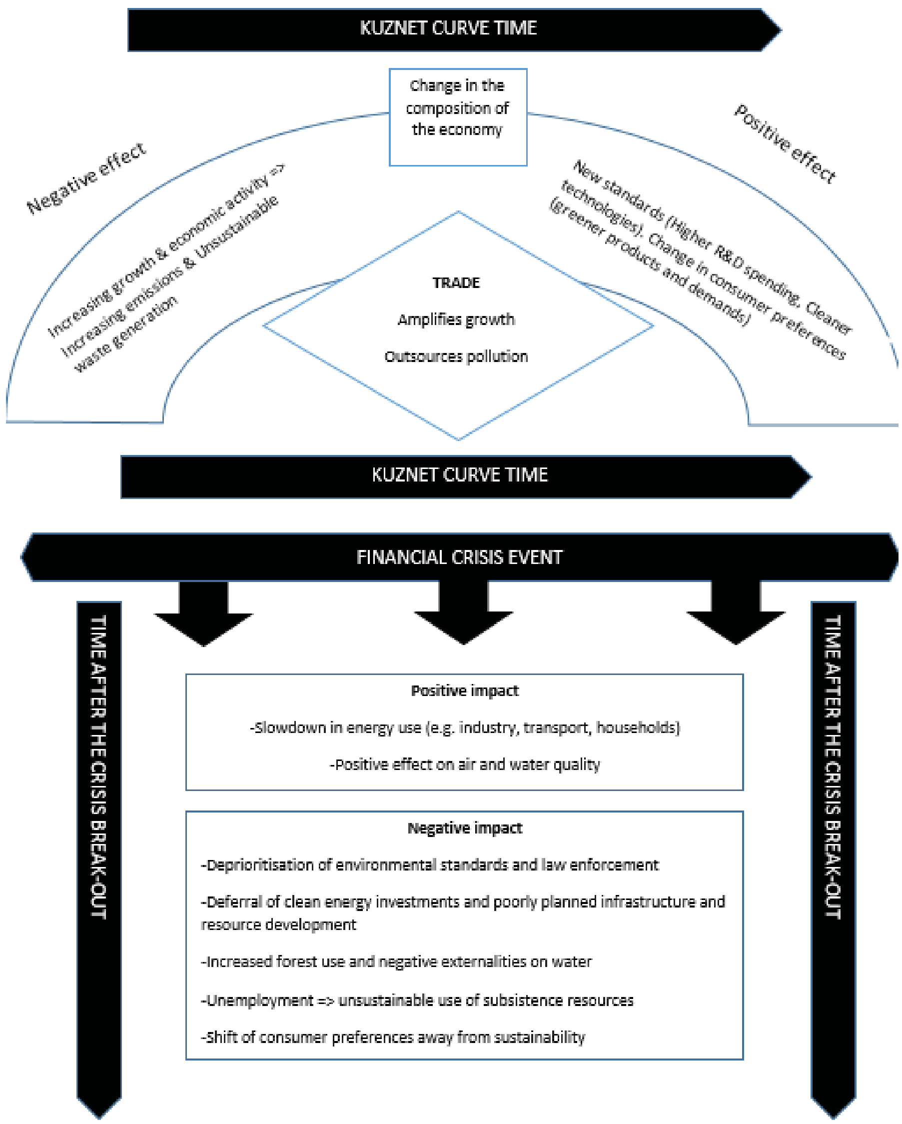

Table 2 – Financial crisis occurrence, 1970-2017, according to Laeven and Valencia (2018)

Country Group	Banking Crises	Sovereign Debt Crises	Currency Crises
High Income	47	8	29
Upper Middle Income	36	26	71
Lower Middle Income	33	18	65
Low Income	27	13	46
Total	143	65	211

Table 3 – Effect of financial crises on polluting gases' emissions, GMM Specification

