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ECONOMIC DEVELOPMENT AND ENVIRONMENTAL QUALITY NEXUS IN DEVELOPING AND TRANSITION ECONOMIES

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"*One day, in retrospect, the years of struggle will strike you as the most beautiful*."
— Sigmund Freud

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Abstract

This thesis tackles one of the most *debatable* and *in vogue* topics in economics, namely *the economic development and environmental quality nexus*. Notably, it studies *the economic development's effects—in terms of its economic, social, and political dimensions—on the environmental quality for developing and transition economies*. In this vein, four essays, one literature survey, and three empirical papers shape its anatomy and cover different key related aspects. Chapter I provides an updated literature survey on pollution-growth nexus via the environmental Kuznets curve (EKC) hypothesis, both from theoretical and empirical standpoints. On the one hand, it offers a literature review on the most well-known rationale behind the EKC prevalence and discusses the key components of the research design when estimating the EKC. On the other hand, it brings together the most influential empirical papers published in the last decade, focusing on EKC estimation in developing and transition economies. Overall, the findings reveal that the recent empirical studies, indeed, succeeding to curtail some of the deficiencies suggested by theoretical contributions, might indicate a certain consensus regarding pollution-growth nexus and EKC validity. First, reinforcing the EKC nature, several studies reveal a long-run relationship between indicators. Second, according to income coefficients' signs, the traditional bell-shaped pattern seems to be at work for some developing and transition economies. However, in some cases, the estimated turning point lies outside the income sample range, calling into question not only the true pattern between pollution and growth but also the identification of EKC. Taken collectively, both the theoretical foundations and empirical evidence could contribute to a better understanding of the pollution-growth nexus in the EKC context, and suggest some useful insights into the future works on the subject as well as the crucial policy implications in this group of countries. Chapter II focuses on the relationships between pollution and growth in eleven Central and Eastern European (CEE) countries. On the one hand, it unveils an increasing nonlinear link between GDP and CO2 at the aggregate level, which is powerfully robust to different estimators and control variables. On the other hand, the country-level analysis reveals that the relationship between GDP and CO2 is characterized by much diversity among CEE countries, namely: *N*-shaped, inverted-*N*, U-shaped, inverted-U, monotonic, or no statistical link. Thus, despite an aggregated upward trend, some CEE countries managed to secure both higher GDP and lower CO2 emissions. From a policy perspective, EU policymakers could pay more attention to these countries and amend the current unique environmental policy to account for country-heterogeneities to support economic growth without damaging the environment. Chapter III explores, for a rich sample of developing states, the responsiveness (both within the period and over a twenty-year horizon) of aggregated and sectoral CO2 emissions following external disturbances to output and urbanization, assuming a transmission channel that incorporates two of the key elements used in mitigating environmental degradation—renewable energy and energy efficiency. On the one hand, robust to several alternative specifications, the results indicate that output, urbanization, and energy intensity increase the aggregated CO2 emissions, while renewable energy exhibits an opposite effect. Moreover, regarding the CO2 responsiveness in the aftermath of output and urbanization shocks, the pattern may suggest that these countries are likely to attain the threshold that would trigger a decline in CO2 emissions. However, the findings are sensitive to both countries' economic development and Kyoto Protocol ratification/ascension status. On the other hand, the sector-specific analysis unveils that the transportation, buildings, and non-combustion sector exhibits a higher propensity to increase the future CO2 levels. Overall, this chapter may provide useful insights concerning environmental sustainability prospects in developing states. Chapter IV studies the link between CO2 emissions and political stability. Considering a sample of low and lower-middle income countries, it shows that a nonlinear, bell-shaped pattern characterizes the relationship between variables at the aggregate level. Moreover, while this result is robust to a broad set of alternative specifications, significant heterogeneities are found regarding countries' distinct characteristics and alternative pollution measures. Besides, the country-specific estimates unveil contrasting patterns regarding the relationship between CO2 and political stability. Overall, the findings suggest that both the formal and informal sides of political stability play a vital role in mitigating CO2 pollution in developing countries, and may provide meaningful insights for policymakers.

Keywords: environmental Kuznets curve hypothesis; CO2 emissions; economic growth; urbanization; political stability; renewable energy; energy efficiency; literature survey; Central and Eastern European countries; developing economies; heterogeneous panels; cross-sectional dependence; nonstationarity, cointegration.

JEL Codes: Q01, Q28, Q32, Q43, Q53, Q56, O13, P28, P48

Résumé

Cette thèse aborde l'un des sujets les plus *discutés* et *en vogue* dans le domaine de l'économie, à savoir *le lien entre le développement économique et la qualité environnementale*. En particulier, on met l'accent sur *les effets du développement économique—tant dans ses dimensions économique, sociale que politique—sur la qualité de l'environnement pour les économies en développement et en transition*. Dans ce sens, quatre essais, une étude de la littérature et trois études empiriques modélisent son anatomie et couvrent divers aspects clés associés. Le chapitre I propose une mise à jour de la littérature sur la relation entre la pollution et la croissance économique, vue à travers l'hypothèse de la Courbe de Kuznets Environnementale (CKE), à la fois théoriquement et empiriquement. D'une côté, il présente une revue de la littérature sur les raisons les plus connues de la prévalence de la CKE et discute les composants essentiels du plan de recherche lors de l'estimation de la CKE. De l'autre côté, il rassemble les travaux empiriques les plus influents publiés au cours de la dernière décennie, qui se concentrent sur l'estimation de la CKE dans les économies en développement et en transition. Dans l'ensemble, les résultats révèlent que des études empiriques récentes, parvenant à réduire certaines lacunes suggérées par les contributions théoriques, pourraient en effet indiquer un certain consensus sur la relation entre la croissance et la pollution, à savoir la validité de la CKE. Tout d'abord, en renforçant la nature de la CKE, plusieurs études révèlent un lien à long terme entre les indicateurs. Deuxièmement, selon les signes des coefficients de revenu, le modèle traditionnel en forme de cloche semble s'appliquer à certaines économies en développement et en transition. Cependant, dans certains cas, le point maximum estimé se situe en dehors de la plage des valeurs de revenu, ce qui remet en question non seulement la vraie forme de la relation entre les variables, mais aussi la stratégie d'identification de CKE. Pris collectivement, les fondements théoriques et les preuves empiriques pourraient contribuer à une meilleure compréhension de la relation pollution-croissance économique dans le contexte de la CKE, et suggérer des idées utiles pour les travaux futurs sur ce sujet, ainsi que les implications politiques cruciales pour ce groupe de pays. Le chapitre II se concentre sur le lien entre la pollution et la croissance économique dans onze Pays d'Europe Centrale et Orientale (PECO). D'une part, il révèle un lien de croissance non linéaire entre le PIB et le CO2 agrégé, qui est fortement robuste pour différents estimateurs et variables de contrôle. En revanche, l'analyse au niveau des pays révèle que la relation entre le PIB et le CO2 se caractérise par une grande diversité dans les PECO, à savoir: en forme de *N*, en *N* inversé, en forme de U, en U inversé, monotone ou sans lien statistique. Ainsi, malgré une tendance globale à la hausse, certains pays d'Europe Centrale et Orientale ont réussi à assurer à la fois un PIB plus élevé et une réduction des émissions de CO2. Du point de vue politique, les décideurs de l'UE pourraient accorder plus d'attention à ces pays, c'est-à-dire envisager de changer la politique environnementale unique actuelle pour intégrer plus rigoureusement les hétérogénéités des pays et, en même temps, soutenir la croissance économique sans nuire à l'environnement. Le chapitre III explore, pour un échantillon complet de pays en cours de développement, la réponse (à la fois dans la période actuelle et sur un horizon de vingt ans) des émissions de CO2 agrégées et sectorielles résultant des perturbations externes du PIB et de l'urbanisation, en supposant un canal de transmission qui intègre deux des éléments clés utilisés dans la lutte contre la dégradation de l'environnement—les énergies renouvelables et l'efficacité énergétique. D'une part, robustes à plusieurs spécifications alternatives, les résultats indiquent que la production globale, l'urbanisation et l'intensité énergétique augmentent les émissions totales de CO2, tandis que les énergies renouvelables ont l'effet inverse. Par ailleurs, en ce qui concerne la réponse du CO2 aux chocs de production et d'urbanisation, le modèle peut suggérer que ces pays atteindront le seuil maximum qui conduirait à un changement de la tendance des émissions à la baisse. Cependant, les résultats varient en fonction du niveau de revenu et du statut des pays sur la ratification/l'adhésion au Protocole de Kyoto. D'autre part, l'analyse sectorielle montre que les transports, les bâtiments et les secteurs non-combustion sont plus susceptibles de contribuer à l'augmentation des niveaux futurs de CO2. En général, ce chapitre peut fournir des informations précieuses sur les perspectives de durabilité environnementale dans les pays en développement. Le chapitre IV examine le lien entre les émissions de CO2 et la stabilité politique. Pour un échantillon de pays à revenu intermédiaire et faible, il montre qu'une évolution non linéaire en forme de cloche décrit la relation entre les variables au niveau agrégé. De plus, bien que ce résultat reste stable pour une large gamme de spécifications alternatives, nous identifions des hétérogénéités significatives dans les caractéristiques distinctes des pays et les mesures alternatives de pollution. En outre, des estimations désagrégées révèlent des schémas contrastés pour la relation entre le CO2 et la stabilité politique. Dans l'ensemble, les conclusions suggèrent que la dimension formelle et informelle de la stabilité politique joue un rôle clé dans l'atténuation de la pollution par le CO2 dans les pays en cours de développement, fournissant ainsi des informations utiles aux décideurs.

Mots-clés: l'hypothèse de la courbe de Kuznets environnementale; émissions de CO2; croissance économique; urbanisation; stabilité politique; énergie renouvelable; efficacité énergétique; enquête bibliographique; Pays d'Europe Centrale et Orientale; économies en cours de développement; modèles hétérogènes pour des données de panel; la dépendance en coupe transversale; non-stationnarité, cointégration.

Codes JEL: Q01, Q28, Q32, Q43, Q53, Q56, O13, P28, P48

Rezumat

Această teză abordează unul dintre cele mai *discutabile* și *în vogă* subiecte în domeniul economiei, și anume *joncțiunea dintre dezvoltarea economică și calitatea mediului*. În particular, aceasta se concentrează pe *efectele dezvoltării economice—din punct de vedere atât a dimensiunii sale economice, sociale, dar și politice—asupra calității mediului pentru economiile în curs de dezvoltare și în tranziție*. În această direcție, patru eseuri, respectiv un rezumat al literaturii de specialitate și trei lucrări empirice, constituie structura tezei. Capitolul I realizeaza un rezumat de actualitate al literaturii privind relația dintre poluare și creșterea economică, văzută din perspectiva ipotezei Curbei Kuznets de Mediu (CKM), atât din punct de vedere teoretic cât și empiric. Pe de o parte, acesta prezintă o revizuire a literaturii cu privire la cele mai cunoscute motivații din spatele prevalenței CKM și discută componentele esențiale ale cercetării atunci când estimăm CKM. Pe de altă parte, reunește cele mai influente lucrări empirice publicate în ultimul deceniu, care se concentrează pe estimarea CKM în economiile în curs de dezvoltare și de tranziție. În ansamblu, concluziile dezvăluie că studiile empirice recente, într-adevăr, reușind să reducă unele deficiențe sugerate de contribuțiile teoretice, ar putea indica un anumit consens în privința relației dintre creștere și poluare, respectiv validitatea CKM. În primul rând, consolidând natura CKM, mai multe studii dezvăluie o legătură pe termen lung între indicatori. În al doilea rând, în funcție de semnele coeficienților asociați venitului, modelul tradițional în formă de clopot pare să fie adevcat pentru unele economii în curs de dezvoltare și de tranziție. Cu toate acestea, în unele cazuri, punctul de maxim estimat se situează în afara intervalului valorilor venitului, punând în discuție nu numai adevarata formă a relației dintre variabile, ci și strategia de identificare a CKM. Luate colectiv, atât fundamentele teoretice cât și evidențele empirice contribuie la o mai bună înțelegere a relației dintre poluare și creșterea economică în contextul CKM, sugerând câteva idei utile viitoarelor lucrări ce vor aborda această temă; de asemenea sunt delimitate implicațiile cruciale ale politicii de mediu pentru acest grup de țări. Capitolul II se concentrează pe legătura dintre poluare și creșterea economică în unsprezece țări din Europa Centrală și de Est (ECE). Pe de o parte, acesta dezvăluie o legătură neliniară, de creștere, între PIB și CO2 la nivel agregat, care este puternic robustă pentru diferiți estimatori și variabile de control. Pe de altă parte, analiza la nivel de țară relevă că relația dintre PIB și CO2 se caracterizează printr-o mare diversitate în țările ECE, și anume: formă de *N*, *N*-inversat, formă de U, U-inversat, monotonă sau chiar lipsa legăturii statistice. Astfel, în ciuda unei tendințe ascendente agregate, unele țări din ECE au reușit să asigure atât un PIB mai mare, cât și emisii de CO2 mai scăzute. Din perspectiva politicii, factorii de decizie din UE ar putea acorda mai multă atenție acestor țări, respectiv pot considera modificarea actualei politici unice de mediu pentru a incorpora mai exigent eterogeneitățile țărilor și, simultan, sprijini creșterea economică fără a dăuna mediului. Capitolul III explorează, pentru un eșantion cuprinzător de state în curs de dezvoltare, răspunsul emisiilor de CO2 agregate și sectoriale (atât în perioada curentă cât și de-a lungul unui orizont de douăzeci de ani) în urma perturbațiilor externe în PIB și urbanizare, presupunând un canal de transmisie care încorporează două dintre elementele cheie utilizate în lupta contra degradării mediului—energia regenerabilă și eficiență energetică. Pe de o parte, robuste la mai multe specificații alternative, rezultatele indică faptul că producția agregată, urbanizarea și intensitatea energetică cresc emisiile totale de CO2, în timp ce energia regenerabilă prezintă un efect opus. Mai mult, în ceea ce privește răspunsul CO2 la șocurile în producție și urbanizare, modelul poate sugera că aceste țări vor atinge pragul maxim care ar determina schimbarea trendului emisiilor în sensul scăderii. Cu toate acestea, rezultatele variază în funcție de nivelul de venit și statutul țărilor privind ratificarea/ascensiunea la Protocolul de la Kyoto. Pe de altă parte, analiza sectorială arată că sectorul transporturilor, clădirilor și non-combustiei sunt mai predispuse să contribuie la creșterea nivelurilor viitoare de CO2. În general, acest capitol poate oferi informații valoroase cu privire la perspectivele de sustenabilitate a mediului în statele în curs de dezvoltare. Capitolul IV studiază legătura dintre emisiile de CO2 și stabilitatea politică. Pentru un eșantion de țări cu venituri medii-mici și mici, acesta arată că o evoluție neliniară, sub formă de clopot, descrie relația dintre variabile la nivel agregat. Mai mult, deși acest rezultat rămâne stabil la o serie vastă de specificații alternative, identificăm eterogeneități semnificative cu privire la caracteristicile distincte ale țărilor și diferite măsuri alternative de poluare. În plus, estimările la nivel dezagregat dezvăluie tipare contrastante privind relația dintre CO2 și stabilitatea politică. Per total, concluziile sugerează că atât dimensiunea formală cât și informală a stabilității politice joacă un rol esențial în atenuarea poluării cu CO2 în țările în curs de dezvoltare, astfel, oferind informații relevante pentru factorii de decizie.

Cuvinte cheie: ipoteza curbei Kuznets de mediu; emisiile de CO2; creștere economică; urbanizare; stabilitate politică; energie regenerabilă; eficiență energetică; sondaj de literatură; țările din Europa Centrală și de Est; economii în curs de dezvoltare; modele eterogene pentru date panel; dependență transversală; nonstaționaritate; cointegrare.

Coduri JEL: Q01, Q28, Q32, Q43, Q53, Q56, O13, P28, P48

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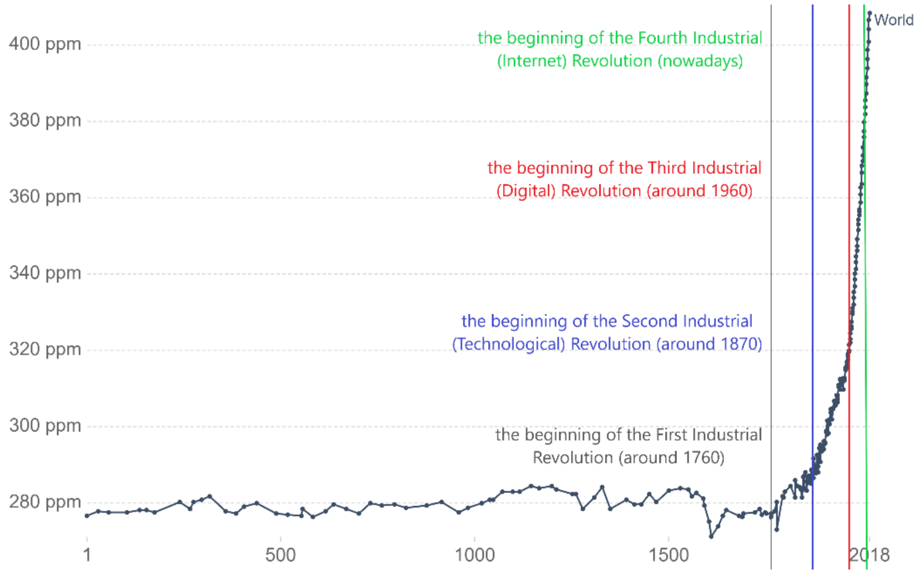
General Introduction and Overview

1. Context of the research

Over time, following the awareness of the adverse effects that the dynamic and multidimensional process of economic development has on the environment, the interest in maintaining and enhancing the quality of the environment has increased considerably. The First Industrial Revolution (FIR) onset was the basis for diversification and intensification of economic activities, leading to significant changes in nations' economic systems. More on this point, along with the development of the industry, various key changes interfere concerning the evolution of the economic sphere, such as (i) the gradual replacement of manual production with the mechanized ones (i.e. technical progress), (ii) the diversification of production/division of labor, (iii) the productivity gains due to increased production, (iv) the emergence of numerous conglomerates due to the process of concentration of production, and (v) shifts in the sectoral economic structure—the largest contribution to the gross domestic product belongs to the industry. Indeed, the aspects mentioned above, among others, have substantially contributed to the development of the countries, but they have also caused several threats to the environment.

Prior to the FIR, the population's activities were mainly agrarian and, thus, the connection between man and nature being also very tight. On the one hand, the FIR led to the acceleration of technological progress, which has significantly helped improve the population's living standards. However, on the other hand, the worrying increase in environmental degradation, accompanied by the alteration of the human-nature relationship, may be considered some of its main side effects. In this fashion, a straightforward example is given by the sharp increase of the atmospheric carbon dioxide (CO2) concentration, following the FIR's start. According to Figure 1, before the emergence of FIR, the average concentration of the CO2 in the atmosphere ranges between approximatively 270 and 280 parts per million (ppm), then the trend rapidly changes and the concentration reach in 2018 the record value of 400 ppm, and even exceed it. Put differently, considering an average CO2 concentration of about 277 ppm in 1760 and 400 ppm in 2018, the growth rate in 2018 compared with 1760 is roughly 44.4%.

Figure 1: Global CO2 atmospheric concentration



Notes: Average concentration of carbon dioxide (CO2) in the atmosphere, measured in parts per million (ppm). Source: Adapted from Ritchie & Roser (2017) based on National Oceanic and Atmospheric Administration (NOAA)/Earth System Research Laboratories (ESRL) (2018).
https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions

Broadly speaking, two clear-curt conclusions may be drawn by evaluating this simple suggestive plot. First, globally, environmental degradation has reached unprecedented levels, endangering the well-being of societies. Second, its exponential evolution suggests, among others, the difficulty of combating these kinds of phenomena once they have been triggered. As Figure 1 illustrates, despite the passage of new industrial stages that assume, among others, an evolution of societies in terms of technologies and methods to mitigate environmental degradation, and also an inevitable shift in population's perceptions of environmental issues, the atmospheric concentration of CO2 has remained steady upward. These facts indicate that the efforts made today in the fight against climate change may only be seen after a fairly long period, while consistent international cooperation may underpin the efficacity of the related actions.

Accordingly, the last decades' actions of (supra)national authorities and several profile organizations, have been directed towards finding an equilibrium point between economic development and the environment, namely to ensure sustainable development. On this path, at the international level, the United Nations (UN) put into place the United Nations Framework Convention on Climate Change (UNFCCC), whose main scope is to adjust the "greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UN, 1992, p. 9).[1] On the one hand, under this framework has been adopted the well-known Kyoto Protocol and the Paris Agreement, which governs the parties' actions regarding the reduction of GHG emissions. Notably, the former treaty has targeted merely the developed states, while the latter agreement has labor the point towards the involvement of both industrialized and developing economies in tackling climate change.

On the other hand, within the Kyoto Protocol also operates three flexible mechanisms, one of which [i.e. the Clean Development Mechanism (CDM)] is designed to jointly engage developed and developing states in limiting emissions and securing sustainable development. Specifically, industrialized countries (i.e. Annex B Parties to the Kyoto Protocol) can contribute to meeting their climate commitments by purchasing the Certified Emission Reductions (CERs) issued following the implementation of projects and/or programs aimed to reduce GHG emissions in developing economies (i.e. Non-Annex I states). Indeed, probably as any other market-based mechanism, the CDM has its weaknesses and strengths [see e.g. Carbon Market Watch (CMW), 2018] but, overall, it has proven to be an effective tool in the fight against climate change [see UN Climate Change (UNCC), 2018]. Based on the last report mentioned above, over the period 2001-2018, the CDM has engaged 140 countries (36 being included in the group of 46 of the poorest countries in the world), while the projects and programs that have been registered in 111 developing countries have reached a record number of 8116. Moreover, among its many achievements, one of the most prominent is the equivalent reduction of roughly 2 billion tonnes of CO2 in Non-Annex I economies (i.e. 2 billion CERs have been issued due to a reduction in emissions through the projects and programs implemented in developing states), following the financing of the significant number of climate action projects totaling 303,8 billion US$ (UN, 2018).

Certainly, the CDM has represented a first step regarding the involvement at the global level of developing countries in the fight against climate change, paving the way for a more active contribution of these states in reducing GHG emissions alongside the developed ones. In this vein, the Paris Agreement has provided a novel framework concerning the actions aimed at tackling climate change, which equally targets both

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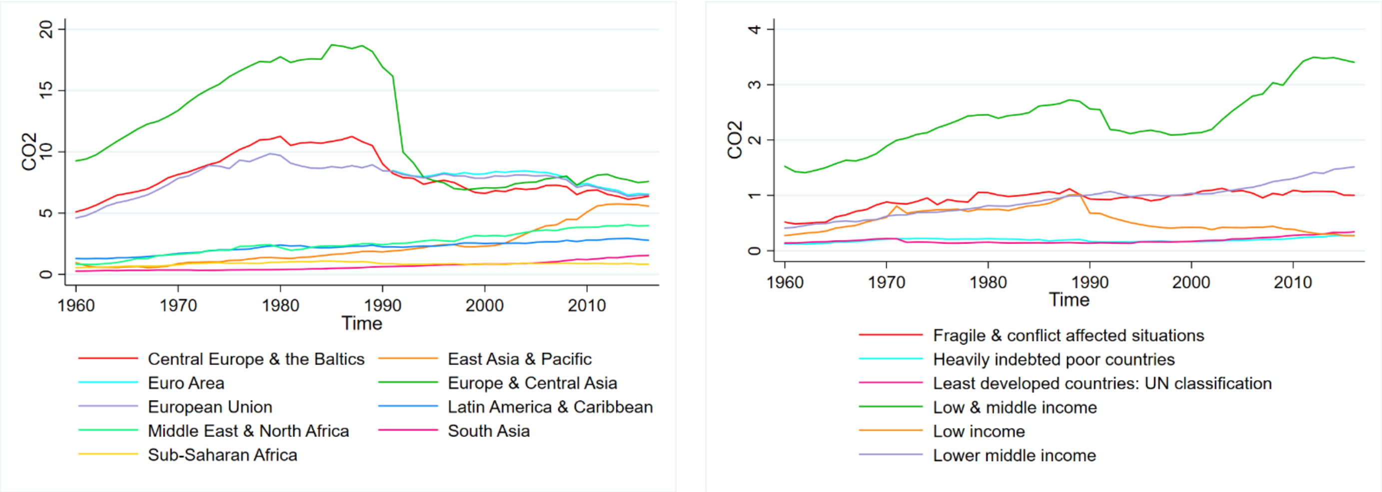
[1] https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf.

industrialized and developing economies. Likewise, it has established the basis of the CDM's predecessor, namely the Sustainable Development Mechanism (SDM), which borrows some of the characteristics and builds on the shortcomings that CDM has revealed during its implementation; thus, post-2020, the SDM may represent the next phase of international carbon markets and a vital tool in lowering the global emissions levels (CMW, 2017).

As stated previously, regarding climate change mitigation, the emphasis was initially put more on industrialized economies due to their predisposition to pollute more than developing countries and financial capacity to contribute to related actions. However, along with economic development, circumstances are gradually changing, and major transformations occur in developing countries from both economic, social, and political perspectives, leading (more or less) to an increase in environmental degradation. As such, their propensity to contribute to the worsening of climate change is growing concurrently with their active involvement at the (inter)national level in combating it. Figure 2 illustrates the evolution of CO2 per capita by region and income group or other classifications, paying particular attention to developing economies. Overall, apart from the nonlinearities visible in some series' evolution, the vast majority of them seem to be characterized by an upward trend, which is more or less pronounced over the analyzed period and/or the recent years.

Figure 2: CO2 per capita emissions over time [1960-2016]



(a) by region

(b) by income group and other classifications

Notes: CO2 emissions are measured in metric tonnes per capita. The starting date for the Euro Area group is 1991. We use the World Bank classification that excludes the high income economies for the regions where this is available, namely East Asia & Pacific, Europe & Central Asia, Latin America & Caribbean, Middle East & North Africa, and Sub-Saharan Africa. Source: Author's elaboration using the World Development Indicators Data-World Bank (2020).

Given the (sudden) dynamics of climate change and the desire to find some legitimacies about its evolution/behavior and explore its potential determinants, the related macroeconomic literature has seen a real breakthrough. Undeniably, the wave of the research in the field was even more noticeable since the early 1990s with the introduction of Environmental Kuznets Curve (EKC) hypothesis[2] (Grossman & Krueger, 1991) and the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) framework[3] (Dietz & Rosa, 1994, 1997). These two popular theoretical backgrounds taken separately or together, respecified or mixed with other theoretical and/or empirical foundations, have been the starting grid for numerous empirical and theoretical works that have targeted the drivers (especially economic growth) of environmental degradation. Besides, since their genesis several other theoretical studies (see e.g. Xepapadeas, 2005; Brock & Taylor, 2010; Kijima et al., 2010; Ordás Criado et al., 2011) have provided various insights with respect to pollution-growth nexus, adding to the general understanding of this seemingly simplistic relationship which, eventually, turned out to be much more complex. Also, this rapidly expanding literature has been the starting point for many surveys, criticisms, and recommendations, both in terms of the underlying economic theory, and econometric and statistical aspects (see e.g. Stern et al., 1996; Borghesi, 1999; Lieb, 2003; Stern, 2004; He, 2007; Wagner, 2008; Aslanidis, 2009; Vollebergh et al., 2009; Carson, 2009; Stern, 2010; Bo, 2011; Pasten & Figueroa, 2012; Kaika & Zervas, 2013a, b; Bernard et al., 2014; Hervieux & Mahieu, 2014; Stern, 2015; Sen et al., 2016; Stern et al., 2017; Tiba & Omri, 2017). However, in the light of those mentioned above, most studies have mainly focused on developed countries, while specific groups of states such as developing and transition ones have not received such great attention. Lately, the literature has started to develop in this direction, but the empirical evidence can still be considered scarce.

Building on these facts and in consonance with the UN Sustainable Development Goals (SDGs), we exploit the peculiarities of transition and developing economies (e.g. the liberalization and globalization process, energy transition and its efficiency, sectoral structure, environmental prospects, among others) to pinpoint the impact of economic

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[2] According to traditional EKC, the relationship between economic growth and environmental degradation follows a bell-shaped pattern.

[3] The STIRPAT framework represents the stochastic counterpart of IPAT identity proposed by Ehrlich & Holden (1971, 1972), based on which the human pressures on the environment are computed as a product between three terms: population, affluence, and technology.

development—through its three dimensions namely, economic, social and political—on environmental degradation as effectively as possible. More specifically, depending upon the context, along with the commonly acknowledged determinant of environmental pollution, namely the economic growth (see e.g. the peioneering works of Shafik & Bandyopadhyay, 1992; Panayotou, 1993; Shafik, 1994; Stern et al., 1996; Panayotou, 1997; Dasgupta et al., 2002; Coondoo & Dinda, 2002; Stern, 2003, 2004; Martinez-Zarzoso & Bengochea-Morancho, 2004; and the more recent studies of Kasman & Duman, 2015; Yang et al., 2015; Hanifa & Gago-de-Santos, 2017; Ozokcu & Ozdemir, 2017; Alvarado et al., 2018; Albulescu et al., 2019; Awad, 2019; Destek & Sarkodie, 2019; among others), we explore the potential impact of other key aspects of economic development process, which are more related to its social and political dimensions, namely the urbanization (see e.g. Poumanyvong & Kaneko, 2010; Martínez-Zarzoso & Maruotti, 2011; Zhu et al., 2012; Liddle, 2013; Sadorsky, 2014a; Wang et al., 2015; Wang et al., 2016; Chen et al., 2019; Xie & Liu, 2019; among others), and political stability, respectively (see e.g. Desai, 1998; López & Mitra, 2000; Welsch, 2004; Cole, 2007; Leitão, 2010; Gani, 2012; Halkos & Tzeremes, 2013; Zhang et al., 2016; Joshi & Beck, 2018; among others).[4]

Consequently, this thesis contributes to the nascent literature on economic development's effects on environmental quality in transition and developing countries. In this vein, aiming to broaden the knowledge in the field, we provide four genuine essays, one literature survey, and three empirical essays whose objectives stem to some extent from the lessons learned following the literature survey.

2. A glimpse on thesis' data and methodology

2.1. Data

Given that the thesis aims to provide original empirical evidence and contribute to the literature on the environmental pollution-economic development nexus for transition

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[4] Concerning the link between urbanization/political stability and environmental degradation, some studies control to a greater or lesser extent for their potential effects, while exploring the impact of other phenomena on environmental pollution [see e.g. Iwata & Okada (2014), Li et al. (2016), Awad & Warsame (2017), Lin & Zhu (2017), Joshi & Beck (2018) for urbanization, and Shahbaz et al. (2013), Ozturk & Al-mulali (2015), Abid (2017), Sarkodie & Adams (2018) for political stability. Furthermore, it is worth noted that regarding the political stability as a whole, most of the works investigate the effects of its different components on environmental pollution (or put in other words the political stability is proxied by various indicators related to political system) such as corruption, governance, democracy, institutional quality, among others.

and developing countries, the data collection necessary for the empirical analysis may be challenging. It is generally agreed that concerning the transition economies, the data quality and availability are relatively poor for the years that precede the fall of the Communist Bloc. The same holds for several low and lower-middle income states, whose series of macroeconomic indicators, for certain reasons, are completely missing for specific periods or display missing values.

The first chapter being a literature survey that comprises, among its specific elements, a short empirical exercise, does not require extra effort for data collection. However, we mention that for some countries included in our descriptive investigation, the series values are available only starting with 1990.

The second chapter focuses on Central and Eastern European (CEE) states, which experienced major imbalances at the beginning of the 1990s. Thus, we mitigate such instabilities by restricting our sample to start only in 1996. This period allows obtaining a relatively well-balanced sample around a critical period that triggered important structural changes, namely the mid-period of the two dates of European Union (EU) enlargement with CEE countries (2004 and 2007, with Croatia joining EU in 2013). On top of that, starting our analysis with 1996, we control for the possible hard times that these economies cross after the end of the Cold War.

Regarding the last two chapters (the third and fourth one), which target the low and lower-middle income countries, the samples' members are solely selected according to data availability. Likewise, we also set the time dimension starting point (i.e. 1992 for the third chapter and 1990 for the last one), taking into account the lack of observations for the primary indicators. Indeed, having the starting year at the beginning of the 1990s, we also avoid the distortions caused by both the Soviet Empire's collapse and/or the end of the Cold War. Besides, via the robustness checks, depending on the period examined, we drop the years before and/or following the end of the Cold War to further control for its potential detrimental effects.

Overall, the empirical studies of the thesis resort to various data sources, namely Emissions Database for Global Atmospheric Research (Janssens-Maenhout et al., 2017), World Bank Indicators, Eurostat, Heritage Foundation, KOF Swiss Economic Institute (Dreher, 2006; Gygli et al., 2019), Observatory of Economic Complexity (Haussman &

Hidalgo, 2009; Hausman et al., 2011), UN Development Programme, Global Footprint Network, European Environmental Agency, International Country Risk Guide of Political Risk Services Group, and UN Conference on Trade and Development.

2.2. Methodology

The empirical strategy employs in each chapter seeks to fit as well as possible on the characteristics of the sample, and the uni- and multi-variate properties of the variables under investigation. Consequently, in light of the progress in statistics and econometrics, we try to keep up with it as much as possible, using a series of modern statistical and econometric techniques to capture the phenomena studied with a high degree of accuracy.

In the first chapter, complementary to some classical descriptive techniques, we also use with illustrative purposes several nonparametric ones. These nonparametric methods, such as local linear, local polynomial, and lowess regression, are implemented to consolidate our judgment with respect to the potential patterns between the variables.

Next, the econometric modeling in the second chapter relies on three estimators, namely the Mean Group (MG) (Pesaran & Smith, 1995), the Mean Group Fully Modified Least Squared (MG-FMOLS) (Pedroni, 2000, 2001), and the Augmented Mean Group estimator (AMG) (Eberhardt & Teal, 2008, 2010; Eberhardt & Bond, 2009), which have good small sample properties and deals with the variables' nonstationary and cointegration. Moreover, these estimators are designed for heterogeneous slope coefficients panel data models, where cross-sectional dependence (the AMG approach) may be at work. As well, the A(MG) techniques allow the estimation of country-specific regressions, while they are also robust to a different order of variables' integration.

To answer the third chapter's research questions from a methodological standpoint, we employ the panel vector autoregression (VAR) analysis. In this manner, bearing in mind the sample's features, we specify a generalized method of moments (GMM) panel VAR model in the spirit of Love & Zicchino (2006) and Abrigo & Love (2016). This quite appealing empirical strategy allows us to further compute, based on the model's estimations, the important impulse response functions (IRFs), and forecast-error variance decompositions (FEVDs), which help us shape the conclusion regarding the study's main objective.

In the last chapter, we model the nexus between variables using the Panel Autoregressive Distributed Lag (ARDL) approach. In this regard, given the cointegration presence, we employ the panel vector error correction model (PVECM) version of the ARDL technique, which enables us to retrieve both the long-run elasticities and short-run dynamics between variables. Specifically, in line with the assumed hypotheses, we center our analysis around the technique preferred by the data, namely the Pool Mean Group (PMG) estimator coined by Pesaran et al. (1999). Furthermore, to control for the correlation across countries, in the robustness section we employ a set of four much novel techniques, namely the Cross-Section Augmented ARDL (CS-ARDL) (Chudik et al., 2013), the Cross-Section Augmented Distributed Lag (CS-DL) (Chudik et al., 2013; Chudik et al., 2016), the Common Correlated Effects (CCE) (Pesaran, 2006; Chudik & Pesaran, 2015) and the AMG approach (Eberhardt & Teal, 2008, 2010; Eberhardt & Bond, 2009). It is also worth mentioning that depending on the technique, we employ its error correction counterpart, relax the long-run slope coefficients poolability assumption, and specify a static or dynamic model.

In sum, this thesis's methodology falls within the one specific to the panel time-series data models, where the nonstationarity, cointegration, slopes heterogeneity, and cross-sectional dependence may be considered a concern—all together or mixtures between them.

3. Thesis outline

Chapter I «*New Insights into the Environmental Kuznets Curve Hypothesis in Developing and Transition Economies: A Literature Survey*» gives a fresh look on the literature concerned with examining the pollution-growth nexus via the EKC hypothesis in developing and transition economies. Overall, the previous related works have provided mixed empirical findings regarding the EKC validity, while, during the years, several theories that have tried to explain the potential bell-shaped pattern between environmental degradation and economic growth have emerged in the literature. Our study brings together into an integrated setup, both the most well-known economic reasonings behind the EKC incidence and a significant number of empirical papers published in the last decade in various top journals in the field. Indeed, on the one hand, focusing on a more homogeneous group of countries such as developing and transition economies, which possess a series of particularities compared to developed nations, we can obtain specific insights and better understand the well-debatable relationship between pollution and growth. On the other hand, we certainly could not deny that the advance in statistical and econometric techniques and the increase in data availability/quality have changed how researchers address the EKC hypothesis. Thus, we expect to observe some improvements in its prediction and the associated threshold value.

More specifically, to offer a more comprehensive picture of the pollution-growth nexus and, ultimately, distinguish whether the empirical works have managed to overcome the shortcomings suggested by the theory, we proceed as follows. First, we cover in our theoretical survey the economic rationale behind EKC and the crucial components of the research design when estimating it, namely the model specification, assumptions, econometric methodology, and identification strategy. In short, we discuss not only the economic theory behind EKC but also the advance in the econometric tools. Second, using descriptive and several nonparametric techniques, we conduct a short descriptive empirical exercise to disentangle the pollution-growth pattern for four top global CO2 emitters (namely China, the European Union, India, and the Russian Federation), and also at the global level. Third, in the empirical survey, we differentiate between panel-data and time-series studies, while we also discuss some new econometric perspectives regarding the modeling of environmental degradation-economic growth nexus.

According to the empirical review, several studies find a long-term relationship between indicators, strengthening EKC's intrinsic nature. Also, the bell-shaped pattern is invoked quite often as an empirical result among many of these works. Thus, it seems that the difficult times experienced by developed countries in terms of achieving sustainable development, among others, have been a solid foundation of valuable know-how for developing ones, helping them to get through this stage much more quickly. Nonetheless, some studies find turning point values that exceed the upper or lower income range limit. This may indicate that economic growth still increases environmental degradation and/or the associated identification strategy is deficient.

Regarding the identification strategy and research design in general, it seems that many problematic aspects raise by the theory have been mitigated along with the progress in statistical and econometric tools. Moreover, our short nonparametric descriptive exercise may highlight the importance of using complementary techniques, among other robustness checks, to guarantee the high accuracy of results before concluding. In this fashion, new techniques borrowed from other spheres, such as the wavelet analysis that moves beyond the time domain, can bring ancillary information and provide a different view on modeling the relationship between environmental quality and economic growth.

Overall, this chapter attempts to offer a more comprehensive and updated assessment of the evolution of the relationship between environmental quality and economic growth through EKC. Dividing our survey into three different key phases, namely (i) theoretical review, (ii) empirical exercise, and (iii) empirical review, while targeting a group of economies that have not enjoyed much attention in the literature, and with a slightly different role in terms of involvement in international climate change agreements compared to developed countries, we aim to provide new valuable insights on this subject. In addition, this review offers a solid basis for valuable information that helps us identify gaps in the literature that we address empirically in subsequent studies that shape this thesis.

Chapter II «*Pollution and Economic Growth: Evidence from Central and Eastern European Countries*» examines the relationship between pollution (expressed by CO2 emissions per capita) and economic growth (expressed by GDP per capita) in eleven CEE countries. Referred as transition economies, the CEE states have undergone laborious changes on their path to liberalization (i.e. the transition from a socialist economy to a market economy) that has involved several economic, social, and political processes. By all means, these transformations have shifted in one way or another how the authorities and the population relate to the environmental issues, perceive the news about climate change, and, ultimately, react to all these aspects. In the wake of the aforementioned, in our analysis, we start from the premise that economic growth and other adjacent processes at the macroeconomic level may significantly impact environmental degradation.

Motivated by the sparse literature on this group of economies, we build our study around the intuition that these countries may have different development paths, and their economies carry the footprint associated with past communist regimes. Concerning the development paths, we consider an extended EKC where the cube of GDP is intended to capture possible differences in the stage of economic development (i.e. technological changes). Regarding the past communist regimes' common footprint, we include in the cointegrating vector, both energy consumption per capita and economic freedom.

Our econometric strategy relies on three estimators designed to capture the potential heterogeneities among countries, namely the MG, MG-FMOLS, and the more recently developed AMG approach, which accounts for cross-sectional dependence and allows a country-specific estimation. The empirical methodology reflects the data characteristics while also considers the sample's N and T dimensions. Put differently, these estimators, in addition to being part of the category of estimators specific to nonstationary panels, are also recommended when dealing with moderate macro panels in terms of both N and T dimensions.

We find that our third-order polynomial specification is indeed supported by the data, given that the effect of the cube of GDP is significant at the aggregated level. In particular, the findings indicate an increasing nonlinear relationship between CO2 and GDP, robust to an extensive set of alternative specifications. Thus, the increase in CO2 following a boost in the economic growth is relatively slight around an estimated GDP level of around 19,900 US$, but the magnitude of this effect increases as we move to the right and left of this GDP inflection point. Moreover, the results show the CO2-GDP nexus' complexity at the disaggregated level, considering the extensive selection of patterns revealed by the country-level estimates.

This chapter contributes to expanding empirical literature on pollution-growth nexus using the extended EKC hypothesis as a theoretical background. To the best of our knowledge, we are the first to investigate this relationship solely for the group of eleven CEE states. More than that, we concomitantly look at both aggregated and country-specific levels. In doing so, to capture the causal effect of GDP on CO2, we build the identification strategy trying to take into account the shortcomings that econometric theory has raised over the past recent years (especially the potential cross-sectional dependence and slopes heterogeneity). As such, we provide novel comprehensive findings that may help us further understand the complex relationship between GDP and CO2 in this particular group of economies.

Chapter III «*Developing States and the Green Challenge. A Dynamic Approach*» investigates the aggregated and sector-specific CO2 emissions' responsiveness following exogenous shocks to growth and urbanization, considering a transmission scheme that incorporates two of the widely used instruments in mitigating environmental degradation, namely the renewable energy and energy efficiency. In this regard, using the STIRPAT framework, we focus on 68 developing economies span over the period 1992-2015. Being Non-Annex parties to the Kyoto Protocol and only starting with Paris Agreement more active players in fighting climate change, developing economies distinguished from developed nations in terms of their roles concerning the international environmental agenda for climate change. Nonetheless, the CDM under the Kyoto Protocol umbrella is designed to involve both developed and developing economies in actions aimed at reducing environmental degradation. More specifically, via the green projects implemented in developing states (mostly projects related to renewables and energy efficiency), the developed ones can also meet some of their emission reduction commitments.

One the one hand, our study is motivated by these peculiarities of developing countries regarding their position to environmental issues, especially at the international level, and the ongoing structural transformation they cross in terms of economic development. Besides, it is generally acknowledged and postulated by the related literature that external disturbances have a more pronounced impact on developing economies than developed ones. Indeed, this may be easily linked to less industrialized nations' previously mentioned characteristics, which may increase, among others, their vulnerability. On the other hand, similar to the transition economies, the link between output and pollution is still not much documented, while based on the economic intuition and a large body of the previous works, several developing states did not yet achieve the GDP threshold that may trigger a decrease in pollution. Indeed, the same may hold when we bring into discussion the ongoing urbanization process that these economies have experienced on the road to foster economic development. In this fashion, we examine the effects of both growth and urbanization on CO2 in the context of the traditional and urbanization related EKC hypothesis, while we are not ruling out that the potential shocks to their dynamics may affect the share of renewables and energy intensity of the economy, which in turn may significantly impact the CO2 emissions.

Given our data's uni- and multi-variate properties, we employ the recently developed GMM-panel VAR approach of Abrigo & Love (2016). This empirical strategy not only helps us to address the potential endogeneity between variable but also allow us to have a perspective of the future effect of indicators on CO2 (this is especially of interest to see if a potential threshold effect will be at work for output and urbanization) through the computation of IRFs. Also, the approach is applied in the context of the two well-known theoretical frameworks, namely the STIRPAT model and the EKC hypothesis, allowing us to endorse the presumed transmission channel and capture the essential structural shocks.

The aggregate findings robust to many alternative specifications show that both on impact and cumulated over twenty years, only renewables share decreases CO2 emission, while output, urbanization, and energy intensity positively affect CO2. In the long-run, output and urbanization may exhibit a threshold effect on CO2, in line with the traditional and urbanization-related EKC. However, we find important heterogeneities when we break the sample according to the states' development level and their Kyoto Protocol ratification/ascension status. Besides, the sector-specific analysis suggests that the emissions from transport, buildings, and the non-combustion sector are more likely to increase in the future, compared to those from the industrial combustion and power industry sector.

Having the roots of its objectives in the lessons drawn based on the first chapter, and being seen as a complementary part of the second one, through this chapter we offer an original assessment of the current and future state of developing countries in terms of CO2 pollution (and environmental sustainability in the broad sense).

Chapter IV «*Does Political Stability Hinder Pollution? Evidence from the Developing States*» explores the effects of (overall) political stability on environmental degradation in 47 low and lower-middle income economies. Jointly with the economic and social system, the political system is at the core of a nation's well-functioning, while it has tight connections with various elements of the other two. Therefore, any potential fluctuations in the overall or its subcomponents' dynamics—whether we refer here to its formal side (the governmental related subcomponents) or the informal one (non-governmental related subcomponents), can trigger a series of chain reactions, which due to systems' interconnects may significantly impinge also on the environmental conditions. Taking a brief look at some political stability statistics, we notice that in recent decades (specifically over 2006-2016 period), the number of worldwide political conflicts has doubled, and what is even more worrying is that violent conflicts have increased the most [Global Peace report (GPI), 2017]. Moreover, historical evidence has shown that these episodes of political instability are more frequent in poorer countries.

Driven by these facts and corroborated with the specificities regarding the developing countries' status in terms of global environmental agenda (presented in the previous chapter), we consider both opportune and of interest the enrichment at the empirical level the not very extensive knowledge in this area. Consequently, in our desire to capture as comprehensively as possible the dimensions of political stability, we proxy it with the ICRG composite index, while environmental degradation is captured by a widely used global pollutant, namely the CO2 emissions. The other CO2 potential determinants we include in the model are chosen based on the STIRPAT and EKC literature, being also in consonance with the 2030 SDGs.

Bearing in mind the sample's features, we opt for a quite appealing empirical strategy, which allows us to retrieve both the long- and short-run coefficients, and, more importantly, to account for the potential reverse causality between variables. Besides, we go even further and apply this approach, namely the ARDL, in its classical and newly-developed version (i.e. robust to cross-sectional dependence), considering different estimators and scenarios. Likewise, we employ a series of complementary techniques and alternative specifications to check our results' stability.

We find that the political stability exhibits a bell-shaped effect on CO2 emissions, meaning that for low levels of political stability the CO2 pollution is also minimal, but its levels increase along with an increase in political stability until a threshold is reached and the trend reverse—for high political stability the CO2 emissions are also low. According to the main preferred model, we estimate that the CO2 switches its trend for a political stability value around roughly 66.5 (in index points), which corresponds to moderate political stability. This result remains qualitatively unchanged when several robustness checks are implemented. However, it is highly sensitive to countries' distinct characteristics and for alternative measures of pollution. In addition, despite the aggregated bell-shaped relationship, the individual estimates reveal distinct patterns between variables.

In a nutshell, this last chapter offers a renewed perspective on the pollution-political stability nexus by adding to the growing literature, especially in terms of the nonlinear modeling between variables. It also highlights the importance of complementarity between aggregate and disaggregated estimates in providing the most complete as possible conclusions when studying different macroeconomic phenomena. Naturally, it can be also viewed as a continuation of previous chapters, in which we go beyond the potential nonlinearities between economic growth (urbanization) and environmental degradation postulated by the EKC (urbanization EKC), and search if such nonlinearities are also present regarding the impact of other economic development dimensions, namely the political one, on CO2 emissions.