	(1) CO2_pc growth	(2) SO2_pc growth	(3) NOx_pc growth	(4) PM25_pc Growth	(5) CO2_pc Growth	(6) SO2_pc Growth	(7) NOx_pc growth	(8) PM25_pc growth
Lagged Dep. Var.	-0.036	0.067	0.013	-0.049	-0.008	0.013	-0.020	0.043
	(0.057)	(0.104)	(0.107)	(0.121)	(0.018)	(0.046)	(0.062)	(0.100)
financial_crisis	-0.026***	-0.018***	-0.017***	-0.004	-0.027***	-0.016**	-0.017***	-0.004
	(0.007)	(0.006)	(0.004)	(0.003)	(0.008)	(0.007)	(0.004)	(0.003)
trade_growth	-0.000**	-0.000	-0.000	-0.000**	-0.000	0.000	-0.000	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
urb_pop_perc growth	1.370***	0.842***	0.471***	0.187	0.791*	0.584***	0.543***	0.217*
	(0.392)	(0.240)	(0.145)	(0.121)	(0.428)	(0.189)	(0.164)	(0.112)
L.const_gdp_pc growth	0.126*	0.018	0.051	0.044	0.094	0.135	0.084	0.047
	(0.071)	(0.081)	(0.056)	(0.048)	(0.080)	(0.126)	(0.067)	(0.071)
energy_pc growth	-	-	-	-	0.024	-0.000	-0.004	-0.014
	-	-	-	-	(0.021)	(0.016)	(0.012)	(0.014)
Constant	0.011**	-0.010**	-0.000	-0.006***	0.014**	-0.015***	-0.002	-0.006***
	(0.004)	(0.005)	(0.003)	(0.002)	(0.006)	(0.004)	(0.003)	(0.002)
Hansen - *p-value*	0.279	0.229	0.109	0.716	0.731	0.283	0.519	0.553
AR2 - *p-value*	0.71	0.843	0.783	0.731	0.716	0.454	0.466	0.822
N	5654	4945	4946	4946	4544	3940	3941	3941

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. All results come from system two-step GMM specifications. In columns (1)-(4), only the lagged dependent variable is treated as endogenous, while in columns (5)-(8) *energy_pc_growth* is considered endogenous too. The second lag of endogenous variables is used as instrument.

Table 4 – Effect of financial crises on polluting gases' emissions, Fixed Effects Specification

	(1) CO2_pc growth	(2) SO2_pc growth	(3) NOx_pc growth	(4) PM25_pc growth	(5) CO2_pc growth	(6) SO2_pc growth	(7) NOx_pc growth	(8) PM25_pc growth
Lagged Dep. Var.	-0.042	-0.050	0.014	-0.011	-0.035	-0.059**	0.006	-0.004
	(0.030)	(0.031)	(0.025)	(0.051)	(0.029)	(0.029)	(0.028)	(0.054)
financial_crisis	-0.017	-0.020***	-0.016***	-0.001	-0.021**	-0.014*	-0.015***	-0.002
	(0.011)	(0.007)	(0.005)	(0.003)	(0.009)	(0.008)	(0.005)	(0.003)
trade_growth	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
urb_pop_perc growth	0.865	0.581***	0.242	0.263	0.246	0.351	0.174	0.364
	(0.566)	(0.202)	(0.186)	(0.192)	(0.674)	(0.292)	(0.171)	(0.248)
L.const_gdp_pc growth	0.312***	0.240**	0.169***	0.130**	0.221***	0.234*	0.135**	0.121*
	(0.080)	(0.100)	(0.054)	(0.054)	(0.079)	(0.121)	(0.058)	(0.066)
energy_pc growth	-	-	-	-	0.044	0.038	0.028	0.014
	-	-	-	-	(0.038)	(0.037)	(0.035)	(0.016)
Constant	0.015**	-0.010***	0.002	-0.008***	0.017**	-0.015***	0.000	-0.009***
	(0.008)	(0.003)	(0.002)	(0.002)	(0.008)	(0.004)	(0.002)	(0.003)
Country F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	5654	4945	4946	4946	4544	3940	3941	3941

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses.