«CHAPTER I»

New Insights into the Environmental Kuznets Curve Hypothesis in Developing and Transition Economies: A Literature Survey*

Abstract: We perform an updated literature survey on pollution-growth nexus via the environmental Kuznets curve (EKC) hypothesis, both from theoretical and empirical standpoints. First, we conduct a literature review on the most well-known rationale behind the EKC prevalence and discuss the key components of the research design when estimating the EKC. Second, we bring together the most influential empirical papers published in the last decade, which focus on EKC estimation in developing and transition economies. Overall, succeeding to curtail some of the deficiencies suggested by theoretical contributions, the recent empirical studies might indicate a certain consensus regarding pollution-growth nexus, and EKC validity. On the one hand, reinforcing the EKC nature, several studies reveal a long-run relationship between indicators. On the other hand, according to income coefficients' signs, the traditional bell-shaped pattern seems to be at work for some developing and transition economies. However, in some cases, the estimated turning point lies outside the income sample range, calling into question not only the true pattern between pollution and growth but also the identification of EKC. Taken collectively, both the theoretical foundations and empirical evidence, could contribute to a better understanding of the pollution-growth nexus in the EKC context, and suggest some useful insights into the future works on the subject as well as the crucial policy implications in this group of countries.

Keywords: environmental Kuznets curve hypothesis; developing and transition economies; literature survey.

JEL Codes: Q53, Q56, Q43

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I.1. Introduction

Recently, one of the major concerns of nations has become global warming, and particularly the adverse effects that this phenomenon produces on Earth and implicitly on the quality of life. Along with the start of the Industrial Revolution, there are significant changes at the global level, both economically and socially, which also reflects on the environment.

As an answer to the concerns related to environmental degradation–economic growth nexus, and the desire to synthesize them into a general mission of the population and the competent bodies, the World Commission on Environment and Development (1987) in the report entitled Our Common Future (i.e. Brundtland Report), shaped the definition of sustainable development. According to this publication, "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987, p. 41).[1] Indeed, this may not be the first and the perfect attempt to define what sustainable development constitutes, but we surely can argue that is one of the most used and debated explanation in the related literature (see e.g. Seghezzo, 2009; Ciegis et al., 2009; Stoddart, 2011; Holden et al., 2014, among others). Furthermore, if we look back in history, before the Brundtland report, Malthus (1798) in his book "Essay on the Principle of Population" outlines some important future changing in nations' economic structure. He argues that the world's population grows at a geometric rate while the food supply increases at an arithmetic rate, leading over time to exhaustion of natural resources. Later, a report writes by Meadows et al. (1972), and suggestively named "The Limits to Growth" brings to light the same issues related to the excessive increases in population and economy due to industrial expansion, while natural resources follow a downward trend. Authors such as Basiago (1999) and Sandmo (2015) highlight the importance of these two studies as fundamental pillars in the development of environmental and energy economics as an autonomous field.

Consequently, the importance of awareness of environmental protection and its interdependence with specific indicators at the macro- and micro-economic level have become an important topic in the early literature. Besides, along with the development of

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[1] https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf.

new theoretical concepts, more and more empirical studies have begun to emerge. Nowadays, as a result of the increase in data availability and the development of more sophisticated statistical techniques, there is a substantial flow of research papers related to the field of environmental and energy economics.

This study aims to review in an integrated framework the key theoretical aspects and give an updated empirical overview of the relationship between environmental degradation and economic growth via the Environmental Kuznets Curve (hereafter EKC) hypothesis. By doing so, first, we tackle the theoretical knowledge regarding the EKC, by stating the most well-known rationales behind its prevalence. Next, we move across towards the research design in terms of EKC testing and provide some details about its fundamental components, namely the model specification, assumptions, econometric methodology, and identification strategy. Second, we survey the empirical papers published in the last decade (i.e. from 2010 to 2019) that focus on developing[2] and transition economies and investigate the validity of the EKC hypothesis. Therefore, comprising together the latest published research, we would have a more homogeneous picture of the EKC literature. Moreover, along with the rapid development of more advanced statistical techniques and the increase in data availability and quality, the EKC testing approaches have also changed (Dasgupta et al., 2002; Lieb, 2003). As such, we are inclined to believe that, on the one hand, the recent studies are more accurate vis-à-vis the research design, while, on the other hand, the increased data quality has improved the prediction of EKC both in terms of parameters and turning point estimates. Relying on this intuition, and opposite with the review of He (2007), who targets the SO2 EKC hypothesis for the developing and transition economies and Shahbaz & Sinha (2019), who concentrate on the CO2 EKC hypothesis, we survey the papers independent of pollution indicator used in EKC testing. Also, compared to the survey of Tiba & Omri (2017) on the relationship between energy, environment, and growth, we focus solely on the EKC hypothesis works and provide an updated review of the related literature.

Our findings are as follows. First, several studies reveal a long-term relationship between environmental pollution and income. Thus, the long-run character of EKC seems to prevail and strengthen the belief that the EKC is rather a phenomenon that may be observed over a relatively long period, all the more that the effects of environmental

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[2] In this paper, the term "developing" refers to both developing and emerging economies.

policy are visible after years from implementation. Second, it is encouraging to see that the bell-shaped pattern between pollution and growth seems to emerge frequently for some developing and transition states—perhaps contrary to the general intuition that it is more challenging for these countries, compared to developed ones, to reach the optimal level of growth that could ensure the decline of pollution level, i.e. inducing an upward bending curve. Overall, this may suggest that less developed nations might improve their environmental quality by avoiding and learning from the mistakes made by developed countries, and even switch pollution trends in favor of the environment for a lower income level (Munasinghe, 1999; Dinda, 2004; Yao et al., 2019). However, the mixed results are expected when spanning different periods and using different pollution indicators, even for the same country or group of countries. Third, in some cases, the estimated turning point lies outside the income sample values. As such, this may imply, on the one hand, a possible monotonically increasing pattern between indicators (see e.g. Cole et al., 1997; Stern & Common, 2001; Lieb, 2003) and, on the other hand, might reveal potential weaknesses in the identification of EKC (see e.g. Bernard et al., 2014). Regarding the latter, it becomes imperative for the researcher to determine the minimum set of assumptions to identify the genuine causal effects between variables and if we refer to the parametric approach to identify the parameters point estimate. Also, a broader perspective in terms of the statistical methods may provide further insights into EKC and narrow some of the related uncertainties. In this fashion, the methods designed to minimize the model assumptions, such as semi-, and non-parametric techniques[3], along with the ones that go beyond the time-domain approach, such as wavelet techniques related to the time-frequency domain, may provide a sound basis of comparison for the traditional econometric tools, or vice versa (i.e. parametric methods should be seen as complementary to these methods). Ultimately, a valuable alternative to achieve robustness is when the results of different techniques incline, more or less, towards the same conclusion. For example, based on our short nonparametric descriptive exercise, China exhibits an increasing pattern between CO2 and GDP, a result also suggested by several time-series and panel studies included in our empirical review—although the sign of the associated income coefficients indicate a bell-shaped pattern, some studies find

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[3] It is worth mentioning that we do not argue that this type of analysis should be performed instead of a parametric one, or provide better results at the advantage of fewer assumptions.

turning points that lie outside the income sample range, thus, indicating a positive relationship.[4]

The rest of the paper is organized as follows. Section 2 discusses the theoretical arguments that constitute the basis of the bell-shaped pattern between pollution and economic growth, Section 3 explores the potential patterns between CO2 emissions and economic growth descriptively, Section 4 reviews the empirical studies on EKC, and Section 5 concludes and provide some policy implications.

I.2. Theoretical aspects of EKC

Presumably, one of the most tested hypotheses in the literature that stresses the relationship between environmental degradation and economic growth is the EKC hypothesis. The assumption that the link between pollution and economic growth follows a bell-shaped pattern is first introduced in the literature by Grossman & Krueger (1991). In their seminal paper, the authors analyze the implications that the North American Free Trade Agreement (NAFTA) has on the environment through the medium of economic growth. Based on the empirical findings, they conclude that the form of the relationship between economic growth and environmental degradation is inverted-U shaped. Thus, the quality of the environment tends to deteriorate along with economic growth until an income threshold is reached, from which the trend is reversed in favor of the environment. Approximately during the same period, Shafik & Bandyopadhyay (1992) and Panayotou (1993) also search into the implications of economic growth on the environment, while the latter named the relationship between these two macro-indicators the EKC.

I.2.1. The rationale behind the EKC hypothesis

Throughout the years, the number of studies that have approached both theoretically and empirically the EKC hypothesis and its extensions have increased considerably. Most researchers have tried to answer the following question: which are the drivers that shape the relationship between environmental degradation and economic development? Some

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[4] We take China as an example since a large number of studies considered focus on testing EKC for this country, compared to other states. However, a comparison could be made for the other states as well. Besides, we look for an overall behavior independent of the period analyzed, pollution indicator, and empirical methodology.

authors provide potential explanations based on economic intuition. In contrast, others develop well-grounded theoretical models around a series of assumptions and/or restrictions which at least theoretically generate a bell-shaped pattern between pollution and economic growth. In the following, we look at some well-known rationale behind the EKC hypothesis provided by the existing literature, from both the sides of economic intuition and theory, and briefly discuss them.

First, Grossman & Krueger (1991) argue that the scale, structural, and technological effect may explain the nexus between pollution and growth. The scale effect manifests as a result of economic activity expanse, which in turn induces a rise in the pollution levels. In contrast, structural or compositional effect accounts for the structural changes that take place within the economy. Furthermore, once nations attain industrial apogee, they focus more on the development of information-based industries and services. Thus, as a state becomes intensive in services, it ensures a higher economic growth rate, and eventually, a steady decline in environmental degradation. Besides, in the post-industrial phase, countries have the necessary resources to invest in research, development, and innovation programs, and due to technological advancement, old technologies are gradually replaced with more efficient and less polluting ones (Panayotou, 1993, 2003).

Second, the nation's economic development also implies an increase in the population income. As such, if the quality of the environment is regarded as a normal good, its demand may be influenced positively. In the related literature, some researchers have empirically confirmed the presumption that environmental quality is a normal good (see e.g. Kristrom & Riera, 1996; Bruneau & Echevarria, 2009; Martini & Tiezzi, 2014), while researchers such as Pearce & Palmer (2005) and Ghalwash (2007) have argued that the quality of the environment is more a luxury good. Consequently, the soundness of the EKC hypothesis may be a consequence of these fluctuations in the income elasticity of demand for environmental improvement.

Third, along with the rise in income, the individual's perception of the adverse effects of environmental degradation on quality of life also increases. As an overall outcome, compared to poorer countries, developed states tend to adopt more stringent environmental policies and regulations. Hence, in developing states, environmental regulations are fewer, and they are prone to become pollution havens for dirty industries that migrate from developed ones (Lucas et al., 1992). Also, authors such as Stern et al. (1996), Suri & Chapman (1998), and Stern (2003), among others, advocate that the bell-shaped pattern for developed nations may be explained through the implications of trade. Moreover, researchers such as Dasgupta et al. (2002), among others, argue that improvements in environmental quality are possible even in developing countries. Besides, the pollution may follow a downward trend for a lower level of income than those experienced by developed countries, considering the increase in the availability and novelty of methods to combat pollution.

Fourth, in the early literature, some authors provide theoretical models that attempt to explain the EKC behavior. In this fashion, some of these early theoretical works are discussed in the well-known study of Stern (2004). Likewise, more recently, Kijima et al. (2010) provide a comprehensive and valuable survey on both theoretical static and dynamic models behind the EKC hypothesis with detailed mathematical explanations, along with a review on empirical analysis. In Table I.1, we summarize these theoretical contributions concerning the EKC hypothesis as they appear in Kijima et al. (2010).

Table I.1: Theoretical studies on EKC based on Kijima et al. (2010)

Static models	
Model type	***Authors***
Models with macroeconomic production functions	Lopez (1994), Lopez & Mitra (2000).
Models with utility functions only	McConnell (1997), Andreoni & Levinson (2001), Lieb (2002), Di Vita (2004).
Dynamic models	
Model type	***Authors***
Resource allocation	John & Pecchenino (1994), John et al. (1995), Selden & Song (1995), Lieb (2004), Dinda (2005), Chimeli & Braden (2008), Prieur (2009).
Technology and resource selection	Stokey (1998), Hartman & Kwon (2005), Tahvonen & Salo (2001).
Tax policy	Jones & Manuelli (2001), Egli & Steger (2007).
Real options approach	Wirl (2006), Kijima et al. (2011).

In addition to these theoretical works, Brock & Taylor (2010) taking stock of the earlier theory literature (e.g. Stokey, 1998) establish the EKC hypothesis—Solow model nexus. In their seminal contribution, the authors use the underlying assumptions of the well-known neoclassical growth model introduced by Solow (1956) and account for environmental pollution in the main equation of the Cobb-Douglas production function. As such, they developed a new model (i.e. Green Solow model) which provides a theoretical setup that may explain the bell-shaped pattern between pollution and economic growth through the same forces that assure the course of economic growth, namely the law of diminishing returns and the advancement of new technology (Brock & Taylor, 2010). Subsequently, as Kijima et al. (2010) argue, the Green Solow model is "a macroeconomic dynamic model in which total production is allocated to consumption and abatement expenditure" (Kijima et al., 2010, p. 1193). Indeed, the Green Solow model is a simple dynamic model that may give a strong rationale behind the EKC hypothesis, and an adapted empirically testable convergence equation for emissions per capita.

Conversely, Ordás Criado et al. (2011) further develop the Green Solow model and provide a theoretical framework in which the reduction in pollution is endogenously determined. In particular, the theoretical predictions formulated by authors suggest that through the scale (defensive) effect, the growth rates in pollution are associated positively (negatively) with GDP growth (emissions levels). Next, using convergence-type equations estimated based on three different econometric approaches (i.e. parametric, semi-, and non-parametric), the authors show that the data validate both the scale and defensive effect. Besides, the possible reverse causality between pollution and growth implied by the theoretical model is addressed empirically by employing instrumental variables. Overall, the empirical findings suggest that the more flexible specifications (semi-, and non-parametric) are preferred when modeling the data, compared with the classical parametric ones. Moreover, opposed to Brock & Taylor (2010), who link CO2 emissions (a global stock pollutant) with economic growth, the theoretical model introduced in Ordás Criado et al. (2011) is designed for local flow pollutants, such as SO2 and NOx emissions.

In this subsection, we review some notable empirical and theoretical works that target the pollution-growth nexus and seek directly, or at least indirectly, into the rationale that may explain the bell-shaped pattern between the indicators. However, as also suggested by these studies, the reasons behind the validity of the EKC hypothesis are more diverse, and in the related theoretical and empirical literature, the views are also mixed. Among the researchers who provide literature surveys, critics and search into the rationale of EKC hypothesis, we mention the works of Stern et al. (1996), Borghesi (1999), Lieb (2003), Dinda (2004), Stern (2004), He (2007), Carson (2009), Bo (2011), Pasten & Figueroa (2012), Kaika & Zervas (2013a, b), Stern (2015), and Tiba & Omri (2017).

I.2.2. Model specification, assumptions, econometric methodology, and identification strategy

I.2.2.1. Model specification

The classical and probably the most used empirical strategy to model the link between environmental degradation and economic growth is through the polynomial equations of the second, and third degree (see e.g. Grossman & Krueger, 1991; Panayotou, 1993; and the more recent studies of Miyama & Managi, 2014; Lazăr et al., 2019; Chen et al., 2019b; among others). The use of quadratic function allows testing the traditional EKC hypothesis (i.e. the potential bell-shaped pattern between pollution and growth), while the specification of a higher polynomial order, such as the cubic function, allows the representation of multiple patterns. These patterns cover the N shape (a potential extended EKC when the coefficient of income, squared income and cubic income is positive, negative and positive, respectively, and statistically significant), the traditional bell-shaped pattern (the coefficient of income and squared income is positive and negative, respectively, and statistically significant), and also a monotonic increasing (decreasing) relationship when only the income coefficient is statistically significant and positive (negative). Indeed, modeling the EKC through the parametric approach implies that the functional form and also the distribution is already assumed[5] (Miyama & Managi, 2014). Thus, for example, an imposed shape of the relationship through the introduction in the equation of a squared or cubic income term, when the relationship is linear, could induce weak identification, and also could bias the turning point (Bernard et al., 2014). However, to reduce the bias that may potentially arise from imposing a specific functional form, econometrically one may (i) assume the largest polynomial, i.e. cubic specification, and estimate sequentially also the quadratic and linear equation to show consistency in coefficients' significance (for example, if the income terms are statistically significant in a third-order polynomial equation, intuitively in the second-order polynomial equation they should lack statistical significance; see e.g. Lazăr et al., 2019) (ii) use specific tests for the presence of a potential nonlinear relationship (see e.g. Lind & Mehlum, 2010), or (iii) employ simultaneous with the parametric techniques also the semi-, and non-parametric alternatives to assure robustness, or at least to deduce a pattern between variables descriptively (see e.g. Millimet et al., 2003; Ordás Criado et al., 2011; Bernard et al., 2014;

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[5] Also, the parametric quadratic function implies symmetry since, at both sides of the threshold, the pollution increases and decrease by the same rate.

among others). Besides, it is worth noting that not only the results obtained for the income coefficients signs, but also equally, the presence or absence of a turning point helps in determining the pattern followed by the data.

A second strand of studies (see e.g. Millimet et al., 2003; Tsurumi & Managi, 2010a, b; Ordás Criado et al., 2011; Chen & Chen, 2015; Sen et al., 2016; Zhang et al., 2017; Luzzati et al., 2018; among others) have challenged the classical parametric approaches, which most are based on an imposed order for the polynomial equation, by estimating the pollution-income nexus using more flexible empirical strategies, such as semi-, and non-parametric methods. In this regard, the findings of Millimet et al. (2003) and Ordás Criado et al. (2011) show that compared to parametric counterparts, the semi-, and non-parametric alternatives are preferred when modeling the data. Although the amount of semi- and non-parametrical EKC literature has increased over the years, it remains relatively low compared to parametric one. First, one of the reasons may be related to the well-known curse of dimensionality issues in fully nonparametric models, induced when many factors are included in the equation. Bearing in mind a crucial and well-debated econometric objection about EKC, namely the omitted variable bias (see e.g. Stern, 2004), there is a need to account for at least the most influential factors of pollution along with the income (e.g. energy consumption, trade, foreign direct investments, structure of economy, globalization, economic freedom—to mention just a few of them) to obtain reliable and consistent results. Consequently, the curse of dimensionality could be a plausible impediment in applying nonparametric methods, but it can also be alleviated by working with semiparametric methods. Second, the graphical representation results of semi- and non-parametrical models may be more complex and harder to interpret, thereby most researchers seem to prefer more straightforward results, such as point estimates. Third, the insufficiency of clear-cut statistical inference procedures in the nonparametric field could influence its soundness and applicability. Forth, usually in economics and also in energy and environmental economics subfields, the vast majority of studies rely on some theories or prior empirical evidence. Therefore, in most cases, the specification of the model is already predefined. Furthermore, these theories and empirical regularities—some of the well-known mentioned in the above subsection—come along with different (parameters) assumptions and/or restrictions, which may be more convenient to address through parametric techniques. Some of these possible deficiencies of semi-, and non-parametric models are also acknowledged in the context of

EKC estimation by authors such as Tsurumi & Managi (2010a) and Bernard et al. (2014), among others.

I.2.2.2. Model assumptions, and econometric methodology

Although in the last two decades, some theories regarding the validity of EKC have emerged in the literature, the vast majority of the studies rely mostly only on econometric assumptions and/or restrictions (e.g. exogeneity, long-, and/or short-run homogeneity and heterogeneity, order of integration—for the independent factors; equal variance, lack of autocorrelation, normality—for residuals; persistence, order of integration—for endogenous variable; among others), in modeling the relationship between pollution and economic growth.

On the one hand, the potential econometric issues (e.g. cross-sectional dependence, time-series properties, such as stationarity and cointegration, endogeneity bias caused by simultaneity, omitted variables, models misspecification, dynamic endogeneity or data measurement errors; among others) that can arise in estimating the pollution-growth nexus and produce biased estimates, if they are neglected, could be reduced by considering a (minimum) set of assumptions. However, it is generally acknowledged that both the data and sample characteristics play an essential role in dictating the choice of the most appropriate model specification and also the optimum econometric strategy. For instance, in testing EKC, the parameters' homogeneity assumption in panel data models may be too restrictive, and the overall results may not describe the real general or individual pattern for each panel member (see e.g. Stern, 2010; Kaika & Zervas, 2013a, b). Therefore, if the turning point occurs at the panel level, the behavior does not need to be preserved at the country level, and the turning point could be well above the observed income values. As Bernard et al. (2014) point out, when working with a panel composed of different countries, disaggregation may be a valid solution to mitigate the bias of data pooling.

In the view of the previous, recent studies, such as Barra & Zotti (2017), illustrate for a sample of 120 countries spanned over 2000–2009 that once considering the nonstationarity property of the data, the evidence of an inverted-U shaped relationship between CO2 emissions and GDP vanishes in favor of a monotonic increasing one. Besides, to overcome the different sample composition issues, the authors eliminate alternatively from the sample the same geographical region and income distribution states. Overall, the estimates suggest that the sample composition reshapes the main findings. Furthermore, Miyama & Managi (2014), among others, suggest that excluding low income countries from analysis due to data availability may alter the results. As such, to deal with missing data problems and its undesirable consequences on EKC estimation, they propose a series of imputation methods. Also, Stern & Common (2001) suggest that the inclusion or exclusion of developing states from the analysis may influence the occurrence of a turning point.

On the other hand, the development of novel panel[6] estimators that allow for different long-, and short-run slope assumptions (see e.g. the panel ARDL technique with the associated Pooled Mean-Group, Mean-Group, and Dynamic Fixed Effects estimators discussed in Pesaran et al., 1999), which are also robust to various potential econometric problems, such as the different order of integration for regressors, and variables' cointegration (see e.g. Pesaran & Smith, 1995; Pesaran, 2006; Eberhardt & Bond, 2009; Eberhardt & Teal, 2010), cross-sectional dependence (see e.g. Pesaran, 2006; Eberhardt & Bond, 2009; Eberhardt & Teal, 2010; Chudik & Pesaran, 2015; Chudik et al., 2016), and endogeneity (see e.g. Pesaran et al., 1999; Chudik & Pesaran, 2015; Chudik et al., 2016) facilitate the EKC estimation. Besides, the preliminary analysis techniques, such as stationarity and cointegration tests, have also been developed to deal with cross-sectional dependence, parameter heterogeneity, among other potential econometric issues. Nonetheless, taking note of the aspects mentioned above is ultimately the task of the researcher to properly formulate the set of assumptions and adapt the methods to sample particularities.

I.2.2.3. Identification strategy

The assumptions and restrictions consider by the researcher help in shaping the proper identification strategy and inference. In the light of previous EKC literature, which provides no consensus on its validity and the associated turning point, the recent landmark study of Bernard et al. (2014) waves a red flag regarding the weak identification of both EKC and the related turning point. More specifically, the authors investigate the

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[6] We discuss here some of the recent developments of panel data techniques, as panels include both *N* and *T* dimensions, and the EKC is usually tested using panel data models. Still, it is worth mentioning that the advanced in the time-series econometric tools are more or less similar.

estimation precision of the EKC turning point using Delta and Fieller method, while controlling for a wide set of potential econometric issues (i.e. endogeneity, persistence, and functional form). The overall findings show that the estimation of the EKC turning point lacks precision (i.e. the associated confidence intervals are very large) and, thus, the policy implications based on EKC may be altered. However, the results suggest that precision is higher when considering local pollutants, a long-term perspective, or nonparametric alternatives.