Table 5 – Effect of financial crises on polluting gases' emissions for different income groups

	GMM Specification				Fixed Effects Specification			
Income Groups	**CO2**	**SO2**	**NOx**	**PM25**	**CO2**	**SO2**	**NOx**	**PM25**
High Income	-0.031***	-0.020**	-0.026***	-0.004	-0.018**	-0.014	-0.023***	-0.006
	(0.006)	(0.010)	(0.006)	(0.007)	(0.008)	(0.012)	(0.004)	(0.005)
Upper Middle Income	-0.057**	-0.018	-0.015	-0.011	-0.044**	-0.018	-0.016	-0.010
	(0.022)	(0.016)	(0.011)	(0.010)	(0.017)	(0.015)	(0.012)	(0.007)
Lower Middle Income	-0.035	-0.028*	-0.032**	-0.002	-0.011	-0.034**	-0.016*	0.011
	(0.022)	(0.015)	(0.015)	(0.006)	(0.027)	(0.015)	(0.009)	(0.007)
Low Income	-0.007	-0.023	-0.016	-0.004	0.023	-0.009	-0.005	0.001
	(0.028)	(0.015)	(0.013)	(0.004)	(0.035)	(0.014)	(0.010)	(0.005)

Notes: In the first panel of the Table, a system two-step GMM specification has been used. The lagged dependent variable has been instrumented with its 2nd to 8th lag, using the option *collapse* to reduce the number of instruments. Where the AR2 test is rejected, the instrument count starts from the 3rd lag instead. Values of Hansen, AR2 and AR3 tests are available upon request.

Table 6 – Effect of financial crises on polluting gases' emissions across different time periods

	1970s	1980s	1990s	2000s
CO2_pc growth	-0.010	-0.008	-0.018	-0.041***
	(0.046)	(0.012)	(0.012)	(0.006)
SO2_pc growth	-0.027	-0.012	-0.023**	-0.014
	(0.025)	(0.011)	(0.010)	(0.011)
NOx_pc growth	-0.027*	-0.017**	-0.013*	-0.038***
	(0.014)	(0.007)	(0.007)	(0.008)
PM25_pc growth	-0.013	0.001	-0.005	-0.008
	0.009	0.006	0.004	0.007

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. The coefficients reported in the Table are relative to the financial crisis dummy variable. A system GMM is used, instrumenting the lagged dependent variable with its second lag. AR2 and Hansen test p-*values* are available upon request.

Table 7 – Effect of financial crises coinciding with output loss on polluting gases' emissions

	GMM				Fixed Effects			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
	CO2_pc growth	**SO2_pc growth**	**NOx_pc growth**	**PM2.5_pc growth**	**CO2_pc growth**	**SO2_pc growth**	**NOx_pc growth**	**PM2.5_pc growth**
Lagged Dep. Var.	-0.036	0.071	-0.003	-0.048	-0.042	-0.050	0.013	-0.011
	(0.057)	(0.104)	(0.110)	(0.120)	(0.030)	(0.031)	(0.025)	(0.051)
Financial Crises	-0.047***	-0.051***	-0.039***	-0.017***	-0.031**	-0.051***	-0.035***	-0.016***
	(0.010)	(0.009)	(0.006)	(0.004)	(0.014)	(0.010)	(0.006)	(0.005)
Trade growth	-0.000**	-0.000	-0.000	-0.000**	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Urb. Pop. Growth	1.363***	0.817***	0.467***	0.177	0.863	0.576***	0.241	0.257
	(0.395)	(0.241)	(0.144)	(0.121)	(0.566)	(0.202)	(0.186)	(0.193)
GDP Growth	0.122*	0.014	0.059	0.044	0.308***	0.228**	0.162***	0.123**
	(0.071)	(0.076)	(0.056)	(0.046)	(0.080)	(0.100)	(0.054)	(0.054)
Constant	0.011**	-0.009**	-0.000	-0.005**	0.015**	-0.009***	0.003	-0.007***
	(0.004)	(0.005)	(0.003)	(0.002)	(0.008)	(0.003)	(0.003)	(0.002)
AR2 - *p-value*	0.71	0.90	0.72	0.74	-	-	-	-
Hansen - *p-value*	0.24	0.25	0.10	0.74	-	-	-	-
N	5654	4945	4946	4946	5654	4945	4946	4946

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. In the GMM specification, the lagged dependent variable is treated as endogenous and instrumented with its second lag, while all the other variables are treated as exogenous.

Table 8 – Medium-term effect of financial crises on polluting gases' emissions, Impulse-Response Functions

	(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
CO2	-0.031**	-0.019	-0.017	0.033	-0.019*	0.006	-0.023**	0.022	0.001	-0.004	-0.028**
	(0.014)	(0.012)	(0.014)	(0.028)	(0.010)	(0.012)	(0.009)	(0.018)	(0.012)	(0.014)	(0.013)
N	5968	5815	5662	5509	5357	5205	5053	4901	4749	4597	4445
SO2	-0.034***	-0.034***	-0.006	-0.000	0.009	0.016	0.025*	0.008	0.017	0.009	0.002
	(0.010)	(0.008)	(0.010)	(0.008)	(0.008)	(0.015)	(0.015)	(0.011)	(0.012)	(0.010)	(0.010)
N	5660	5511	5362	5213	5064	4915	4766	4617	4468	4319	4170
Nox	-0.022***	-0.023***	0.004	0.002	0.004	0.009	0.015***	0.006	0.019*	0.009	0.005
	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.008)	(0.006)	(0.006)	(0.010)	(0.007)	(0.006)
N	5661	5512	5363	5214	5065	4916	4767	4618	4469	4320	4171
PM25	-0.014***	-0.009*	0.006	0.006	0.014**	0.011	0.018***	0.009*	0.014*	0.007	0.009*
	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)	(0.007)	(0.006)	(0.005)	(0.008)	(0.006)	(0.005)
N	5661	5512	5363	5214	5065	4916	4767	4618	4469	4320	4171
Country F.E.	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Time F.E.	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses.

Table 9 – Medium-term effect of financial crises on polluting gases' emissions for different income groups, Impulse-response functions

	(0)	(1)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
						High Income Countries					
CO_2	-0.036***	-0.040***	-0.004	0.006	-0.006	-0.011	0.005	0.013	0.014	-0.003	-0.017
	(0.011)	(0.013)	(0.010)	(0.010)	(0.012)	(0.011)	(0.015)	(0.011)	(0.022)	(0.027)	(0.012)
SO_2	-0.062**	-0.029*	-0.001	0.020	0.014	-0.055**	0.031	-0.012	-0.012	-0.017	-0.003
	(0.030)	(0.016)	(0.016)	(0.019)	(0.014)	(0.023)	(0.044)	(0.022)	(0.018)	(0.029)	(0.022)
NO_x	-0.039***	-0.026***	0.000	0.008	0.011	-0.016	0.015	0.009	0.003	0.008	0.010
	(0.014)	(0.009)	(0.009)	(0.009)	(0.009)	(0.012)	(0.016)	(0.010)	(0.010)	(0.010)	(0.013)
$PM_{2.5}$	-0.045***	-0.017	0.021	0.025**	0.008	-0.003	0.035*	0.017	-0.018	-0.012	0.026
	(0.013)	(0.015)	(0.013)	(0.012)	(0.022)	(0.030)	(0.020)	(0.012)	(0.021)	(0.018)	(0.017)
						Upper Middle Income Countries					
CO_2	-0.057***	-0.012	-0.038**	0.003	-0.013	0.033*	0.021	0.045	0.014	-0.005	-0.039
	(0.021)	(0.029)	(0.018)	(0.011)	(0.019)	(0.017)	(0.017)	(0.053)	(0.018)	(0.024)	(0.037)
SO_2	-0.043*	-0.048***	-0.032	-0.012	0.026	0.058*	0.050	-0.000	-0.007	0.040*	0.029
	(0.023)	(0.015)	(0.021)	(0.014)	(0.016)	(0.031)	(0.033)	(0.019)	(0.018)	(0.021)	(0.023)
NO_x	-0.033***	-0.019	-0.007	-0.005	0.017	0.035**	0.017*	-0.005	0.005	0.030*	0.020
	(0.011)	(0.014)	(0.014)	(0.010)	(0.013)	(0.017)	(0.010)	(0.011)	(0.017)	(0.016)	(0.014)
$PM_{2.5}$	-0.018**	-0.010	-0.022	-0.008	0.013	0.029*	0.013	0.004	0.024	0.016	0.006
	(0.009)	(0.010)	(0.015)	(0.009)	(0.011)	(0.015)	(0.009)	(0.010)	(0.016)	(0.011)	(0.010)
						Lower middle income countries					
CO_2	-0.049*	-0.038	0.006	0.089	-0.035	0.017	-0.064***	0.031	-0.019	0.001	-0.027
	(0.024)	(0.026)	(0.047)	(0.100)	(0.027)	(0.035)	(0.022)	(0.033)	(0.040)	(0.040)	(0.021)
SO_2	-0.034*	-0.030	-0.016	-0.009	-0.005	0.027	0.012	0.008	0.036	0.005	-0.013
	(0.018)	(0.020)	(0.019)	(0.017)	(0.018)	(0.030)	(0.020)	(0.026)	(0.029)	(0.021)	(0.021)
NO_x	-0.007	-0.018*	0.002	-0.001	-0.004	0.009	0.011	0.010	0.032	-0.006	-0.012
	(0.010)	(0.010)	(0.012)	(0.012)	(0.010)	(0.013)	(0.009)	(0.012)	(0.022)	(0.012)	(0.012)
$PM_{2.5}$	0.001	0.002	0.020*	0.009	0.018*	0.014	0.018	0.014	0.011	0.007	0.003
	(0.010)	(0.008)	(0.010)	(0.010)	(0.010)	(0.009)	(0.013)	(0.009)	(0.012)	(0.012)	(0.009)
						Low Income Countries					
CO_2	0.039	-0.004	-0.027	0.074	0.008	0.002	-0.012	0.010	0.004	-0.040*	-0.024
	(0.060)	(0.026)	(0.016)	(0.044)	(0.017)	(0.022)	(0.017)	(0.024)	(0.024)	(0.023)	(0.021)
SO_2	-0.008	-0.019	0.037*	0.001	0.008	0.006	0.014	0.025	0.036	-0.013	-0.008
	(0.013)	(0.012)	(0.021)	(0.016)	(0.017)	(0.022)	(0.017)	(0.018)	(0.026)	(0.016)	(0.018)
NO_x	-0.008	-0.012	0.018*	0.009	0.004	-0.001	0.017	0.019	0.037**	-0.013	-0.013
	(0.010)	(0.009)	(0.010)	(0.011)	(0.015)	(0.015)	(0.013)	(0.014)	(0.016)	(0.011)	(0.014)
$PM_{2.5}$	0.010	-0.005	0.012	-0.000	0.010	-0.004	0.019	0.007	0.024*	0.002	-0.002
	(0.007)	(0.010)	(0.008)	(0.013)	(0.018)	(0.014)	(0.015)	(0.013)	(0.014)	(0.012)	(0.014)