In the same manner, few years before the study of Bernard et al. (2014), the seminal work of Wagner (2008) and Vollebergh et al. (2009) highlights some of the most prominent weaknesses of EKC econometrics since its grounding, and raise the relevance of its identification, respectively. On the one hand, Wagner (2008) discusses two econometric issues that lately have governed the panel data EKC literature, namely the stochastic properties of nonlinear terms of integrated variables and the cross-sectional dependence. In particular, the author shows that employing standard nonstationary panel data techniques, which do not take into account the nonlinear transformations of integrated variables and cross-sectional dependence, the bell-shaped pattern between emissions and income holds. However, when using stationary defactored data to deal with the problems mentioned above and appropriate estimation techniques, the EKC hypothesis seems to be invalidated (all the more, these findings are robust for a comprehensive set of tests, and when the poolability assumption is relaxed). The estimations are conducted on a reduce model between CO2 (SO2) and GDP for a panel of 100 (97) countries spanned over the period 1950-2000.

On the other hand, Vollebergh et al. (2009) go beyond the standard econometric issues and emphasize the relevance of a proper identification strategy as a starting point in investigating the reduced form pollution-income nexus in panel data. Considering that one can distinguish between the impact of income and time effects on pollution, the authors argue that countries alike are characterized by identical time effects. Accordingly, the corroborated estimates of the income and time effects on CO2 and SO2 emissions for 24 OECD countries over the period 1960-2000, based on the pairwise differencing technique, show that the bell-shaped pattern holds only for SO2 emissions (i.e. a locally regulated pollutant). Overall, the work of Vollebergh et al. (2009) may suggest that imposing different identifying restrictions for the exogenous variable (income) and control variable (time) yield to different model specifications, and in turn, to different findings regarding the pollution-income patterns. Besides, the authors establish a solid link between the theoretical models on EKC (see e.g. Brock & Taylor, 2005, 2010; Ordás Criado et al., 2011), and the minimal set of requirements needed for the identification of pollution-income nexus in EKC context.

In addition, Stern (2010) addresses both the issues pointed by Wagner (2008) and Vollebergh et al. (2009), namely the higher order terms of integrated income variable, the cross-sectional dependence, and the identification of income and time effects in EKC reduced models, through the between estimation technique. Using the same datasets for CO2 and SO2 emissions as Wagner (2008) and Vollebergh et al. (2009), the author shows that overall the results do not validate the traditional EKC hypothesis. In the same vein, the study of Stern et al. (2017) considers both the problems raised by Wagner (2008) and Volleberg et al. (2009) and also the omitted variable bias of between estimator employed in Stern (2010). As such, to mitigate their related undesirable effects on EKC results, the authors suggest working to long-run growth rates of pollution and income variables, while adding additional factors to account for the variation around the trend. The findings indicate that the EKC is not at work both for the full sample of CO2 and SO2 emissions. Moreover, Sen et al. (2016) use a slightly modified identification strategy for income and time effects, based on the pairwise differencing approach as Vollebergh et al. (2009), and further control for the potential issues caused by nonstationarity, employing nonlinear nonstationary parametric and nonparametric techniques. The overall findings indicate that the time effects do not have the power to detract the positive income effects, pointing out that the regional CO2 EKC hypothesis is not at work for the period 1950–2010.

Here, we discussed some of the latest most influential studies that couple the EKC with the relevance of identification procedures. The general idea of these studies lies in the fact that a large part of the empirical EKC literature lacks in providing a (reasonable) identification strategy, which reflects in misleading findings concerning its validity and the computation of associated turning point. Consequently, the identification of the pollution-growth nexus should not be "taking as is given", but rather assembled through convincing assumptions and investigated using appropriate econometric tools.

I.3. CO2 emissions stylized facts: a short descriptive empirical exercise

Clear evidence of deterioration in the quality of the environment is the sharp increase in greenhouse gas (GHG) emissions following human activities, in the post-industrial period, compared to the levels recorded prior to it. Also, CO2 is considered to be the greatest environmental threat, given the rapidity that its concentrations have increased over the years. During the pre-industrial period, the atmospheric CO2 concentration resulting from the combustion of fossil fuels is about 280 parts per million (ppm)[7], while in 2016, it reaches about 403 ppm, on average. Put differently, due to fossil fuel combustion and cement production, in 2016, the atmospheric CO2 is 145% above pre-industrial levels (see World Meteorological Organization, 2017).[8]

Moreover, the CO2 emissions account for 72% of global GHG emissions in 2016, while 50% of this CO2 emissions come from electricity and heat production together with the industry sector. According to Olivier et al. (2017), the top six CO2 emitters in 2016 are China, the United States (US), India, the Russian Federation, Japan, and the European Union(28) (EU28), being responsible for approximatively 68% and 63% of total global CO2 and total GHG emissions, respectively. However, in 2016, the CO2 emissions decline in the Russian Federation (−2.1%), US (−2.0%), Japan (−1.2%) and China (−0.3%), while an increase is registered in India (4.7%) and the EU(28) (0.2%) (Olivier et al. 2017). Besides, the CO2 emissions are just an example of an air pollutant that contributes to the degradation of the environment, but the spectrum is much broader (e.g. air, water, land, noise, and light pollutants). Indeed, a vast majority of empirical studies have used CO2 emissions as a proxy for environmental degradation (see e.g. Tables I.2-3 in the next section). Perhaps, its importance to climate change and data availability have determined the researchers to focus more on its related impacts, in comparison to other types of pollutants.

Consequently, considering four out of six top CO2 emitters mentioned above [i.e. China, India, the Russian Federation, and the EU(28)], and also the global level (i.e. the World), we illustrate the relationship between CO2 emissions and GDP per capita

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[7] =number of molecules of the gas per million (106) molecules of dry air.

[8] https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/GHG_Bulletin_13_EN_final_1_1.pdf?LGJNmHpwKkEG2Qw4mEQjdm6bWxgWAJHa.

descriptively[9], using both descriptive and nonparametric statistical techniques. Regarding the nonparametric techniques, we employ the local linear, local polynomial, and lowess nonparametric regressions models to better disentangle the pattern between CO2 pollution and economic growth. In doing so, we consider the standard specification of a general nonparametric model as follows:

$$y = \phi(x) + \varepsilon \tag{1}$$

We proxy environmental degradation by CO2 emissions per capita and economic growth by GDP per capita. The data are collected from the World Bank (2018) and the Janssens-Maenhout et al. (2017), for the period 1970-2016[10]. Next, equation (1) becomes:

$$CO2 = \phi(GDP) + \varepsilon \tag{2}$$

The CO2 is the endogenous variable, GDP is the predictor variable and $\varepsilon \sim NID(0, \sigma^2)$ the error term. $\phi(.)$ denotes the unknown smooth continuous function, whose functional form is not specified, i.e. is estimated based on data.[11]

Column (a) from Figure 1 displays the evolution of CO2 emissions and GDP for each country. In contrast, column (b) and column (c) shows the scatter plot between indicators, and the curve fitting of nonparametric regressions[12], respectively. First, we can observe that China, India, and the World exhibit a relatively smooth monotonically increasing relationship. At the same time, in the EU(28), and the Russian Federation, the nonlinearities are more pronounced. Second, overall, the pollution decreases with economic development in the EU(28), and we note the opposite in the remaining cases. Third, judging at the descriptive level, the EKC hypothesis seems to hold only for the Russian Federation. Altogether, the straightforward descriptive analysis from Figure I.1 emphasizes some important disparities related to the relationship between CO2 emissions and growth among countries considered. In the next section, we aim at

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[9] We exclude Japan and the US from our analysis, considering that they belong to the group of developed countries. However, we keep the EU(28) and include the World as they also comprise the developing and transition countries.

[10] Due to data availability for the EU(28), the Russian Federation, and at the global level, the period covered is 1990-2016. Also, in the empirical analysis, we use the natural logarithm of the data.

[11] For more information related to nonparametric regression models, see Cleveland (1979), Cleveland (1981), Robinson (1983), Cleveland & Devlin (1988), Cleveland & Loader (1996), Henderson & Parameter (2015), among others.

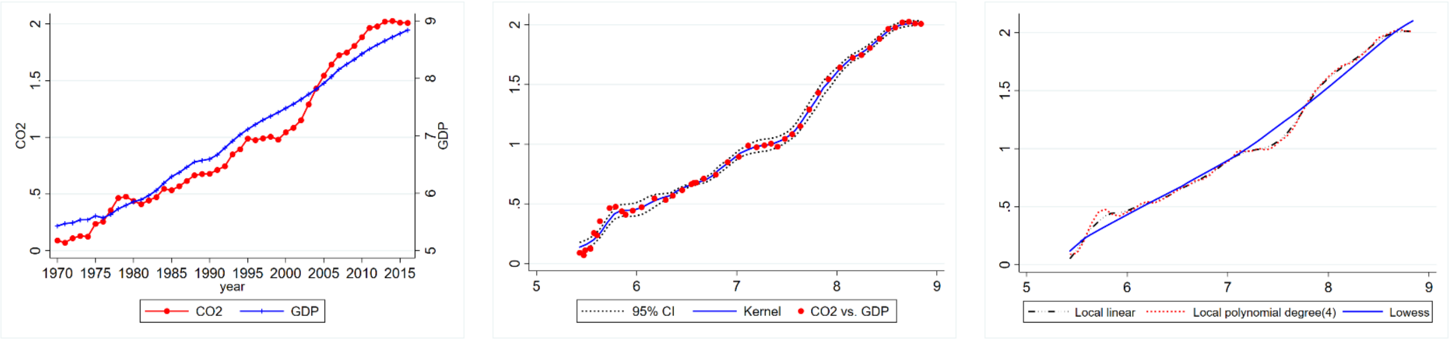
[12] We present the nonparametric regression models solely in a descriptive way, to better visualize and disentangle the pollution-growth nexus patterns. As such, we do not concern ourselves with variable nonstationary, cointegration, and other technical aspects related to time-series econometrics, these being beyond the aim of the present study. However, we note that some of those aspects are discussed during the paper theoretically.

presenting more in-depth empirical findings related to pollution-growth patterns of some recent studies that have tested the EKC hypothesis.

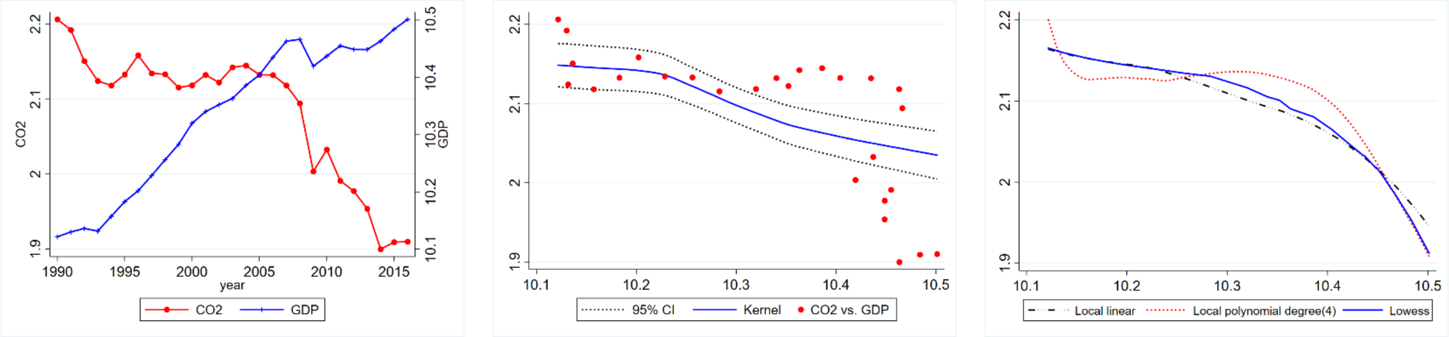
Figure I.1: CO2-GDP nexus graphs

(a) **(b)** **(c)**

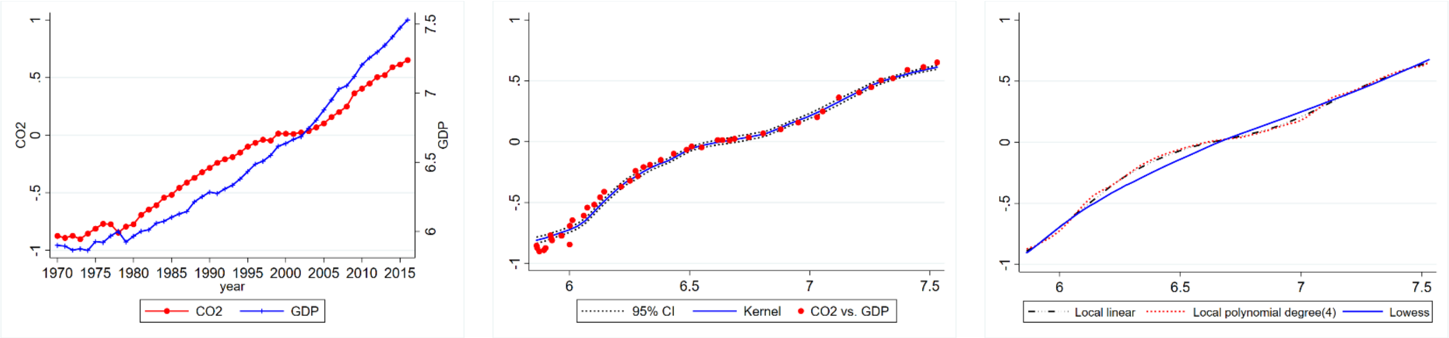
China



European Union(28)



India

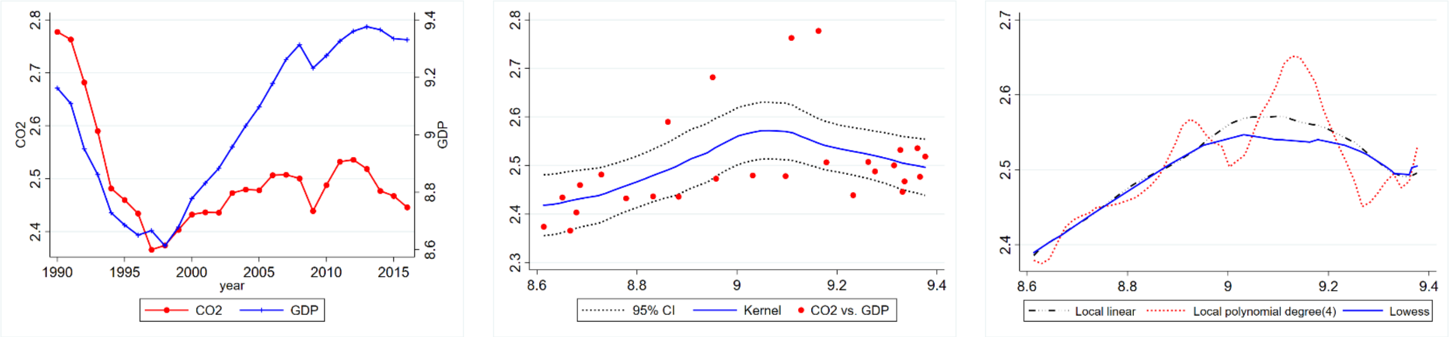


Notes: Column (a) shows the evolution of CO2 emissions and GDP per capita during the period analyzed. In column (b), along with the scatterplot, we fitted a local constant kernel regression with 95% confidence bands. In column (c), we performed a local linear, local polynomial of degree(4) and lowess regression. For the kernel, local linear, and local polynomial, we specify the default Epanechnikov function and (0.1) bandwidth. The default bandwidth option is used for lowess regression.

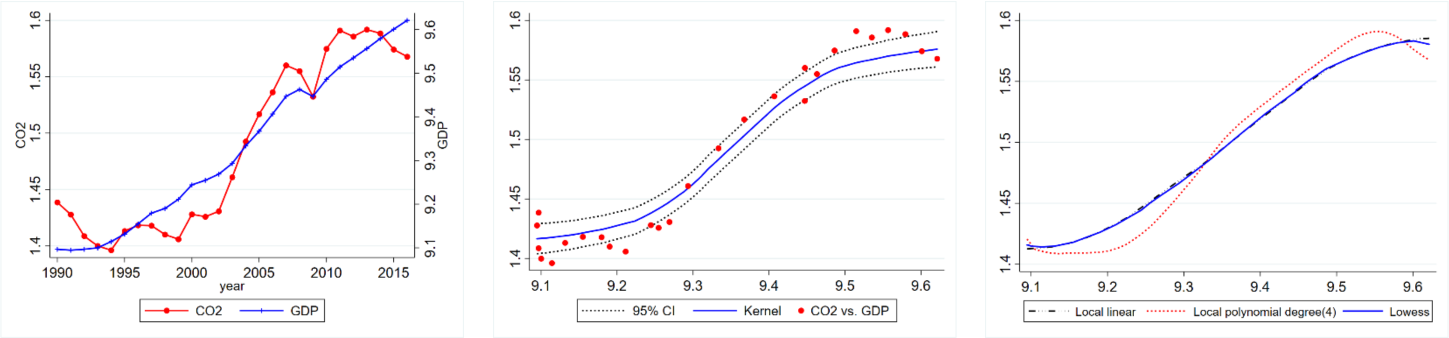
(**Figure I.1:** continued)

(a) **(b)** **(c)**

Russian Federation



World



Notes: Column (a) shows the evolution of CO2 emissions and GDP per capita during the period analyzed. In column (b), along with the scatterplot, we fitted a local constant kernel regression with 95% confidence bands. In column (c), we performed a local linear, local polynomial of degree(4) and lowess regression. For the kernel, local linear, and local polynomial, we specify the default Epanechnikov function and (0.1) bandwidth. The default bandwidth option is used for lowess regression.

I.4. Empirical literature review on EKC hypothesis

Our survey attempts to bring together some of the papers that have stressed the relationship between pollution and growth through the EKC hypothesis for developing and transition states, and are published in the literature during the period from 2010 to 2019.[13] In this respect, first, we divide our empirical literature review into three parts, namely panel data analysis, time-series analysis, and the last part, which addresses some of the new perspectives on modeling environmental degradation and economic growth nexus. The first two parts are related to the time-domain approach[14], while the last one lies both in time- and time-frequency domain. Moreover, each of these parts corresponds to one standalone subsection as below. Second, related to each paper, we provide information about the authors and the year of publication, sample, time span, empirical methodology, endogenous variable, pollution-growth pattern, and the estimated income turning point value.

I.4.1. Panel data analysis

Table I.2 displays the studies that use panel data models to explore the EKC hypothesis. For a more homogeneous view, we split the items based on the specific technique approached, namely cointegration techniques and other panel data methods.

The first strand of studies uses larger groups of countries, which are further divided according to income level, and test the EKC hypothesis for the subsamples of developing and/or transition countries (see Albulescu et al., 2019; Chen et al., 2019a, b; Kim et al., 2019; Ridzuan, 2019; Alvarado et al., 2018; Luzzati et al., 2018; Omri, 2018; Ulucak & Bilgili, 2018). The majority of these works use CO2 emissions as the leading indicator of environmental pollution, except Ulucak & Bilgili (2018), who proxy environmental degradation with the ecological footprint, and Chen et al. (2019a, b) and Ridzuan (2019) who use local pollutants. Moreover, two studies out of eight, namely Omri (2018) and Ulucak & Bilgili (2018), employ cointegration techniques, and both provide evidence in favor of the traditional EKC hypothesis. Likewise, the remaining works employ other panel data models, such as FE, RE, 2SLS, quantile regression models or semi-

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[13] We note that the review of the literature is not exhaustive, as we include studies published between 2010 and 2019 in popular journals on the subject, which meet the needs of the present work.

[14] The studies that embody both types of analysis are included in the section in which we consider that the primary analysis harmonize.

, and non-parametric models. Overall, the findings indicate a bell-shaped pattern between pollution and growth (with the notable exception of Luzzati et al., 2018, who find a monotonically increasing pattern for CO2 emissions and a U-shaped pattern for total primary energy supply). Regarding the turning point, Chen et al. (2019a, b), for the inverted-U shaped curve, estimate that its value in per capita terms equals 9112.90 US$ (PM2.5), 8102.51 US$ (PM10), and 9901.53 US$ (SO2), while Luzzati et al. (2018), for the U-shaped curve, find that its value is 498 US$ (total primary energy supply).

The second strand of studies investigates the EKC validity considering almost exclusively developing and transition economies samples. In this regard, Leblois et al. (2017) examine the deforestation rate EKC hypothesis for a group of 128 developing countries over the period 2002-2010. Based on the FE estimator, the results suggest the lack of a significant statistical link between environmental degradation and economic growth. In the same vein, Culas (2012) explores the relationship between the rate of deforestation and growth for 43 tropical developing nations, categorized by geographical region, namely, Latin America, Africa, and Asia. The findings reveal a bell-shaped pattern for Latin America and Africa, with a turning point computed at 6072 and 1483 US$ per capita, respectively. For Asia, the relationship is found to be U-shaped, and the level of GDP for which the rate of deforestation switches its trend is about 2320 US$ per capita. Also, Joshi & Beck (2018) point out that the relationship between CO2 emissions and growth for 87 non-OECD countries is monotonically increasing. Hove & Tursoy (2019) and Özokcu & Özdemir (2017) also test the EKC hypothesis for 24 and 52 emerging countries, respectively. The former authors show that the pattern is inverted-U shaped (U-shaped) for nitrous oxide emissions (CO2 emissions and fossil fuel consumption). In contrast, the latter authors unveil an *N*-shaped pattern for CO2 emissions.

Furthermore, to examine the pollution-growth pattern, several researchers use specific group of countries, namely MENA or Middle East states (Arouri et al., 2012; Ozcan, 2013; Charfeddine & Mrabet, 2017), BRIC states (Pao & Tsai, 2010, 2011), African states (Osabuohien et al., 2014; Awad, 2019), ASEAN or Asian states (Hanif et al., 2019; Nasir et al., 2019), CEE states (Lazăr et al., 2019), SAARC states (Waqih et al., 2019), or newly industrialized states (Destek & Sarkodie, 2019). As such, Arouri et al. (2012) validate the CO2 EKC hypothesis for 12 MENA states covering the period 1981-2005. The turning point of CO2 emissions is found for a GDP level of 37,263 US$ per capita. Charfeddine &

Mrabet (2017) test the EKC hypothesis for ecological footprint using a sample of 15 MENA countries observed over the period 1995-2007. The empirical findings suggest a bell-shaped pattern for the whole sample and oil-exporting countries and a U-shaped pattern for non-oilexporting countries. Likewise, the results provided by Ozcan (2013), based on the FMOLS estimator, unveil a U-shaped pattern between CO2 emissions and growth, with an income threshold equals to 8.23 in logs. The study is conducted for 12 Middle East nations, span over the period from 1990 to 2008. Also, using cointegration techniques, Pao & Tsai (2010, 2011) confirm the presence of the bell-shaped pattern between CO2 emissions and growth in BRIC countries. The computed income turning points for the convex curve are 5.638 and 5.393 in logs, respectively. Moreover, Awad (2019) for 46 African states and Osabuohien et al. (2014) for 50 African states find evidence in favor of the EKC hypothesis, both for CO2 emissions and air pollution measured as mean annual exposure, and CO2 and PM10 emissions, respectively. In the same vein, for 15 developing Asian states using the ARDL approach, Hanif et al. (2019) validate the CO2 EKC hypothesis, while Nasir et al. (2019) for 5 ASEAN economies using FMOLS and DOLS estimators unveil a monotonically increasing pattern. Besides, the findings of Destek & Sarkodie (2019) for 11 newly industrialized countries, and Waqih et al. (2019) for 4 SAARC countries, using panel cointegration techniques, reveal a bell-shaped pattern for ecological footprint and CO2 emissions, respectively. Also, Lazăr et al. (2019) unveil a monotonically increasing pattern between economic growth and a series of pollution indicators, such as CO2 emissions, SO2 emissions, biocapacity, and ecological footprint. The authors employ a series of heterogeneous panel estimators, namely MG-FMOLS, MG, and AMG, for CEE states over the period 1996-2015. On this last point, it is worth noting that all these papers use panel cointegration techniques to investigate the pollution-growth nexus pattern.