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. Country and year fixed effects are included in the regressions.

Table 10 – Robustness Checks, GMM Specification

	(1) CO2_pc growth	(2) SO2_pc growth	(3) NOx_pc growth	(4) PM25_pc growth	(5) CO2_pc growth	(6) SO2_pc growth	(7) NOx_pc growth	(8) PM25_pc growth
Lagged Dep. Var.	-0.016	0.042	0.083	-0.240	0.010	0.070	0.044	-0.041
	(0.255)	(0.149)	(0.097)	(0.150)	(0.010)	(0.097)	(0.099)	(0.114)
financial_crisis	-0.041**	-0.062***	-0.039***	-0.014	-0.032***	-0.018***	-0.014***	-0.003
	(0.020)	(0.017)	(0.015)	(0.011)	(0.011)	(0.006)	(0.004)	(0.003)
trade_growth	-0.000	-0.000	-0.000	-0.000***	-0.000	-0.000	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
urb_pop_perc growth	1.287***	0.806***	0.396**	0.275	1.302***	0.805***	0.435***	0.166
	(0.411)	(0.303)	(0.161)	(0.182)	(0.364)	(0.249)	(0.141)	(0.120)
L.const_gdp_pc Growth	0.048	0.071	0.004	0.090*	-0.123	0.125	0.146**	0.101*
	(0.102)	(0.127)	(0.063)	(0.051)	(0.229)	(0.107)	(0.058)	(0.055)
_cons	0.017**	-0.006	0.006	-0.007**	0.016**	-0.012**	-0.002	-0.007***
	(0.009)	(0.005)	(0.003)	(0.003)	(0.007)	(0.005)	(0.003)	(0.002)
AR2 - *p-value*	0.812	0.779	0.800	0.119	0.456	0.871	0.981	0.801
Hansen - *p-value*	0.214	0.154	0.118	0.564	0.13	0.226	0.143	0.698
N	5654	4945	4946	4946	5654	4945	4946	4946

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. In columns (1) – (4) the financial crisis dummy variable and the lagged dependent variable are instrumented, while the other covariates are treated as exogenous. In columns (5)-(8), lagged per capita GDP growth and the lagged dependent variable are instrumented, while the other model variables are considered as exogenous.

Appendix A

Table A1 – Medium-term effect of financial crises coinciding with output loss on polluting gases' emissions, Impulse-Response Functions

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
CO2		-0.023*	-0.012	0.047	-0.012	0.004	-0.031**	-0.025	-0.006	0.001	-0.018
		(0.013)	(0.021)	(0.061)	(0.019)	(0.022)	(0.014)	(0.017)	(0.016)	(0.018)	(0.018)
	N	6906	6753	6600	6448	6296	6144	5992	5840	5688	5536
SO2		-0.035***	0.023	-0.007	0.003	-0.012	0.035	-0.014	0.023	0.027	-0.011
		(0.012)	(0.018)	(0.010)	(0.013)	(0.014)	(0.027)	(0.018)	(0.018)	(0.017)	(0.014)
	N	5511	5362	5213	5064	4915	4766	4617	4468	4319	4170
NOx		-0.029***	0.008	0.001	-0.004	-0.002	0.006	-0.001	0.025	0.016	-0.007
		(0.007)	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)	(0.010)	(0.016)	(0.011)	(0.009)
	N	5512	5363	5214	5065	4916	4767	4618	4469	4320	4171
PM2.5		-0.007	0.012	0.003	0.010	0.007	0.020**	0.008	0.005	0.018*	0.006
		(0.006)	(0.007)	(0.008)	(0.009)	(0.007)	(0.009)	(0.007)	(0.009)	(0.010)	(0.008)
	N	5512	5363	5214	5065	4916	4767	4618	4469	4320	4171
Country F.E.		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Trend		No	No	No	No	No	No	No	No	No	No
Time F.E.		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses.

Table A2 – Robustness Check: Effect of crises on emissions using Reinhart and Rogoff (2011) database on financial crises

	Fixed Effects Specification				GMM Specification			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
	CO2_pc growth	**SO2_pc growth**	**NOx_pc growth**	**PM25_pc growth**	**CO2_pc growth**	**SO2_pc growth**	**NOx_pc growth**	**PM25_pc growth**
Lagged Dependent Variable	-0.0761**	-0.0628**	-0.0421	-0.0209	-0.0671	-0.199	-0.230	-0.766
	(-2.19)	(-2.00)	(-1.42)	(-0.79)	(-0.28)	(-0.54)	(-0.51)	(-1.24)
Crisis_RR	-0.0161***	-0.0126**	-0.0105***	-0.00582*	-0.0155***	-0.00664	-0.0098***	-0.00209
	(-3.39)	(-2.20)	(-3.82)	(-1.98)	(-3.30)	(-1.23)	(-3.12)	(-0.54)
trade_growth	-0.00822	-0.00844	0.00336	-0.00462	-0.0147	-0.00240	-0.000173	-0.00994
	(-0.45)	(-0.41)	(0.22)	(-0.41)	(-0.74)	(-0.15)	(-0.02)	(-1.12)
urb_pop_perc growth	0.651*	0.725	0.530	0.218	1.481***	1.727**	1.152***	0.642**
	(1.73)	(1.40)	(1.57)	(1.21)	(4.22)	(2.09)	(2.90)	(2.28)
L.const_gdp_pc growth	0.452***	0.420***	0.257***	0.0982**	0.120	0.207	0.173	0.255
	(8.07)	(4.74)	(4.82)	(2.59)	(0.88)	(1.10)	(0.85)	(1.23)
_cons	0.0173***	-0.0148***	0.00147	-0.00575**	0.0151***	-0.0253	-0.00275	-0.0180*
	(3.88)	(-3.51)	(0.47)	(-2.54)	(3.00)	(-1.62)	(-0.46)	(-1.75)
AR2 - *p-value*	-	-	-	-	0.715	0.474	0.495	0.179
Hansen - *p-value*	-	-	-	-	0.114	0.208	0.132	0.742
N	2957	2472	2472	2472	2957	2472	2472	2472

Notes: Statistical significance values: * p<0.10, ** p<0.05, *** p<0.010. Standard errors are included in parentheses. . Results in columns (5)-(8) come from system two-step GMM specifications. The lagged dependent variable is treated as endogenous, and instrumented with its second lag.