The third strand of works uses panel data models to investigate the pattern between pollution and growth for Chinese provinces. In this regard, a group of studies shows that EKC is at work for Chinese provinces (Du et al., 2012; Chen & Chen, 2015; Hao et al., 2016; Li et al., 2016; Wang et al., 2016; Zhang et al., 2017; Chen et al., 2018; Hao et al., 2018b; Wenbo & Yan, 2018; Liu et al., 2019), while other studies reveal either an inverted-*N* shaped pattern (Liu et al., 2015; Kang et al., 2016; Li et al., 2019; Zhao et al., 2019) or a monotonically increasing pattern (Yang et al., 2015). More specifically, evidence in favor of EKC hypothesis is found for CO2 emissions (Du et al., 2012; Chen &

Chen, 2015; Li et al., 2016; Chen et al., 2018; Wenbo & Yan, 2018; Liu et al., 2019), CO2 emission intensity (Wenbo & Yan, 2018), SO2 emissions (Wang et al., 2016), coal consumption (Hao et al., 2016), wastewater and solid waste emissions (Li et al., 2016), COD and NH3-N emissions (Zhang et al., 2017), and soot and dust emissions (Chen et al., 2018). Moreover, the inverted-*N* shaped pattern occurs for CO2 emissions (Liu et al., 2015; Kang et al., 2016), SO2 emissions and solid waste (Zhao et al., 2019), and carbon intensity of human wellbeing (Li et al., 2019). Besides, Yang et al. (2015) find a monotonically increasing relationship for CO2 emissions and industrial gas, while Hao et al. (2018b) a U-shaped pattern for the environmental quality index, which translates in a bell-shaped one, as the dependent variable is an inverse indicator of environmental degradation. With respect to the income turning points, the recent studies of Li et al. (2019) and Zhao et al. (2019) show that their estimated values based on the inverted-*N* shaped curve are 850 and 110,000 yuan per capita for carbon intensity of human wellbeing, and 4057 and 24,484 yuan per capita (4298 and 33,355 yuan per capita) for SO2 emissions (solid waste), respectively. Moreover, for CO2 emissions, Chen & Chen (2015) and Liu et al. (2019) find an income peak of the bell-shaped curve equals to 49,813.79 and 55,297.3 yuan per capita, respectively. Hao et al. (2016) show that the value of the income threshold of the coal consumption bell-shaped curve ranges between 18,456 and 23,585 yuan per capita (39,692-48,521 yuan per capita) for classical panel models (spatial panel models). Additionally, studies such as Du et al. (2012), Kang et al. (2016), Li et al. (2016), Hao et al. (2018b), and Li et al. (2019) find turning points that lie outside the income range values. However, the EKC patterns and the estimated turning points depend on the sample size (i.e. the number of provinces included), the period analyzed, and the proxy used for environmental degradation.

Other studies examine the EKC hypothesis either for the economic sectors of Iranian provinces (Dehghan Shabani & Shahnazi, 2018), metropolitan regions of Republic of Korea (Park & Lee, 2011), Indian cities (Sinha & Bhattacharya, 2017), or Chinese cities (Stern & Zha, 2016; Hao et al., 2018a). On the one hand, the results of Dehghan Shabani & Shahnazi (2018) based on the DOLS estimator illustrate that the EKC is at work for the period 2002-2013 for all economic sectors (i.e. agricultural, industrial, transportation, and services sector). However, the estimated turning points, namely 0.134 in logs (agricultural sector), 0.918 in logs (industrial sector), 0.880 in logs (transportation sector), and 0.555 in logs (services sector), are above the average GDP value for each sector. On the other hand, Sinha & Bhattacharya (2017) use a sample of 139 Indian cities and test the SO2 EKC hypothesis for the period 2001-2013. Overall, the authors find a bell-shaped pattern for industrial and industrial high-income areas, while for industrial lowincome areas, the relationship seems to be *N*-shaped. Also, for residential areas, the SO2-growth nexus pattern does not exhibit nonlinearities. The SO2 emissions peak varies from 18.87 to 1110.10 Rs. Lacs, for the electricity consumption model, and from 20.51 to 1564.36 Rs. Lacs, for the petroleum consumption model, according to income level subsamples. Both the lowest values, i.e. 18.87 and 20.51, are situated outside the income range values. In the same vein, Stern & Zha (2016) investigate the EKC hypothesis for 50 Chinese cities over the period 2013-2014 using both the growth rates and traditional EKC models. Overall, according to both approaches, the pattern between pollution and growth seems to be U-shaped. Also, the computed turning point based on the traditional model and FE estimator is 453,454 RMB per capita for PM2.5 (yet not statistically significant) and 87,493 RMB per capita for PM10. Also, Hao et al. (2018a) test the pollution-growth nexus pattern for 283 Chinese cities span over 2003-2010. The authors use three environmental degradation indicators, namely SO2 emissions, industrial soot emissions, and industrial wastewater discharge, and apply the GMM technique. They show that the inverted-U shaped curve holds for soot emissions, while for SO2 emissions, the pattern is U-shaped. Furthermore, using a dataset of 16 metropolitan regions from the Republic of Korea, covering the period 1990-2005, Park & Lee (2011) show that relationship form between SO2 emissions and growth is *N*-shaped (with the peak equals to 5700 US$ and the trough equals to 28,000 US$ per capita). Conversely, a U-shaped curve is at work for CO2 emissions (with the peak that ranges from 26,400 US$ to 30,000 US$ per capita) and NO2 emissions (with the peak equals to 27,600 US$ per capita).

Table I.2: Panel data literature survey

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
			Cointegration analysis			
Awad (2019)	46 African countries	1990-2017	FMOLS, DOLS	CO2 emissions, air pollution measured as mean annual exposure	Bell-shape	-
Dehghan Shabani & Shahnazi (2019)	28 provinces of Iran	2002-2013	DOLS	CO2 emissions	Bell-shape	0.134* in logs (agricultural sector), 0.918* in logs (industrial sector), 0.880* in logs (transportation sector), 0.555* in logs (services sector)
Destek & Sarkodie (2019)	11 newly industrialized countries	1977-2013	AMG	Ecological footprint	Bell-shape	-
Hanif et al. (2019)	15 Asian developing countries	1990-2013	ARDL	CO2 emissions	Bell-shape	-
Lazăr et al. (2019)	11 CEE countries	1996-2015	MG-FMOLS, MG, AMG	CO2 emissions, SO2 emissions, biocapacity, ecological footprint	Monotonically increasing	-
Nasir et al. (2019)	5 ASEAN countries	1982-2014	FMOLS, DOLS	CO2 emissions	Monotonically increasing	-
Waqih et al. (2019)	4 SAARC countries	1986-2014	ARDL, FMOLS	CO2 emissions	Bell-shape	-
Omri (2018)	69 countries (high income countries, upper-middle income countries, lower-middle income countries, lowincome countries)	2001-2011	FMOLS	CO2 emissions	Bell-shape (lower-middle income countries, low income countries)	-
Ulucak & Bilgili (2018)	45 countries (low income countries, middle income countries, high income countries)	1961-2013	CUP-FM, CUP-BC	Ecological footprint	Bell-shape (low income countries)	-
Charfeddine & Mrabet (2017)	15 MENA countries	1975-2007	FMOLS, DOLS	Ecological footprint	Bell-shape (panel, oil-exporting countries), U-shape (non-oil-exporting countries)	-

(**Table I.2:** continued)

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Osabuohien et al. (2014)	50 African countries	1995-2010	DOLS	CO2 emissions, PM10 emissions	Bell-shape	-
Ozcan (2013)	12 Middle East countries	1990-2008	FMOLS	CO2 emissions	U-shape	8.23 in logs
Arouri et al. (2012)	12 MENA countries	1981-2005	CCE-MG	CO2 emissions	Bell-shape	37,263 US$ per capita {constant 2005}
Pao & Tsai (2011)	BRIC countries	1980-2007, 1992-2007 (Russia)	Cointegration techniques	CO2 emissions	Bell-shape	5.638 in logs
Pao & Tsai (2010)	BRIC countries	1971-2005, 1990-2005 (Russia)	Cointegration techniques	CO2 emissions	Bell-shape	5.393 in logs
Other panel data models						
Albulescu et al. (2019)	14 Latin America countries (high-income countries, low income countries)	1980-2010	FE, RE, FE panel quantiles regression	CO2 emissions	Bell-shape for the first quantiles (low income countries)	-
Chen et al. (2019)	62 countries (35 more developed countries, 27 less developed countries)	1970-2012	FE, 2SLS	PM2.5 emissions, PM10 emissions, SO2 emissions	Bell-shape (27 less developed countries)	9112.90 US$ per capita (PM2.5), 8102.51 US$ per capita (PM10), 9901.53 US$ per capita (SO2) {constant 2010}
Hove & Tursoy (2019)	24 emerging economies	2000-2017	GMM	CO2 emissions, fossil fuel energy consumption, nitrous oxide emissions	Bell-shape (nitrous oxide emissions), U-shape (CO2 emissions, fossil fuel consumption)	-
Kim et al. (2019)	131 countries (developing countries, advanced countries)	1960-2013	Panel data IV quantile regression	CO2 emissions	Bell-shape (developing countries)	-
Li et al. (2019)	30 provinces of China	1995-2016	Spatial panel models	Carbon intensity of human wellbeing	Inverted-*N* shape	850 yuan per capita and 110,000* yuan per capita {constant 2000}
Liu et al. (2019)	29 provinces of China	1996-2015	FE panel data partially linear additive model	CO2 emissions	Bell-shape	55,297.3 yuan per capita {deflated to the 1996 consumer price index}

(**Table I.2:** continued)

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Ridzuan (2019)	170/174 countries (high income countries, low income countries)	1991-2010	Driscoll and Kraay nonparametric variance-covariance estimator	SO2 emissionas	Bell-shape (low income countries)	-
Zhao et al. (2019)	30 provinces of China	1999-2017	Spatial regression models	SO2 emissions, solid waste, wastewater discharge	Inverted-*N* shape (SO2 emissions, solid waste)	4057 and 24,484 yuan per capita (SO2), 4298 and 33,355 yuan per capita (solid waste) {constant 2000}
Alvarado et al. (2018)	151 countries (high income countries, middle-high income countries, middle-low income countries, low income countries)	1980-2016	FE, RE	CO2 emissions	Bell-shape (middle-low income countries)	-
Chen et al. (2018)	30 provinces of China	1998-2012	GMM	CO2 emissions, soot and dust emissions, wastewater discharge	Bell-shape (CO2 emissions, soot and dust emissions)	-
Hao et al . (2018a)	283 Chinese cities	2003-2010	GMM	SO2 emissions, industrial soot emissions, industrial wastewater discharged	Bell-shape (soot emissions), U-shape (SO2 emissions)	-
Hao et al. (2018b)	30 provinces of China	2006-2015	Nonspatial models (pooled OLS, spatial FE, time period effects, spatial and time-period effects), spatial Durbin model	Environmental quality index	*N*-shape (which translates in a bell-shape curve as the dependent variable is an indirect indicator of environmental degradation)	9500 RMB per capita 420,000* RMB per capita {constant 2005}

(**Table I.2:** continued)

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Joshi & Beck (2018)	87 non-OECD	1995-2010	GMM	CO2 emissions	Monotonically increasing	-
Luzzati et al. (2018)	115 countries (low income countries, middle income countries, high income countries)	1971-2015	Semiparametric model, FGLS	CO2 emissions, total primary energy supply	Monotonically increasing (low income countries; CO2 emissions), U-shape (low income countries; total primary energy supply)	498 US$ per capita (total primary energy supply) {constant 2010}
Wenbo & Yan (2018)	30 provinces of China	2004-2015	GMM	CO2 emissions, CO2 emissions intensity	Bell-shape	-
Leblois et al. (2017)	128 developing countries	2002-2010	FE	Deforestation rate	No statistical link	-
Özokcu & Özdemir (2017)	52 emerging countries	1980-2010	FE, Driscoll-Kraay Standard Errors	CO2 emissions	*N*-shape	-
Sinha & Bhattacharya (2017)	139 Indian cities	2001-2013	FE, RE	SO2 emissions	Electricity model: bell-shape (industrial, industrial high income areas), *N*-shape (industrial low income areas), linear (residential, residential low income areas) Petroleum model: bell-shape (industrial, industrial high income areas), *N*-shape (industrial low income areas), linear (residential areas), monotonically increasing (residential low income areas), monotonically decreasing (residential medium income areas)	Electricity model: 452.24 Rs. Lacs (industrial), 1110.10 Rs. Lacs (industrial high income), 18.87* Rs. Lacs and 5604.37 Rs. Lacs (industrial low income) Petroleum model: 287.52 Rs. Lacs (industrial), 1564.36 Rs. Lacs (industrial high income), 20.51* Rs. Lacs and 5799.40 Rs. Lacs (industrial low income)

(**Table I.2:** continued)

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Zhang et al. (2017)	27 provinces of China	(a) 1990-2014, (b) 2001-2014	FE, B-spline regression (parametric and semiparametric models), cointegration analysis	(a) COD emissions (b) NH3-N emissions	Bell-shape	-
Kang et al. (2016)	30 provinces of China	1997-2012	Nonspatial model (pooled OLS, spatial FE, time-period FE, spatial and time-period FE), spatial Durbin model (spatial FE, time-period FE, spatial and time- period FE, spatial RE and time	CO2 emissions	Inverted-*N* shape	1545.03* and 57,308.26 RMB per capita (nonspatial two-way FE models), 1480.30* and 82,677.27* RMB per capita (SDM FE models) {constant 1997}
Li et al. (2016)	28 provinces of China	1996-2012	GMM, ARDL (PMG, MG, DFE)	CO2 emissions, industrial wastewater emissions, industrial waste solid emissions	Bell-shape	10,403.96* US$ per capita (CO2 emissions), 1063.88 US$ per capita (wastewater emissions), 23,076.99* US$ per capita (waste solid emissions) {constant 2012}
Hao et al. (2016)	29 Chinese provinces	1995-2012	Nonspatial panel models (pooled OLS, individual FE, time FE, individual and time FE), spatial Durbin models (individual and time FE, individual and time FE bias-corrected, random individual effects, fixed time effects)	Coal consumption	Bell-shape	18,456 to 23,585 yuan per capita (panel models), 39,692 to 48,521 yuan per capita (spatial panel models) {constant 1978}
Stern & Zha (2016)	50 Chinese cities	2013-2014	FE	PM2.5 emissions, PM10 emissions	U-shape	453,454* RMB per capita (PM2.5; not statistically significant), 87,493 RMB per capita (PM10)

(**Table I.2:** continued)

Author	**Sample**	**Period**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Wang et al. (2016)	Chinese provinces	1990-2012	Parametric and semiparametric FE	SO2 emissions	Bell-shape	-
Liu et al. (2015)	31 provinces of China	1997-2010	OLS FE	CO2 emissions	Inverted-*N* shape	127.41 and 10,201.29 yuan per capita {constant 1997}
Chen & Chen (2015)	31 Chinese provinces	1985-2010	Nonparametric and parametric regression	CO2 emissions	Bell-shape	49,813.79 yuan per capita (10.81 in logs)
Yang et al. (2015)	29 provinces of China	1995-2010	Extreme Bound Analysis (General Sensitivity Test), bootstrapping method	CO2 emission, SO2 emission, industrial dust, industrial waste gas, industrial smoke, industrial SO2 emissions, industrial wastewater	Monotonically increasing (CO2 emissions, industrial gas)	-
Culas (2012)	43 tropical developing nations (Latin America, Africa, Asia)	1971-1994	FE, RE	Rate of deforestation	Bell-shape (Latin America, Africa), U-shape (Asia)	6072 US$ per capita (Africa), 1483 US$ per capita (Latin America), 2320 US$ per capita (Asia) {constant 1995}
Du et al. (2012)	29 provinces of China	1995-2009	FE, Biased-corrected LSDVC, GMM	CO2 emissions	Bell-shape	1.214e+15*/1.372e+14* /1.563e+14* yuan per capita {constant 1995}
Park & Lee (2011)	16 metropolitan regions in Republic of Korea	1990-2005	FE, RE, RCM	SO2 emissions, CO emissions, NO2 emissions	*N*-shape (SO2), U-shape (CO, NO2)	5700 and 28,000 US$ per capita (SO2), 26,400 to 30,000* US$ per capita (CO), 27,600 US$ per capita (NO2) {constant 2000}

Notes: ARDL-Autoregressive Distributed Lag; ASEAN-Association of Southeast Asian Nations; CEE-Central and Eastern Europe; CCE-MG-Common Correlated Effects Mean Group; COD-Chemical Oxygen Demand; CO2-Carbon Dioxide; CUP-BC-Continuously Updated Bias Corrected; CUP-FM-Continuously Updated Fully Modified; DFE-Dynamic Fixed Efffects; DOLS-Dynamic OLS; FMOLS-Fully Modified OLS; FE-Fixed Effects; GMM-Generalized Method of Moments; MG-Mean Group; NH3-N-Discharge and Ammonia Nitrogen; NO2-Nitrogen dioxide; PMG-Pooled Mean Group; PSTR-Panel Smooth Transition Regression; RE-Random Effects; RMC-Random Coefficient Model; SAARC-South Asian Association for Regional Cooperation; SO2-Sulfur Dioxide; VAR-Vector Autoregression; VECM-Vector Error Correction Model; 2SLS-Two-Stage Least Squares. The "-" indicates that the turning point is not computed, while the "*" indicates that the estimated turning point is out of sample values. When both long- and short-run analysis is present, we report the pollution-growth nexus pattern and turning point associated with the long-run results. The methodology column gives information about the technique used in investigating the pollution-growth pattern, even if the respective study comprises other statistical and econometric techniques. All the information contained in the table represents our interpretation of the results in the analyzed studies.

I.4.2. Time-series analysis

The country-specific works that tackle the relationship between growth and environmental pollution through the EKC hypothesis are listed in Table I.3. At first glance, we can observe that most researchers use the ARDL bounds test approach technique to investigate the validity of the EKC hypothesis. Also, the FMOLS and DOLS techniques appear frequently as econometric tools in investigating pollution-growth pattern.

First, focusing on China, several contributions (Jalil & Feridun, 2011; Jayanthakumaran et al., 2012; Alam et al., 2016; Adebola Solarin et al., 2017; Wolde-Rufael & Idowu, 2017; Riti et al., 2017; Dong et al., 2018; Chen et al., 2019) find empirical evidence in favor of traditional CO2 EKC hypothesis. Also, while Riti et al. (2017) estimate the peak value of the bell-shaped curve within the income range values, the findings of Jalil & Feridun (2011) and Dong et al. (2018) indicate that the turning point lies outside the sample values. However, the authors cover different periods, and in particular, the three studies which compute the bell-shaped curve maxima, span the period 1978-2006 (Jalil & Feridun, 2011), 1970-2015 (Riti et al., 2017), and 1993-2016 (Dong et al., 2018). Conversely, Onafowora & Owoye (2014) conclude that the pattern between CO2 emission and growth is *N*-shaped, while the associated income peak is equal to 17.050 in logs, and outside of sample values. Moreover, based on the FMOLS estimator, Yao et al. (2019) reveal a monotonically increasing relationship for CO2 emissions. Besides, using environmental quality index (i.e. an inverse indicator of environmental pollution), the results provided by Wang et al. (2015) validate the EKC hypothesis for Gansu province in China. More specifically, the authors employ a Bayesian VAR model, and find a U-shaped pattern between the indicators for the period 1980-2012, with the estimated income threshold value of 2273 RMB per capita.

Second, for Malaysia, the empirical findings seems to cover a broad spectrum of patterns, such as the traditional bell-shaped (Saboori et al., 2012; Saboori & Sulaiman, 2013b; Lau et al., 2014; Ali et al., 2017; Azam et al., 2018), the U-shaped (Begum et al., 2015; Chandran & Tang, 2013), the inverted-*N* shaped (Bekhet & Othman, 2018), the monotonically increasing relationship (Azlina et al., 2014), or no statistical link (Saboori & Sulaiman, 2013a). Furthermore, Saboori et al. (2012) and Saboori & Sulaiman (2013b) unveil that the computed GDP maxima of the bell-shaped curve for the period 1980-2009 is 4700 US$ per capita, and depending on the model 5378/5825/6003/8267 US$ per capita, respectively. However, it is worth noting that the estimated peak value of Saboori & Sulaiman (2013b) lies outside the GDP sample values. As well, considering the inverted-*N* shaped curve, Bekhet & Othman (2018) reveal that the pollution switches its trend for a GDP value of 170.9 RM billion (trough) and 2841.9 RM billion (peak). However, the income peak lies outside the sample range values.

Third, with respect to CO2 EKC for Indonesia, two studies show that the bell-shaped pattern is supported by data (Alam et al., 2016; Sugiawan & Managi, 2016), while other three studies reveal mixed results, namely a monotonically increasing relationship (Yao et al., 2019; Chandran & Tang, 2013) or a U-shaped pattern (Saboori & Sulaiman, 2013a). Concerning the income threshold, Sugiawan & Managi (2016) estimate an out of sample turning point of 7729 US$ per capita. Besides, Chandran & Tang (2013), along with Malaysia and Indonesia, examine the EKC hypothesis for Thailand, Singapore, and the Philippines, for the period 1971-2011. Overall, the empirical findings reject a long-run relationship between variables for the Philippines and Singapore, while for Thailand, the pattern seems to be convex, invalidating the EKC hypothesis. More recently, the empirical analysis of Azam et al. (2018) leads to the same conclusions, namely the presence of the U-shaped pattern for Thailand, and no statistically significant results for Singapore. Opposite, using DOLS estimator, Katircioğlu (2014) shows that the EKC is valid for Singapore, for the period 1971-2010. Also, using the same sample of countries as Chandran & Tang (2013) to test the CO2 EKC hypothesis, Saboori & Sulaiman (2013a) reveal that the inverted-U shaped pattern holds only for Singapore and Thailand. The income peak value is 8.65 in logs (Singapore), and 7.47 in logs (Thailand).

Fourth, the strand of papers that target the CO2 EKC hypothesis for India show that in most cases the bell-shaped pattern holds (Jayanthakumaran et al., 2012; Tiwari et al., 2013; Kanjilal & Ghosh, 2013; Boutabba, 2014; Shahbaz et al., 2015; Wolde-Rufael & Idowu, 2017; Adebola Solarin et al., 2017; Sinha & Shahbaz, 2018; Yao et al., 2019), with the notable exception of Alam et al. (2016), who find that CO2 pollution increases along with economic growth. With regard to the turning point, authors such as Tiwari et al. (2013) and Boutabba (2014) show that its estimated value is 28,131 Indian rupees per capita for the period 1996-2011, and 19,380 Indian rupees per capita for the period 1971-2008, respectively. Also, Yao et al. (2019) find that the threshold arises for an income value of 6.61 in logs, while Sinha & Shahbaz (2018) identify an out of sample turning point which corresponds to a value of 2937.77 US$ per capita.

Fifth, the group of scholars that focus on Tunisia, unveil both a nonlinear bell-shaped relationship between CO2 pollution and growth (Shahbaz et al., 2014; Farhani et al., 2014) and a U-shaped pattern (Ben Jebli & Ben Youssef, 2015). Also, for the period 1961-2004, the results of Fodha & Zaghdoud (2010) reveal an inverted-U shaped pattern for SO2 (with an associated GDP turning point value of 1200 US$ per capita), and a monotonically increasing one for CO2.

In the case of Pakistan, Nasir & Ur Rehman (2011) and Danish et al. (2017) provide evidence that supports the EKC hypothesis for CO2 emissions, while according to Hussain et al. (2012), the pattern seems to be monotonically increasing. Moreover, according to Nasir & Ur Rehman's (2011) findings, the GDP threshold of the concave function is equal to 625 US$ per capita. As well, the studies of Charfeddine (2017) and Mrabet & Alsamara (2017) also provide contradictory findings for Qatar. Using a Markov switching equilibrium correction model for the period 1970-2015, Charfeddine (2017) validates the EKC hypothesis for CO2 emissions and carbon ecological footprint but fails to find evidence in favor of ecological footprint EKC (i.e. the results illustrate a U-shaped pattern). Conversely, Mrabet & Alsamara (2017), employing the ARDL bounds test approach, show that the relationship between CO2 and growth is U-shaped, whereas, for ecological footprint, the traditional bell-shaped curve is at work.

The studies which examine the pollution-growth pattern for Turkey reveal, depending on pollution indicator, either a bell-shaped pattern (Bölük & Mert, 2015; Pata, 2018; Zambrano-Monserrate et al., 2018a; Haug & Ucal, 2019), an U-shaped pattern (Haug & Ucal, 2019) or no statistical link (Haug & Ucal, 2019; Yao et al., 2019). Besides, concerning the income turning point, Bölük & Mert (2015) and Pata (2018) reveal that its estimated value lies outside the income range, and equals 9920 US$ and 14,360 US$ per capita, respectively. Conversely, Zambrano-Monserrate et al. (2018a) and Haug & Ucal (2019) find a within-sample turning point value equals to 9031.37 US$ and 7963.31 US$ per capita (6385.59 US$) for CO2 emissions (CO2 intensity), respectively.

Finally, several contributons that investigate the EKC hypothesis for other developing and transition economies unveil mixed results: (i) a monotonically increasing pattern [Al-Mulali et al. (2015) for Vietnam; Alshehry & Belloumi (2017) for Saudi Arabia; Zambrano-Monserrate et al. (2018) for Peru; Yao et al. (2019) for Russia]; (ii) a monotonically decreasing pattern [Pao et al. (2011) for Russia]; (iii) a U-shaped pattern [Ozturk & Al-Mulali (2015) for Cambodia; Halicioglu & Ketenci (2016) for Azerbaijan, Lithuania, Moldavia, Russia, and Tajikistan]; (iv) an inverted-U shaped pattern [Baek & Kim (2013) for Korea; Shahbaz et al. (2013) for Romania; Bouznit & Pablo-Romero (2016) for Algeria; Alam et al. (2016) for Brazil; Halicioglu & Ketenci (2016) for Armenia, Belarus, Estonia, Kyrgyzstan, Turkmenistan, and Uzbekistan; Ahmad et al. (2017) for Croatia; Pata (2018); Yao et al. (2019) for Brazil, South Africa, and South Korea]; (v) an *N*-shaped pattern [Onafowora & Owoye (2014) for Brazil, Egypt, Mexico, Nigeria, and South Africa]; (vi) an inverted-*N* shaped pattern [Onafowora & Owoye (2014) for South Korea]; (vii) and also no statistical link [Halicioglu & Ketenci (2016) for Georgia, Kazakhstan, Latvia, and Ukraine]. Likewise, Narayan & Narayan (2010), using the cointegration approach for a sample of 43 developing countries over the period 1980-2004, conclude that only in about 35% of the sample, the downward-bending curve is at work.

Furthermore, the authors who compute the associated income turning point of the specific function reveal the following results. On the one hand, Onafowora & Owoye (2014) show that the peak (i.e. 22.083 in logs) of the *N*-shaped curve for Brazil lies outside the sample range, while Yao et al. (2019) unveil that the peak (i.e. 10.57 in logs) of the bell-shaped curve lies within the income sample values. On the other hand, the researchers that estimate the income peak value for South Africa reveal a similar behavior. As such, according to Onafowora & Owoye (2014), the estimated threshold (i.e. 22.963 in logs) value lies outside the sample range, while Yao et al. (2019) find the opposite (the estimated threshold equals 8.75 in logs). For Korea, Baek & Kim (2013) and Yao et al. (2019) reveal that the turning point of the bell-shaped curve lies well within the income sample values. Also, the studies which estimate the income threshold for other states find values outside the sample range [Onafowora & Owoye (2014) for Egypt, Mexico, and Nigeria; Bouznit and Pablo-Romero (2016) for Algeria].

Table I.3: Time-series literature survey

Author	**Sample**	**Year**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Chen et al. (2019)	China	1980-2014	ARDL bounds test	CO2 emissions	Bell-shape	-
Huag & Ucal (2019)	Turkey	1974-2014	Linear and nonlinear ARDL bounds test approach	CO2 emissions, CO2 intensity, CO2 emissions from electricity and heat production, CO2 from manufacturing and construction, CO2 emissions from residential buildings, and commercial and public services, CO2 from transport	Bell-shape (CO2 emissions, CO2 intensity, CO2 from manufacturing and construction, CO2 emissions from residential buildings, and commercial and public services), U-shape (CO2 emissions from electricity and heat production), no statistical link (CO2 from transport)	7963.31 US$ per capita (CO2 emissions), 6385.59 US$ per capita (CO2 intensity) {constant 2010}
Yao et al. (2019)	17 major developing and developed countries	1990-2014	FMOLS, DOLS	CO2 emissions	Bell-shape (Brazil, India, South Africa, South Korea[†]), monotonically increasing (China, Indonesia, Russia), no statistical link (Turkey)	10.57 in logs (Brazil), 6.61 in logs (India), 8.75 in logs (South Africa), 9.74 in logs (South Korea)
Azam et al. (2018)	Malaysia, Singapore, Thailand	1990-2014	FMOLS	CO2 emissions	Bell-shape (Malaysia), U-shape (Thailand), no statistical link (Singapore)	-
Bekhet & Othman (2018)	Malaysia	1971-2015	ARDL bounds test, FMOLS, DOLS	CO2 emissions	Inverted-*N* shape	170.9 RM billion and 2841.9* RM billion {constant 2010}
Dong et al. (2018)	China	1993-2016	ARDL bounds test, FMOLS, DOLS, CCR	CO2 emissions	Bell-shape	96,680.47* yuan per capita {constant 1990}
Pata (2018)	Turkey	1971-2014	ARDL bounds test	CO2 emissions	Bell-shape	14,360* US$ per capita {constant 2010}
Sinha & Shahbaz (2018)	India	1971-2015	ARDL bounds test	CO2 emissions	Bell-shape	2937.77* US$ per capita
Zambrano-Monserrate et al. (2018a)	France, Germany, Greece, Portugal, Turkey	1974-2013	ARDL bounds test	Deforestration (arable land)	Bell-shape (Turkey)	9,031.37 US$ per capita {constant 2010}
Zambrano-Monserrate et al. (2018b)	Peru	1980-2011	ARDL bounds test	CO2 emissions	Monotonically increasing	-
Ali et al. (2017)	Malaysia	1971-2012	ARDL bounds test, DOLS	CO2 emissions	Bell-shape	-

(**Table I.3:** continued)

Author	**Sample**	**Year**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Alshehry & Belloumi (2017)	Saudi Arabia	1971-2011	ARDL bounds test	Transport CO2 emissions	Monotonically increasing	-
Charfeddine (2017)	Qatar	1970-2015	Markov switching equilibrium correction model	CO2 emissions, carbon ecological footprint, ecological footprint	Bell-shape (CO2 emissions, carbon ecological footprint), U-shape (ecological footprint)	-
Danish et al. (2017)	Pakistan	1970-2012	ARDL bounds test, FMOLS, DOLS, CCR	CO2 emissions	Bell-shape	-
Mrabet & Alsamara (2017)	Qatar	1980-2011	ARDL bounds test	CO2 emissions, ecological footprint	Bell-shape (ecological footprint), U-shape (CO2)	-
Riti et al. (2017)	China	1970-2015	ARDL bounds test, ARDL, FMOLS, DOLS	CO2 emissions	Bell-shape	744,665* billion US$ per capita {constant 2010}
Adebola Solarin et al. (2017)	China, India	1965-2013	ARDL bounds test	CO2 emissions	Bell-shape	-
Wolde-Rufael & Idowu (2017)	China, India	1974-2010 (China), 1971-2010 (India)	ARDL bounds test, FMOLS, DOLS	CO2 emissions	Bell-shape	-
Ahmad et al. (2017)	Croatia	1992Q1-2011Q1	ARDL bounds test, FMOLS, DOLS	CO2 emissions	Bell-shape	-
Alam et al. (2016)	Brazil, China, India, Indonesia	1970-2012	ARDL bounds test	CO2 emissions	Bell-shape (China, Brazil, Indonesia), monotonically increasing (India)	-
Bouznit & Pablo-Romero (2016)	Algeria	1970-2010	ARDL bounds test	CO2 emissions	Bell-shape	12.2*/10* in logs
Halicioglu & Ketenci (2016)	15 transition economies	1991-2013	ARDL bounds test, GMM	CO2 emissions	Bell-shape (Armenia, Belarus, Estonia, Kyrgyzstan, Turkmenistan, Uzbekistan), U-shape (Azerbaijan, Lithuania, Moldavia, Russia, Tajikistan), no statistical link (Georgia, Kazakhstan, Latvia, Ukraine)	-
Sugiawan & Managi (2016)	Indonesia	1971-2010	ARDL bounds test	CO2 emissions	Bell-shape	7729* US$ per capita {constant 2005}
Al-Mulali et al. (2015)	Vietnam	1981-2011	ARDL bounds test	CO2 emissions	Monotonically increasing	-
Begum et al. (2015)	Malaysia	1970-2009	ARDL bounds test, DOLS, Sasabuchi-Lind-Mehlum U tests	CO2 emissions	U-shape	-

(**Table I.3:** continued)

Author	**Sample**	**Year**	**Methodology**	**Endogenous variable**	**Pollution-growth pattern**	**Turning point**
Bölük & Mert (2015)	Turkey	1961-2010	ARDL bounds test	CO2 emissions	Bell-shape	9920* US$ per capita {constant 2005}
Ben Jebli & Ben Youssef (2015)	Tunisia	1980-2009	ARDL bounds test	CO2 emissions	U-shape	-
Ozturk & Al-Mulali (2015)	Cambodia	1996-2012	GMM, 2SLS	CO2 emissions	U-shape	-
Shahbaz et al. (2015)	India	1970-2012	ARDL bounds test	CO2 emissions	Bell-shape	-
Wang et al. (2015)	Gansu province (China)	1980-2012	Bayesian VAR models	Environmental quality index	U-shape for Bayesian VAR models with Minnesota prior	2273 RMB per capita {constant 1980}
Azlina et al. (2014)	Malaysia	1975-2011	Johansen cointegration	CO2 emissions	Monotonically increasing	-
Boutabba (2014)	India	1971-2008	ARDL bounds test	CO2 emissions	Bell-shape	19,380 Indian rupees per capita
Farhani et al. (2014)	Tunisia	1971-2008	ARDL bounds test	CO2 emissions	Bell-shape	-
Katircioğlu (2014)	Singapore	1971-2010	DOLS	CO2 emissions	Bell-shape	-
Lau et al. (2014)	Malaysia	1970-2008	ARDL bounds test	CO2 emissions	Bell-shape	-
Onafowora & Owoye (2014)	Brazil, China, Egypt, Mexico, Nigeria, South Africa, South Korea	1970-2010	ARDL bounds test	CO2 emissions	*N*-shape (Brazil, China, Egypt, Mexico, Nigeria, South Africa), inverted-*N* shape (South Korea),	22.083* in logs (Brazil), 17.050* in logs (China), 16.585* in logs (Egypt), 21.344* in logs (Mexico), 32.855* in logs (Nigeria), 22.963* in logs (South Africa), 8.071 and 8.746 in logs (South Korea)
Shahbaz et al. (2014)	Tunisia	1971-2010	ARDL bounds test	CO2 emissions	Bell-shape	-
Baek & Kim (2013)	Korea	1978-2007	ARDL bounds test	CO2 emissions	Bell-shape	10,119/11,711 US$ per capita, {constant 2010}
Chandran & Tang (2013)	Malaysia, Philippines, Thailand, Singapore, Indonesia	1971-2011	Johansen cointegration	CO2 emissions	U-shape (Malaysia, Thailand), monotonically increasing (Indonesia)	-
Kanjilal & Ghosh (2013)	India	1971-2008	Threshold cointegration	CO2 emissions	Bell-shape	-
Saboori & Sulaiman (2013a)	Indonesia, Malaysia, Philippines, Singapore, Thailand	1971-2009	ARDL bounds test	CO2 emissions	Bell-shape (Singapore, Thailand), U-shape (Indonesia, Philippines), no statistical link (Malaysia)	8.65 in logs (Singapore), 7.47 in logs (Thailand)

(**Table I.3:** continued)

Author	Sample	Year	Methodology	Endogenous variable	Pollution-growth pattern	Turning point
Saboori & Sulaiman (2013b)	Malaysia	1980-2009	ARDL bounds test	CO2 emissions	Bell-shape	5378*/6003*/ 8267*/5825* US$ per capita {constant 2000}
Shahbaz et al. (2013)	Romania	1980-2010	ARDL bounds test	Energy emissions	Bell-shape	-
Tiwari et al. (2013)	India	1966-2011	ARDL bounds test	CO2 emissions	Bell-shape	28,131 Indian rupees (531 US$) per capita
Hussain et al. (2012)	Pakistan	1971-2006	Johansen cointegration	CO2 emissions	Monotonically increasing	-
Jayanthakumaran et al. (2012)	China, India	1971-2007	ARDL bounds test	CO2 emissions	Bell-shape	-
Saboori et al. (2012)	Malaysia	1980-2009	ARDL bounds test	CO2 emissions	Bell-shape	4700 US$ per capita {constant 2000}
Jalil & Feridun (2011)	China	(a) 1953-2006, (b) 1978-2006	ARDL bounds test	CO2 emissions	Bell-shape [(a), (b)]	(b) 11,071* to 13,421* RMB per capita {constant 2000}
Nasir & Ur Rehman (2011)	Pakistan	1972-2008	Johansen cointegration	CO2 emissions	Bell-shape	625 US$ per capita {constant 2000}
Pao et al. (2011)	Russia	1990-2007	Johansen cointegration	CO2 emissions	Monotonically decreasing	-
Fodha & Zaghdoud (2010)	Tunisia	1961-2004	VAR	SO2 emissions, CO2 emissions	Bell-shape (SO2), monotonically increasing (CO2)	1200 US$ per capita (3700 PPP US$ per capita) {constant 2000}
Narayan & Narayan (2010)	43 developing states	1980-2004	Cointegration analysis	CO2 emissions	Bell-shape (Jordan, Iraq, Kuwait, Yemen, Qatar, the UAE, Argentina, Mexico, Venezuela, Algeria, Kenya, Nigeria, Congo, Ghana, South Africa)	-

Notes: ARDL-Autoregressive Distributed Lag; CCR-Canonical Cointegrating Regression; CO2-Carbon Dioxide; DOLS-Dynamic OLS; FMOLS-Fully Modified OLS; FE-Fixed Effects; GMM-Generalized Method of Moments; SO2-Sulfur Dioxide; VAR-Vector Autoregression; VECM-Vector Error Correction Model; 2SLS-Two-Stage Least Squares. The ''-'' indicates that the turning point is not computed, while the ''*'' indicates that the estimated turning point is out of sample values. † Although South Korea was included in the developed country group, we report the associated EKC results as, in the present review, we treat it as an emerging market economy. When both long- and short-run analysis is present, we report the pollution-growth pattern and turning point associated with the long-run results. The methodology column gives information about the technique used in investigating the pollution-growth nexus pattern, even if the respective study comprises other statistical and econometric techniques. All the information contained in the table represents our interpretation of the results in the analyzed studies.

I.4.3. New perspectives on modelling environmental degradation and economic growth nexus

A large majority of the empirical studies mentioned above apply classical econometric tools to check the validity of the EKC hypothesis. However, some novel techniques, such as wavelet analysis, have recently emerged in the related literature and have gained the attention of researchers. Compared with the classical econometric techniques that are part of the time domain and the techniques associated with the frequency domain (e.g. the Fourier approach), the wavelet analysis is much more flexible, in the sense that covers both the time and frequency domain (Schleicher, 2002). Thus, this type of analysis may provide a broader perspective on data behavior by allowing to investigate different time horizons (e.g. short, medium, and long term), and highlighting the potential nonlinearities, direction of causality, and lead-lag nexus (cyclical and counter-cyclical course) between variables at distinct frequencies and time periods (Mutascu et al., 2016).

The empirical literature regarding wavelet analysis is relatively new and limited, with almost all studies focusing on modeling the environmental degradation–economic growth nexus for developed countries (see e.g. Mutascu et al., 2016; Fosten, 2019; Raza et al., 2019; among others). Concerning developing and transition countries, authors such as Jammazi & Aloui (2015) and Kalmaz & Kirikkaleli (2019) employ wavelet techniques to examine the relationship between environmental degradation and economic growth. Nevertheless, the EKC hypothesis is explicitly tested only in the study of Jammazi & Aloiu (2015). The authors use a sample of six oil-exporting countries from the Gulf Cooperation Council (Saudi Arabia, Bahrain, Oman, United Arab Emirates, Qatar, and Kuwait), and based on wavelet windowed cross-correlation results, they show that the EKC hypothesis is valid for the period 1980-2012. More recently, Kalmaz & Kirikkaleli (2019) investigate the relationship between CO2 emissions and GDP, among other variables, for Turkey. According to wavelet coherence analysis, overall, the findings suggest a positive correlation between CO2 and GDP over the period 1960-2015.

Although wavelet analysis is recently adopted as a statistical tool in economics, it may represent a promising approach through which one can provide straightforward and valuable insights, and policy recommendations for different economic hypotheses such as EKC. Moreover, taking stock of the complexity of the phenomena and its interconnectedness that govern the field of energy and environmental economics, this type of approach that moves away from time domain may add valuable information when used in empirical analysis, both solely or along with other techniques.

I.5. Conclusion, and policy implications

The environment's quality plays a vital role in nations' welfare and remains a very debatable subject both at the international and national levels. Additionally, no single formula has yet been found to fit all economic contexts in terms of mitigating pollution and its adverse effects. Starting for the premise of sustainable development, the goal of this paper was to provide both a theoretical review of the key aspects of EKC and an updated empirical review of the pollution-growth nexus literature that focuses on the EKC hypothesis testing in developing and transition states.

Consequently, our updated survey may provide valuable information and, to some extent, positive prospects on EKC estimation, since the reviewed works angle towards a consensus both in terms of empirical strategy and the EKC validity. On the one hand, strengthening the EKC character, most of the studies unveiled a long-term relationship between environmental pollution and economic growth. In this fashion, the findings of numerous works emphasized a cointegration relationship between variables. Thus, concerning the related techniques, the advance in statistics and econometrics has facilitated their development and implementation, all of which have had a beneficial impact on EKC estimation. On the other hand, several studies have found evidence in favor of EKC, suggesting that some developing and transition economies have succeeded in attaining the income threshold, and have improved their environmental conditions. However, according to some works, the estimated value of the income turning point lies outside the sample range. In these specific cases, the findings should be treated with care, as this may imply that the future growth may increase pollution levels, and/or highlight possible issues regarding the EKC and the associated threshold identification. Taken collectively, both the theoretical foundations and empirical evidence, could contribute to a better understanding of the pollution-growth nexus in the EKC context, and suggest some meaningful insights into the future works on the subject, as well as the crucial policy implications in developing and transition economies.

In light of the overall results, some policy implications could be drawn. First, some developing and transition states have managed to keep low levels of pollution along with economic growth, and even reached the EKC threshold for a lower level of income compared to developed nations (see e.g. the recent work of Yao et al., 2019; among others). Hence, these states could be treated as a positive example and examined more in detail to get insights into the factors that contribute to inducing a bending downward curve in pollution. In this regard, over the years, the environmental and energy economics literature has unveiled some of the key elements that may promote a reduction in pollution levels (increase environmental quality). Focusing our attention primarily on developing and transition economies, we mention the factors related to energy structure, such as lower energy consumption, higher renewable and nuclear energy share in total energy consumption, higher energy efficiency (see e.g. Baek & Kim, 2013; Azlina et al., 2014; Sugiawan & Managi, 2016; Danish et al., 2017; Dong et al., 2018; Sinha & Shahbaz, 2018; Chen et al., 2019b), the factors associated to the overall political system, such as good governance, corruption control, higher institutional quality, and political stability, and democracy (see e.g. Shahbaz et al., 2013; Osabuohien et al., 2014; Ozturk & Al-Mulali, 2015; Chen et al., 2018; Purcel, 2019; Ronaghi et al., 2019), the coexistence of an eco-friendly and relatively large industry sector and high labor productivity which uphold complex techniques (see e.g. Lazăr et al., 2019), the environmental awareness (Chen et al., 2019a), among others. Besides, Halkos & Bampatsou (2018) revealed the importance that international agreements have on climate change mitigation. Their recent findings showed that the states that signed an international agreement, such as the Kyoto Protocol, exhibit higher environmental efficiency than their counterparts. These results are quite significant (all the more that their sample of 73 countries covered 55 developing ones) and may suggest that the developing world should be engaged more actively at international and also national level in green activities to ensure high environmental efficiency. Likewise, for transition economies, the findings of Zugravu-Soilita (2018) suggested that trade intensity in environmental goods reduced CO2 emissions, primarily through the income effect. However, the opposite is found for water pollution, while for SO2 emissions, the effect lacks significance. Overall, the author argued that in the context of sustainable development, freer trade in environmental goods might be attained through the regional or bilateral agreements that reflect the countries' peculiar context.

Second, after a certain threshold is reached, environmental degradation may be irreversible and costly, both economically and socially (Munasinghe, 1999). Bearing in mind that the effects of policies and regulations are often visible in the long term, to fight against environmental degradation, it is primordial to consider all the potential detrimental factors and take preventive measures. As such, good knowledge of the domestic economic, social, and political environment, along with a constant adaptation of environmental regulations and policies, may bring added value and improve the environmental quality. Furthermore, prolific international cooperation could foster the assimilation of know-how and new green technologies. Nowadays, as also stipulated by the Paris agreement, among other instruments, there is a need for developing and transition economies to become more involved in climate change activism and fight together with developed nations against the threats of global warming. Building on the present literature review, future work could be drawn upon a meta-analysis better to understand the pollution-growth nexus through the EKC incidence.

«CHAPTER II»

Pollution and Economic Growth: Evidence from Central and Eastern European Countries*

Abstract: We investigate the relationships between pollution and growth in eleven Central and Eastern European (CEE) countries. Aggregate results, robust to different estimators and control variables, reveal an increasing nonlinear link between GDP and CO2 for the group of CEE countries. However, at a disaggregated, country-level, the relationship between GDP and CO2 is characterized by much diversity among CEE countries, namely: *N*-shaped, inverted-*N*, U-shaped, inverted-U, monotonic, or no statistical link. Thus, despite an aggregated upward trend, some CEE countries managed to secure both higher GDP and lower CO2 emissions. From a policy perspective, EU policymakers could pay more attention to these countries, and amend the current unique environmental policy to account for country-heterogeneities in order to support economic growth without damaging the environment.

Keywords: CO2 emissions; economic growth; Central and Eastern European countries; environmental Kuznets curve.

JEL Codes: Q32, Q56, O13, P28

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II.1. Introduction

During the last decades, international environmental organizations increased their efforts towards finding a scenario that would ensure economic growth and minimize its negative consequences on the environment (i.e. sustainable development). At the global level, in response to the threats of climate change, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol (1997) and the Paris Agreement (2015). While the former was focused on developed countries, the latter put more emphasis on the role of developing countries in the context of climate change.

Such global agreements are supported by more regional measures. In particular, the European Union (EU) objectives on sustainable development are part of the Europe 2020 and 2030 strategy for smart and sustainable growth. Implemented and monitored at the EU level, these climate actions aim to reduce the greenhouse gas emissions by 20% and 40%, by the end of 2020 and 2030 respectively. Furthermore, these goals are also in line with the EU 2050 low-carbon economy strategy, stressing that all sectors of the economy should contribute to the reduction of greenhouse gas emissions in order to achieve the goal of 80% reduction compared with the 1990 levels.

However, the extent to which these goals could be attained is subject to debate. For example, regarding CO2 (which represents by far the largest share in greenhouse gas emission, namely around 75% in 2017 in EU, see Olivier et al., 2017), it is encouraging to observe that emissions in the EU decreased in 2015 with respect to 1996 by 18% in levels (by 22% per capita). Nevertheless, these numbers cover important disparities across EU, as they are driven by the strong contraction of CO2 emissions per capita in large EU countries, such as UK (-38%), France (-24%), Italy (-20%) or Germany (-18%), while in Central and Eastern European (CEE) countries the situation is less favorable. Indeed, out of the eleven CEE countries, only six experienced negative growth rates of their CO2 emissions per capita during 1996-2015, and in some of them this negative trend reversed in the recent period (for example in Poland in 2015 compared with 2014, see Janssens-Maenhout et al., 2017).

Motivated by the presence of such heterogeneities, the goal of this paper is to analyze the behavior of CO2 emissions in CEE countries. Since we aim at providing insights from the perspective of fighting climate change, we link CO2 with economic development measured by GDP (per capita). This relationship, commonly known as the Environmental Kuznets Curve (EKC) (Grossman & Krueger, 1991; Panayotou, 1993), has received a large and increasing attention in the literature. With respect to the existing studies, our analysis differs on several grounds.

First, while many contributions focus on developed countries, our analysis complements studies that look at developing or emerging countries. By focusing exclusively on CEE countries, we specifically refrain from mixing them with other EU countries (see e.g. Ozokcu & Ozdemir, 2017; Pablo-Romero & Sanchez-Braza, 2017), or other developing or emerging countries (see e.g. Atici, 2009; Iwata et al., 2011; Zaman et al., 2016), since CEE countries present particular features, as emphasized in the following.

Second, with respect to Kasman & Duman (2015) who consider new EU members and candidate countries over 1992-2010, we focus on CEE countries' particularities. Indeed, given that CEE countries experienced major imbalances at the beginning of the 1990s, we mitigate them by restricting our sample to start only in 1996. By so doing, our sample covering the 1996-2015 period is also well balanced around the mid-period of the two dates of EU enlargement with CEE countries (2004 and 2007, with Croatia joining EU in 2013). In addition, to account for the major footprint of the communist period experienced by these countries, we estimate the relationship between CO2 and GDP conditional to a benchmark vector of two important control variable, namely energy consumption, and economic freedom. By capturing crucial features in CEE countries' dynamics during the studied period (e.g. the transition from centrally-planned to market economies), these variables may tackle an important omitted-variables bias in the identification of the CO2-GDP link.

Third, we allow for an extended specification of the EKC, by augmenting the traditional second-order polynomial-shape between CO2 and GDP (see e.g. Kasman & Duman, 2015) with the cube of GDP, in order to account for a potential technological effect. Combined with the use of modern estimators that, in addition to performing fairly well in small sample macroeconomic panels, appropriately account for CEE countries' heterogeneity (arising from factors influencing both CO2 and GDP dynamics) by allowing for slope-heterogeneity (namely: the Mean Group Fully Modified Least Squared (MG-FMOLS), the Mean Group (MG), and the Augmented Mean Group (AMG) estimators), this specification allows providing new evidence on the relationship between CO2 and GDP in CEE countries.

Finally, the related literature drawing upon panel data focuses on an aggregated link between CO2 and GDP. However, such a relationship may ignore country-differences that seem to be at work in CEE countries, as previously emphasized. Consequently, our analysis equally provides results for the relationship between CO2 and GDP for each of the CEE country in our sample.

Our findings are as follows. On the one hand, from an aggregated perspective, there exists an increasing nonlinear link between GDP and CO2 for the group of CEE countries. Specifically, the increase in CO2 following an increase in GDP is relatively mild around a GDP level estimated at roughly 19,900 USD, but the magnitude of this effect increases as we move away from this value towards low and high GDP values. Robust across different estimators, in the presence of additional control variables, and for other measures of environmental quality, this finding suggests that much attention should be given to CEE countries from an environmental perspective, since their ongoing economic development seems to be associated with a reinforcement of CO2 emissions on average.

On the other hand, from a disaggregated perspective, the link between GDP and CO2 is characterized by much diversity among CEE countries. First, in Croatia, Estonia, Poland, and Slovakia the relationship is strongly nonlinear, with the existence of two GDP thresholds defining either an *N*-shaped relationship (in the former two countries) or an inverted-*N* pattern (in the latter two countries). Second, an inverted-U (U) link is found in Czech Republic, and Hungary (Bulgaria, and Latvia), associated with the existence of a maximum (minimum) level of CO2 emissions in these countries. Third, in some countries the relationship is monotonous (increasing in Lithuania), while in Romania and Slovenia the link between GDP and CO2 was not found to be statistically significant. From a policy perspective, these important heterogeneities (spanning from the absence of a statistical link, to the presence of multiple thresholds) should be accounted for when defining and implementing environmental policies in the CEE countries, all the more in the context of current environmental EU goals that hardly seem to incorporate country-specificities. Simple correlations—that must be taken with much caution—may suggest that the presence of a relatively important clean industry sector, along with large labor productivity and complex techniques, may support CO2 reductions in the context of increasing GDP in our sample of CEE countries.

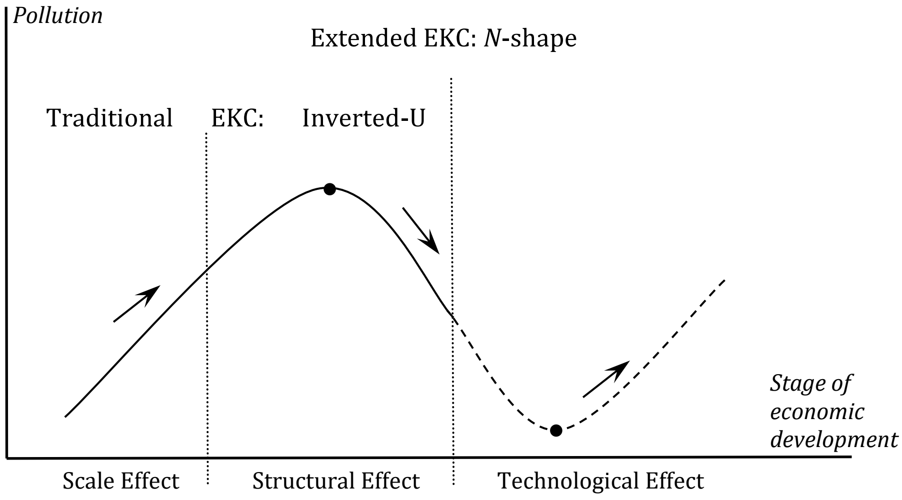
The paper is organized as follows. Section 2 draws upon theory to define our model, and discusses some literature. Section 3 presents the data, and the methodology. Section 4 reports the aggregate results, and explores their robustness. Section 5 provides country-level results. Finally, Section 6 discusses the policy implications of our findings, and suggests some topics for future research.

II.2. Theory, the model, and some related literature

II.2.1. Theory

The Environmental Kuznets Curve (EKC), coined by Grossman and Krueger (1991) and Panayotou (1993), assumes an inverted-U (or bell-shaped) relationship between pollution and economic development. For low economic development, the intensity of environmental degradation is minimal. However, as the economic activity intensifies (for example, due to the industrialization process), the degree of pollution gradually increases until it reaches a maximum value. Finally, above this level of economic development, the level of pollution decreases. Grossman & Krueger (1991) explain the effect of changes in trade policy and foreign investment on pollution through three effects, namely a scale effect, a structural effect, and a technological effect, which are mostly at work at different stages of economic development.

Figure II.1: Traditional EKC [Inverted-U shape] and Extended EKC [*N*-shape]



Subsequently, several studies, including e.g. Milimet et al. (2003), Yang et al. (2015), or Dogan & Seker (2016), explored extensions of the traditional inverted-U EKC.

Specifically, it has been stressed that the relationship between pollution and economic development might be more complex, as the pattern may actually be N-shaped (or even inverted-N shaped). In particular, the N-shape assumes that, as the level of economic development continues to increase, the trend in pollution may reverse and increase again. This may be because at some point economic activity is so intense that its negative impact on the environment cannot be compensated through the structural or the technological effect. Figure II.1 illustrates both the traditional EKC (the continuous curve), and the extended EKC (composed of the continuous and the dotted curve).

II.2.2. The model

Starting from theory, we can specify the following panel model to estimate the EKC

$$CO2_{it} = \alpha_i + \beta_1 GDP_{it} + \beta_2 GDP_{it}^2 + \beta_3 GDP_{it}^3 + \phi X_{it} + \varepsilon_{it}, \qquad (1)$$

which assumes a third-order polynomial in the shape of the relationship between GDP and $CO2$, with X the vector of control variables (to be discussed below), and α and ε country-fixed effects and the error term, respectively. This specification has the merit of covering a large class of EKC, beyond the inverted-U (traditional) or N-shaped (extended) EKC usually suggested by theory. Assuming such a general specification is motivated by the lack of consensus in the literature regarding the precise shape of the EKC (see the discussion in e.g. Yang et al., 2015).

II.2.2. Some related literature

The literature devoted to testing the empirical validity of the EKC is so large and expanding that it regularly makes the object of surveys (see e.g. Lieb, 2003; Dinda, 2004; Aslanidis, 2009; Hervieux & Mahieu, 2014). Many analyses are performed on OECD and developed countries (recent contributions include e.g. Dogan & Seker, 2016; Ben Jebli et al., 2016; Shahbaz et al., 2017; Awaworyi Churchill et al., 2018), or on samples that mix countries with different levels of economic development (see e.g. Iwata et al., 2011; Luo, 2016; Zaman et al., 2016). Since we are interested in CEE countries, we review here some of the recent studies that focus on developing and/or emerging countries.[1]

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[1] Alternatively, some studies are conducted at a sub-national level; for example, Hamit-Haggar (2012) looks at Canadian industrial sectors, Apergis et al. (2017) consider the US states, and Wang et al. (2017) focus on the Chinese provinces.

The literature devoted to these countries seems to have unveiled several types of patterns for the relationship between pollution and economic development (see Yang et al., 2015, for a very valuable state of the art of the findings of many country-, and panel- or cross-section-studies). First, using a strategy that consists of comparing long- and short-run coefficients, Narayan & Narayan (2010) conclude that in about one-third of the 43 developing countries in their sample, CO2 emissions decreased as their income increased. Second, focusing on new EU members and candidate countries, Kasman & Duman (2015) find support for a traditional (inverted-U) EKC, a result equally emphasized in Central America by Apergis & Payne (2009), in Middle East and North African (MENA) countries by Farhani et al. (2014), in Latin America & Caribbean countries by Al-Mulali et al. (2015), in Asian countries by Apergis & Ozturk (2015), and in a larger sample of 86 developing countries by Hanifa & Gago-de-Santos (2017). Third, Ozokcu & Ozdemir (2017) highlighted an extended EKC (*N*-shaped) relationship between CO2 and GDP in 52 emerging countries. Finally, in a comparison of several models in a symbolic regression framework, Yang et al. (2015) reveal that the shape of the relationship between CO2 and GDP may be monotonically increasing, inverted-U, or inverted-*N* in their sample of 38 developing countries. This lack of consensus in the relationship between CO2 and GDP in developing countries calls for a careful analysis of the specificities of CEE countries.

II.3. Data, modeling considerations, and methodology

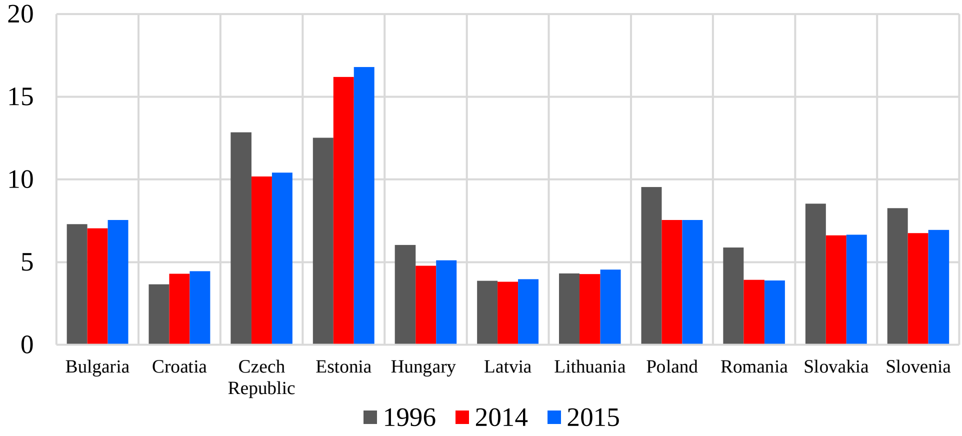
II.3.1. Data

We perform our analysis on eleven CEE countries that joined the EU from 2004 onwards, namely Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia. To abstract from the important imbalances experienced by these countries following the end of the Cold War, we restrict our data to the period 1996-2015. Since there are no missing data, our yearly panel is balanced and contains a total of 220 observations.

Our main variables are *CO2*, defined as the log of CO2 emissions per capita from fossil fuel use and industrial processes, and *GDP*, defined as the log of GDP per capita based on purchasing power parity in constant 2011 prices. In addition, as previously emphasized, when estimating the relationship between GDP and CO2 in CEE countries, we must account for the major footprint of the communist period experienced by these countries. To do so, we include in the vector X of control variables [see equation (1) above] two variables that may appropriately capture for the large economic and institutional changes that took place in these countries during the period we analyze, namely: ENG, defined as the log of gross inland energy consumption per capita, and $ECFR$, defined as the log of the index of economic freedom of Heritage Foundation. Tables A-II.1-2 in the Appendix present the variables, and descriptive statistics.

Descriptive statistics reveal that CO2 emissions per capita present a downward trend in six out of the eleven countries in our sample. Bearing in mind the communist past of these countries, firms in the industrial sector (one of the most important pillars of the economy) were large state-owned companies operating in heavy-polluting industries. After the collapse of the communist regime, many of these companies have been dissolved or privatized over the years, contributing to the decline in energy CO2 emissions. Figure II.2 below presents the CO2 emission per capita in CCE states for the starting (i.e. 1996) and the last two (i.e. 2014 and 2015) years of analysis.

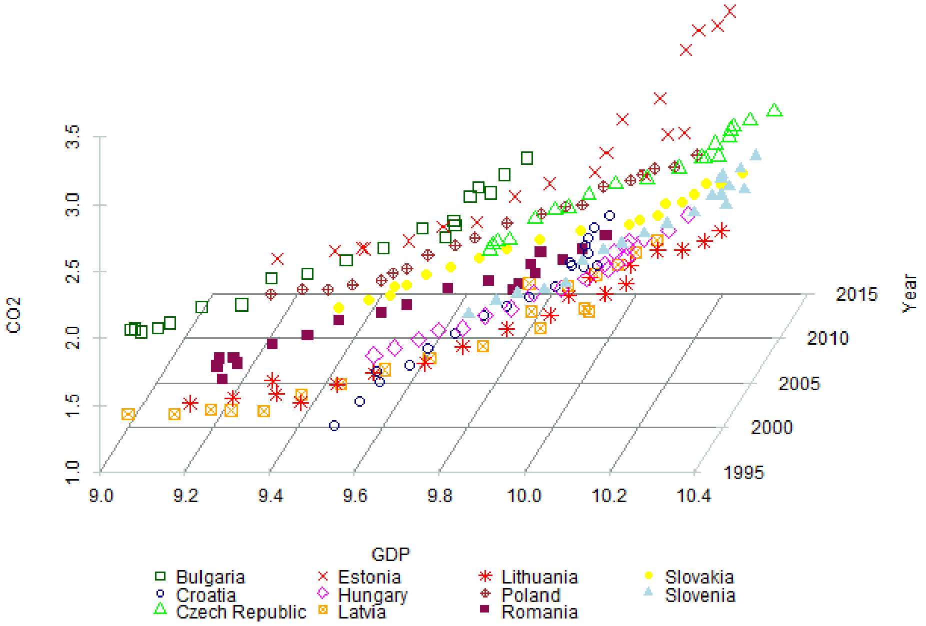
Figure II.2: CO2 emissions per capita by year



Regarding GDP per capita, all countries display an upward trend, with a particularly large increase in the Baltic countries (see Table A-II.2 in the Appendix). Their accelerated economic growth was driven by the development of their financial system, large commercial flows, and fiscal systems attracting foreign direct investments (IMF, 2014). From a broader perspective, all countries benefited from a convergence period characterized by high and sustained economic growth rates, particularly in the early 2000s (see e.g. IMF, 2016).

Besides, with respect to both CO2 and GDP, Figure II.3 illustrates the combined three-dimensional scatterplot for each member of the panel. Additionally, the evolution of CO2 emissions and GDP for the overall group, and by country is displayed in Figure A-II.1 in the Appendix.

Figure II.3. Combined three-dimensional scatterplot for each panel member



II.3.2. Modeling considerations

When estimating the relationship between GDP and CO2, we have to keep in mind the different dynamics experienced by the CEE countries of our sample, particularly regarding CO2. Consequently, we further investigate several properties of the data used in our analysis.

II.3.2.1. Cross-sectional dependence, and heterogeneity

The cross-sectional dependence in our sample is related to the fact that CO2 emissions in one country could depend on CO2 emissions in other countries, and also with potential common dynamics of GDP, given that these countries were a part of a common (closed) system until 1990. To test for cross-sectional dependence we use four tests, namely: Baltagi et al. (2012) Bias-Corrected (BC) scaled LM, Pesaran (2004) CD, Pesaran (2004) scaled LM, and Breusch-Pagan (1980) LM. The statistic of each previously mentioned test has the following form:

$$LM_{Baltagi\ et.\ al} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\hat{p}_{ij}^{2}-1\right)-\frac{N}{2(T-1)} \rightarrow N(0,1), \tag{2a}$$

$$CD_{Pesaran} = \sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}T_{ij}\hat{p}_{ij} \rightarrow N(0,1), \tag{2b}$$

$$LM_{Pesaran\ (scaled)} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left(T_{ij}\hat{p}_{ij}^{2}-1\right) \rightarrow N(0,1), \tag{2c}$$

$$LM_{Breuch-Pagan} = \sum_{i=1}^{N-1}\sum_{j=i+1}^{N}T_{ij}\hat{p}_{ij}^{2} \rightarrow \chi^{2}\frac{N(N-1)}{2}, \tag{2d}$$

where $\hat{p}_{ij}$ represents the estimate of pair-wise correlation coefficients of the errors, and is computed as follows:

$$\hat{p}_{i,j} = \hat{p}_{j,i} = \frac{\sum_{t=1}^{T}\hat{u}_{it}\hat{u}_{jt}}{\left(\sum_{t=1}^{T}\hat{u}_{it}^{2}\right)^{\frac{1}{2}}\left(\sum_{t=1}^{T}\hat{u}_{jt}^{2}\right)^{\frac{1}{2}}}. \tag{2e}$$

Taking into account the overall drawbacks of the four cross-sectional dependence tests with respect to *N* and *T* dimension, the Monte Carlo simulations performed by Pesaran (2004) showed that the CD statistic do not suffer from sample size distorsions when both *N* and *T* are small. The statistics of these tests are provided in Table II.1, and show that the null hypothesis of cross-sectional independence is strongly rejected in all cases in favor of the presence of cross-sectional dependence.

Table II.1: Cross-sectional dependence analysis

Test/Variable	**CO2**	**GDP**	**ENG**	**ECFR**
BC scaled LM	24.01***	91.91***	20.05***	37.39***
	(0.00)	(0.00)	(0.00)	(0.00)
Pesaran CD	6.30***	31.95***	12.28***	20.00***
	(0.00)	(0.00)	(0.00)	(0.00)
Pesaran scaled LM	24.30***	92.20***	20.34***	37.68***
	(0.00)	(0.00)	(0.00)	(0.00)
Breusch-Pagan LM	309.90***	1022.02***	268.40***	450.25***
	(0.00)	(0.00)	(0.00)	(0.00)

Notes: H0 is "cross-sectional independence". p-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Turning now to heterogeneity, although the CEE countries in our sample are part of the EU, they differ across several dimensions. First, the Baltic countries (Estonia, Latvia, and Lithuania) were effectively members of the Soviet Bloc compared to the others that were only part of the Communist Bloc; as such, their economic system might have borrowed much more of the specificities of the former Soviet Union. Second, despite being part of the EU, differences in the geographical location of the countries (e.g. the relief, the maritime connections with the rest of the world, the neighboring countries) may have affected the degree of environmental pollution, as well as their economic development path. Third, given their national autonomy, environmental regulations and economic growth-designed macroeconomic policies may equally differ across countries. Finally, although fairly close, the year of ascension to the EU was different for Bulgaria and Romania (Croatia joined EU only in 2013), and these countries display average national income levels, compared with large national income levels in the other CEE countries in our sample, in 2016 World Bank's classification. Taken together, these features suggest the existence of a certain degree of heterogeneity among CEE countries, consistent with the differences in CO2 dynamics previously emphasized.

II.3.2.2. Stationarity, and cointegration

We now look at the time-series properties of our data, i.e. their stationarity. Given the presence of cross-sectional dependence in our data, we apply several panel tests that are robust to cross-sectional dependence (i.e. the so-called "second-generation" stationarity tests), namely the popular Pesaran (2003) and Breitung & Das (2005) tests.[2] Table II.2 displays the results of the tests without lags and with one lag (we include a constant and a trend for the level specification, and a constant for the difference specification). Overall, the tests reveal that the variables are I(1), i.e. integrated of order one.

Given that our series are nonstationary, first, we examine the potential existence of a cointegration relationship between variables using Pedroni's (1999, 2004) panel cointegration test. This test allows slope coefficients to vary across individuals. The null hypothesis of no cointegration between variables is examined using several statistics, that deal with the within dimension (Panel PP-statistic, and Panel ADF-statistic) and the between dimension (Group PP-statistic, and Group ADF-statistic). According to Pedroni (1999, 2004), the statistics in the first group restrict the autoregressive parameter to be identical for all individuals, in contrast to the second group statistics that allow the autoregressive parameter to vary across individuals. Table II.3 depicts the results of the cointegration tests. All tests were conducted with individual intercept (first column), and

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[2] In the Pesaran (2003) test, the null hypothesis is that all series are nonstationary, while in the Breitung & Das (2005) test the null hypothesis assumes that all panels contain a unit root.

individual intercept and trend (second column), while for the within dimension both unweighted and weighted tests were considered. Irrespective of the specification (with or without trend), the tests reject the null hypothesis of no cointegration.

Second, given the large number of variables in the cointegration vector, there are not enough data to perform the Westerlund (2007) test. However, we report that when we restrict the cointegration vector to the most important variables, namely, CO2, GDP, GDP2, GDP3, and ENG, three of the four Westerlund tests reject the null hypothesis of no cointegration (see Table II.4), confirming the conclusions of the Pedroni (1999, 2004) panel cointegration test.

Table II.2: Stationarity analysis

Test/ Variable	**Pesaran (no lags)**				**Breitung & Das (no lags)**			
	Level (const & trend)		**Difference (const)**		**Level (const & trend)**		**Difference (const)**	
	t-bar	*p-value*	*t-bar*	*p-value*	*lambda*	*p-value*	*lambda*	*p-value*
CO2	-2.671*	(0.097)	-4.432***	(0.000)	-0.786	(0.215)	-5.300***	(0.000)
GDP	-2.524	(0.209)	-2.925***	(0.000)	0.424	(0.664)	-2.490***	(0.006)
ENG	-2.904**	(0.019)	-4.865***	(0.000)	-0.960	(0.168)	-4.919***	(0.000)
ECFR	-2.166	(0.647)	-4.088***	(0.000)	-0.322	(0.373)	-2.265**	(0.011)
	Pesaran (one lag)				**Breitung & Das (one lag)**			
	Level (const & trend)		**Difference (const)**		**Level (const & trend)**		**Difference (const)**	
	t-bar	*p-value*	*t-bar*	*p-value*	*lambda*	*p-value*	*lambda*	*p-value*
CO2	-2.248	(0.542)	-3.242***	(0.000)	-1.109	(0.133)	-3.158***	(0.000)
GDP	-2.562	(0.175)	-2.306**	(0.035)	-0.652	(0.257)	-3.294***	(0.000)
ENG	-2.606	(0.140)	-3.261***	(0.000)	-1.004	(0.157)	-2.587***	(0.004)
ECFR	-2.106	(0.718)	-2.644***	(0.002)	-0.869	(0.192)	-1.767**	(0.038)

Notes: Pesaran (2003) H0 is "all series are nonstationary", and Breitung & Das (2005) H0 is "all panels contain a unit root". p-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table II.3: Pedroni (1999, 2004) cointegration tests

Pedroni Test	**Individual Intercept**		**Individual Intercept & Trend**	
Within dimension	**statistic**	**p-value**	**statistic**	**p-value**
Panel PP-Statistic	-1.881**	(0.029)	-2.373***	(0.008)
Panel ADF-Statistic	-2.887***	(0.001)	-2.742***	(0.003)
Panel PP-Statistic (Weighted)	-2.635***	(0.004)	-7.232***	(0.000)
Panel ADF-Statistic (Weighted)	-3.911***	(0.000)	-4.594***	(0.000)
Between dimension	**statistic**	**p-value**	**statistic**	**p-value**
Group PP-Statistic	-1.605*	(0.054)	-10.297***	(0.000)
Group ADF-Statistic	-3.671***	(0.000)	-5.285***	(0.000)

Notes: Automatic lag length selection based on SIC with a maximum lag of three. Newey-West automatic bandwidth selection and Bartlett kernel. The statistics' significance was determined by comparing calculated and tabulated values provided by Pedroni (1999). H0 is "no cointegration". ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table II.4: Westerlund (2007) cointegration tests

Statistic	Z-value	P-value
Gt	-2.621	0.066*
Ga	3.288	0.774
Pt	-2.021	0.035**
Pa	0.233	0.098*

Notes: Gt and Pt are respectively the group mean test and the panel mean test. Ga and Pa refer to the asymptotic version of the test. The null hypothesis is "no cointegration".

II.3.3. Methodology

Our previous analysis revealed the presence of cross-sectional dependence, heterogeneity, and cointegration. To account for these features, we draw upon the Mean Group (MG) estimator coined by Pesaran & Smith (1995), the Mean Group Fully Modified Least Squared (MG-FMOLS) estimator proposed by Pedroni (2000, 2001), and the Augmented Mean Group (AMG) estimator developed by Eberhardt & Teal (2008, 2010) and Eberhardt & Bond (2009). These estimators, in addition to performing fairly well in small sample macro panels, are particularly appropriate for macro panels with slope heterogeneity (Eberhardt, 2012).[3] Besides, our results for CEE countries may be compared with those of recent contributions that used these estimators to examine the EKC (see e.g. Apergis, 2016).

Starting from a simple fixed-effects slope-heterogeneity panel regression

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it}, \tag{3}$$

Pesaran & Smith (1995) coined the MG estimator that deals with parameters' heterogeneity by averaging the individual slopes obtained from individual OLS regressions for each member of the panel. Formally, the MG estimator can be written (see Hsiao & Pesaran, 2004)

$$\beta_{MG} = \frac{1}{N}\sum_{i=1}^{N} \beta_i, \tag{4a}$$

with its variance defined as

$$Var(\beta_{MG}) = \frac{1}{N(N-1)}\sum_{i=1}^{N}\left(\beta_{i_i} - \bar{\beta}\right)^2. \tag{4b}$$

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[3] In particular, the AMG estimator accounts for cross-sectional dependence through adding a "common dynamic effect", while the (A)MG estimators produce unbiased results even if not all variables are nonstationary.

Moreover, we draw upon Pedroni (2000, 2001), to write the MG-FMOLS estimator as

$$\beta_{MG-FMOLS} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\sum_{t=1}^{T}(x_{it}-\bar{x}_i)^2\right)^{-1}\left(\sum_{t=1}^{T}(x_{it}-\bar{x}_i)y_{it}^{*} - T\gamma_i\right)\right], \tag{5a}$$

with

$$y_{it}^{*} = (y_{it}-\bar{y}_i) - \left(\frac{\Omega_{21,i}}{\Omega_{22,i}}\right)\Delta x_{it} \tag{5b}$$

and

$$\gamma_i = \Gamma_{21,i} + \Omega_{21,i}^{0} + \left(\frac{\Omega_{21,i}}{\Omega_{22,i}}\right)\left(\Gamma_{21,i} + \Omega_{22,i}\right), \tag{5c}$$

with

$$\Omega_i = \lim_{T\to\infty} E\left[\left(T^{-1}\sum_{t=1}^{T} z_{it}\right)\left(T^{-1}\sum_{t=1}^{T} z'_{it}\right)'\right] \tag{5d}$$

the long-run covariance of the stationary vector $z_{it} = (u_{it}, \Delta x_{it})'$, which can be written as the sum between the contemporaneous covariance Ω_i^0 and Γ_i the weighted sum of autocovariances, namely:

$$\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'. \tag{5e}$$

Finally, more recently, Eberhardt & Teal (2008, 2010), Eberhardt & Bond (2009), and Eberhardt (2012) developed the AMG estimator that accounts for both parameters heterogeneity and cross-sectional dependence. Having in mind the traditional panel model, the potential presence of cross-sectional dependence is captured by the structure of both unobservables and observables, namely

$$u_{it} = \varphi_i + \lambda_i f_t + \varepsilon_{it} \tag{6a}$$

and

$$x_{it} = \xi_i + \lambda_i f_t + \gamma_i g_t + v_{it}, \tag{6b}$$

with φ_i and ξ_i group fixed effects, f_t and g_t common factors with heterogeneous factor loadings λ_i, and ε_{it} and v_{it} white noises. The merit of this method is to move away from other estimation techniques for heterogeneous panels (e.g. Common Correlated Effects Mean Group estimator–CCEMG; Pesaran, 2006) that consider the unobservable common factors as a nuisance, by modeling them as a common dynamic process, namely

$$y_{it} = \alpha_i + \beta_i x_{it} + \eta_i t + d_i \phi_t + e_{it}, \tag{6c}$$

with ϕ_t the dynamic process variable constructed from a regression in first differences

$$\Delta y_{it} = \beta \Delta x_{it} + \textstyle\sum_{t=2}^{T} \phi_t \Delta D_t + e_{it} \tag{6d}$$

and $\eta_i t$ a linear trend.

As a result, the AMG estimator is

$$\beta_{AMG} = \frac{1}{N}\sum_{i} \beta_i. \tag{6e}$$

In the following, we will draw upon these estimators to analyze the relationship between GDP and CO2 in our panel of CEE countries.

II.4. Results: aggregated analysis

II.4.1. Results

The estimation of the model (1) using the MG estimator is reported in column (1) of Table II.5. Prior to discussing the main results, two remarks are worthwhile. First, we need to validate the long-run cointegration vector that was used to estimate the elasticities in Table II.5. To this end, we retrieve the estimated residuals from the model (1), namely *ECT*, and add them in the following model

$$\Delta CO2_{it} = \delta_i + \theta ECT_{it-1} + \gamma_1 \Delta GDP_{it} + \gamma_2 \Delta GDP_{it}^2 + \gamma_3 \Delta GDP_{it}^3 + \phi \Delta X_{it} + \varepsilon_{it}, \tag{7a}$$

with Δ the difference operator. In particular, the above equation (7a) is obtained from the following equation

$$\begin{aligned}\Delta CO2_{it} = \delta_i + \theta(CO2_{it} - \beta_1 GDP_{it} - \beta_2 GDP_{it}^2 - \beta_3 GDP_{it}^3 - \omega X_{it}) + \gamma_1 \Delta GDP_{it} \\ + \gamma_2 \Delta GDP_{it}^2 + \gamma_3 \Delta GDP_{it}^3 + \phi \Delta X_{it} + \varepsilon_{it}\end{aligned} \tag{7b}$$

by rewriting

$$CO2_{it} - \beta_1 GDP_{it} - \beta_2 GDP_{it}^2 - \beta_3 GDP_{it}^3 - \omega X_{it} = ECT_{it} \tag{7c}$$

and then applying the one period lag operator to ECT_{it}, namely ECT_{it-1}.

Estimations of this model reported in Table A-II.3 in the Appendix show that the coefficient of the error correction term (ECT) is negative and significant, supporting the existence of a long-run relationship between GDP and CO2.

Second, regarding control variables, as expected there is a significant and positive link between energy consumption and CO2 emissions for the CEE countries. In addition, higher economic freedom is related to a decrease in CO2 emissions, suggesting that the process of economic liberalization contributed to the reduction of pollution in CEE countries in the long-run. In line with our expectations, this finding may capture the transition from a planned to a market economy, during which heavy industries were replaced by more environmental-friendly ones.

Table II.5: Aggregated estimates

Dependent variable: CO2			
	MG	**MG-FMOLS**	**AMG**
	(1)	**(2)**	**(3)**
GDP	760.968**	457.226***	525.619*
	(356.031)	(75.771)	(289.662)
GDP^2	-76.852**	-46.567***	-53.153*
	(35.910)	(7.713)	(29.465)
GDP^3	2.587**	1.580***	1.793*
	(1.207)	(0.261)	(0.999)
ENG	1.136***	1.147***	0.902***
	(0.107)	(0.042)	(0.128)
ECFR	-0.183***	-0.180**	-0.146*
	(0.061)	(0.087)	(0.086)
CDP			0.907***
			(0.219)
Observations	220	209	220
Pattern	increasing	increasing	increasing
GDP for concavity change	9.9004 ($19,938)	9.8182 ($18,365)	9.8812 ($19,559)

Notes: Reported MG coefficients are unweighted averages across countries. Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Let us now discuss the main results. As shown by column (1) in Table II.5, all GDP terms in our third-order polynomial specification significantly affect CO2 in our panel of CEE countries. As a counterfactual, GDP terms are not statistically significant in the quadratic model and linear model for A(MG) estimators (see Tables A-II.4-5 in the Appendix). Furthermore, the positive (negative) sign for the cubic and linear (squared) term suggest that the relationship between GDP and CO2 is *N*-shaped. However, the two estimated GDP values that cancel the first derivative are not local extrema, making the estimated relationship between GDP and CO2 to be increasing (see Figure II.4a).[4] Nevertheless, our analysis reveals magnitude nonlinearities: around the GDP level associated to the change in concavity (estimated at around 9.90, namely around 19,900 USD), the increase in CO2 following an increase in GDP is fairly mild, while this increase

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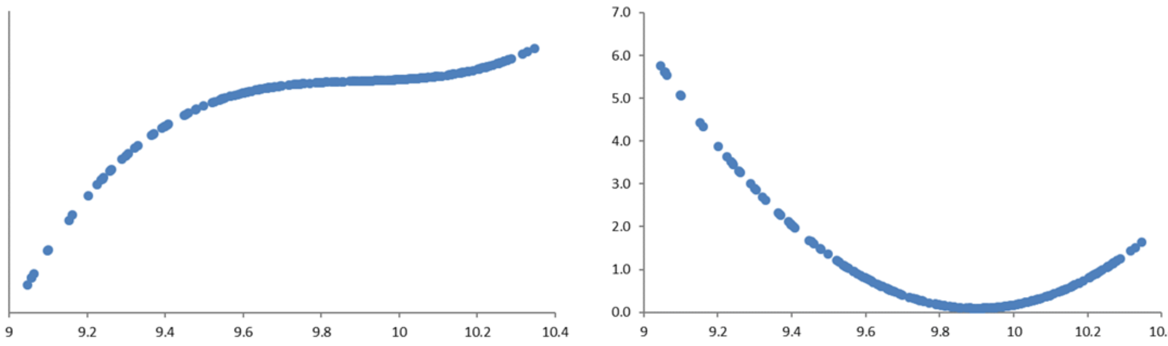
[4] Let us define the generic cubic polynomial function as follows: $f(x) = \beta_3 x^3 + \beta_2 x^2 + \beta_1 x$. Considering our estimated cubic polynomial rgressions, the first derivative $f'(x) = 3\beta_3 x^2 + 2\beta_2 x + \beta_1 = 0$ has a $\Delta = \beta_2^2 - 4\beta_1\beta_3 < 0$, thus, the associated roots are not real numbers. Also, the first derivative receives the sign of the squared term, which is positive in our case. Therefore, we are dealing with an increasing function. Next, the solution of the second derivative $f''(x) = 6\beta_3 x + 2\beta_2 = 0$ is computed using the following formula $x = -\beta_2/3\beta_3$. More specifically, in this computed point, the cubic function changes its concavity, from concave down to concave up; actually, this is an inflection point but not a local extremum (local minimum or maximum).

is stronger as we move away from this value towards low and high GDP values, as illustrated by Figure II.4b.

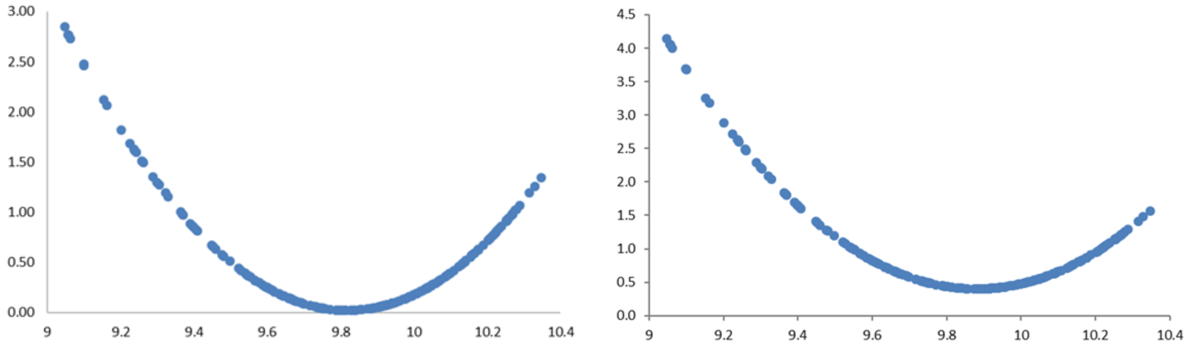
Figure II.4: The estimated relationship between GDP and CO2 [aggregated analysis]


(4a) the estimated relationship CO2/GDP (4b) the derivative $dCO2/dGDP$

II.4.2. Robustness: alternative methods

So far, our findings were based on the MG estimator. In the following, we explore the robustness of our results to the use of two alternative estimators, namely MG-FMOLS and AMG. Estimations reported in columns (2) and (3) of Table II.5 show the following. First, all variables exert a significant effect on CO2, and their sign is consistent with what was previously found using the MG estimator. In particular, the coefficient of the CDP term is significant in the AMG estimation, suggesting the presence of some common CO2 dynamics that may be related, among others, to some footprints associated with the past communist regime. Second, estimations in the corresponding columns of Table A-II.3 in the Appendix reveal a negative and significant coefficient of the error correction term (*ECT*), supporting the long-run relationship between GDP and CO2 arising from the MG-FMOLS and AMG estimators. Third, this relationship is increasing, and the GDP level associated to a change in its concavity is comparable to our previous estimations based on MG, namely around 9.82 (18,400 USD) and 9.88 (19,600 USD) respectively. Finally, as shown by Figures II.5a-b, the change in CO2 following a change in GDP follows the same U-shape as for the MG estimator, and still displays important differences in magnitude for low and high GDP values.

Figure II.5: The estimated relationship between GDP and CO2 [aggregated analysis: robustness]


(a) derivative (MG-FMOLS estimator) (b) derivative (AMG estimator)

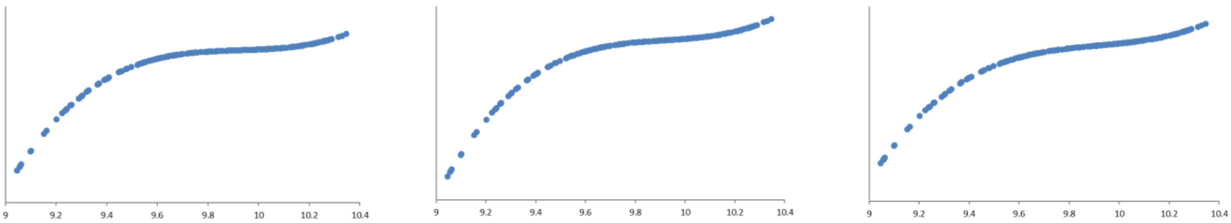
II.4.3. Robustness: additional controls

First, previous evidence suggests the presence of a unit root in our series. In order to see if our results are polluted by the presence of persistence, we include lagged main variables in the main regressions. Columns (1a)-(1b)-(1c) in Table II.6 provide estimations with the lagged value of CO2 and of GDP. Estimations show a certain persistence in the dynamic of CO2, as in some specifications lagged CO2 is significant and positive, as well as a negative impact of lagged GDP on CO2 that may be consistent with beneficial environmental effects in terms of CO2 reduction arising from higher GDP in the past. Based on these estimations, the charts in Figure 6 below reveal a monotonically-increasing link between GDP and CO2 in all models, consistent with our main results. Consequently, accounting for these variables leaves qualitatively unchanged the relationship between CO2 and GDP, which still displays the monotonically-increasing shape already emphasized.

Moreover, to further validate the findings, Table A-II.6 in the Appendix displays the results of the panel error correction model with lagged values of the main variables, namely real GDP per capita and CO2 per capita. On the whole, the effect of the terms in the change of GDP is comparable with benchmark estimations (namely: positive-negative-positive for the linear-square-cube change in GDP).

Second, we extended the cointegration vector to account for several additional variables. In column (4) of Table II.6 we consider the effect of globalization (*GLOB*), measured by the log of the globalization index of the KOF Swiss Economic Institute (see Dreher, 2006, and Gygli et al., 2019), to capture the important structural transformations of CEE countries starting the 1990s. Although globalization is not found to significantly affect CO2 (see column (4)), the significance and shape of the effect of GDP on CO2 are consistent with the main estimations. Additional estimations based on a wide number of alternative measures of globalization confirmed the lack of a significant effect on CO2, and the robustness of the GDP-CO2 relationship in the largest majority of cases (see in the Appendix Tables A-II.7-10 for variables' description and results, and Figure A-II.2 for the estimated relationship between GDP and CO2, respectively).

Figure II.6: The estimated relationship between GDP and CO2 [aggregated analysis], in the presence of GDP and CO2 lags



(6a) **(6b)** **(6c)**

Third, we account for a large number of additional control variables that may seize different countries' structural characteristics (see Table A-II.1 in the Appendix for definitions of these variables). In column (3) of Table II.6 we account for the sectoral structure of the economies between agriculture (*AGR*), industry (*IND*), and services (*SERV*), all expressed in percentage of GDP. Next, given the extent of privatizations in these countries, column (4) adds the influence of foreign direct investment (*FDI*). Moreover, to seize changes on the labor market, column (5) includes labor productivity (*LABORPROD*). In addition, column (6) includes the economic complexity index (*ECI*) that may capture overall changes in productive capacities. Finally, the human development index (*HDI*) introduced in column (7) is intended to control for a wider perspective of economic development. Results in columns (3)-(7) show that the impact of these variables on CO2 is mostly not significant, confirming the robustness of our main specification. More importantly, accounting for them leaves qualitatively unaffected the impact of GDP on CO2, which describes a monotonically-increasing shape consistent with our benchmark estimations (see Figure A-II.3 in the Appendix for the estimated relationship between GDP and CO2).

Table II.6: Robustness: additional variables

Dependent variable: CO2					
	(1a)	**(1b)**	**(1c)**	**(2)**	**(3)**
GDP	880.963**	842.512**	678.545**	764.535**	803.014*
	(429.583)	(424.400)	(334.629)	(329.586)	(464.291)
GDP^2	-88.756**	-84.923**	-68.401**	-77.127**	-81.099*
	(43.157)	(42.707)	(33.573)	(33.285)	(46.811)
GDP^3	2.981**	2.854**	2.299**	2.594**	2.730*
	(1.445)	(1.432)	(1.122)	(1.120)	(1.573)
ENG	1.042***	1.113***	0.977***	1.151***	1.066***
	(0.088)	(0.117)	(0.102)	(0.113)	(0.115)
ECFR	-0.244**	-0.241**	-0.154	-0.131*	-0.233**
	(0.117)	(0.116)	(0.115)	(0.074)	(0.108)
$CO2_{(t-1)}$	0.097*		0.147***		
	(0.054)		(0.047)		
$GDP_{(t-1)}$		-0.137*	-0.213***		
		(0.075)	(0.072)		
GLOB				-0.300	
				(0.240)	
AGR					0.050
					(0.042)
IND					-0.047
					(0.175)
SERV					0.067
					(0.448)
FDI					
LABORPROD					
ECI					
HDI					
Observations	209	209	209	220	220
Pattern	increasing	increasing	increasing	increasing	increasing
GDP for concavity change	9.9239	9.9179	9.9148	9.9099	9.9000

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

(**Table II.6:** continued)

Dependent variable: CO2				
	(4)	**(5)**	**(6)**	**(7)**
GDP	794.784**	682.815**	687.529***	808.657**
	(389.377)	(272.722)	(228.463)	(350.066)
GDP^2	-80.263**	-68.713**	-69.637***	-81.122**
	(39.244)	(27.369)	(23.031)	(35.242)
GDP^3	2.702**	2.305**	2.351***	2.712**
	(1.318)	(0.915)	(0.773)	(1.183)
ENG	1.063***	1.060***	1.093***	1.051***
	(0.115)	(0.099)	(0.090)	(0.080)
ECFR	-0.249**	-0.234***	-0.246***	-0.145
	(0.102)	(0.078)	(0.060)	(0.098)
$CO2_{(t-1)}$				
$GDP_{(t-1)}$				
GLOB				
AGR	0.035	0.016	0.045	0.047
	(0.038)	(0.039)	(0.042)	(0.038)
IND	-0.003	-0.040	0.014	-0.097
	(0.182)	(0.164)	(0.162)	(0.182)
SERV	-0.015	-0.180	0.012	-0.006
	(0.462)	(0.476)	(0.395)	(0.361)
FDI	0.005	0.006	0.006	0.027
	(0.014)	(0.021)	(0.023)	(0.027)
LABORPROD		0.011	0.058	0.007
		(0.230)	(0.203)	(0.158)
ECI			-0.032	-0.033
			(0.058)	(0.053)
HDI				-0.887
				(0.819)
Observations	220	220	220	220
Pattern	increasing	increasing	increasing	increasing
GDP for concavity change	9.9008	9.9361	9.8726	9.9672

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

II.4.4. Alternative measures of environmental quality

Our analysis is conducted using CO2 as a measure of environmental quality. Although this is the most popular measure in the literature, we draw upon existing studies that considered alternative measures of environmental quality. Using the main specification, Table II.7 reports the estimated effect of GDP on the log of per capita biocapacity (*BIOCAP*) as a measure of the capacity of the biosphere to regenerate; the log of per capita ecological footprint (*ECOFT*) as a measure of natural resources required for humans' needs; and the log of per capita sulphur dioxide (*SO2*). When considering the significance of the largest GDP polynomial across the three methods used (MG, MG-FMOLS, and AMG), results are consistent with our main findings. Indeed, except for the absence of a nonlinear effect on

ECOFT,[5] the influence of GDP on different measures of environmental quality displays the monotonically-increasing shape that we emphasized for CO2. Consequently, our main results are confirmed when using several alternative measures of environmental quality.

Table II.7: Aggregated estimates with alternative measures of environmental quality

Dependent variable	**BIOCAP**	**ECOFT**	**SO2**
	(1)	**(2)**	**(3)**
GDP	886.597***	0.204*	6420.179*
	(234.709)	(0.118)	(3914.598)
GDP^2	-90.669***		-642.467*
	(23.692)		(393.764)
GDP^3	3.093***		21.413*
	(0.798)		(13.209)
Main specification	Yes	Yes	Yes
Estimator	All (MG reported)	All (MG reported)	MG
Type of relation	Similar to CO2	Linear	Similar to CO2
Observations	209	209	207

Notes: Reported aggregate results with alternative measures of environmental quality (biocapacity, ecological footprint, and sulphur dioxide emissions), are selected based on the significance of the largest polynomial GDP variable with the three considered estimators MG, MG-FMOLS, AMG. The analyzed period is 1996-2014 for BIOCAP and ECOFT (the 1996 data for Bulgaria was extrapolated), and 1996-2015 for SO2 (due to some missing data, the panel is unbalanced). Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in round brackets, p-values in square brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

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[5] Several existing studies fail to find nonlinearities between GDP and ecological footprint; see the excellent review of Destek et al. (2018). Besides, similar to Ulucak & Bilgili (2018), an inverted-U curve would emerge in our analysis if we take out energy consumption.

II.5. Results: country analysis

Estimations performed at the aggregated level reveal that the shape of the CO2-GDP relationship is monotonically-increasing, and in particular there are no turning points despite the presence of nonlinear terms (GDP2 and GDP3). The absence of turning points at the aggregated level may be due to, among others, either the lack of such turning points for the majority of countries in our sample, or to the presence of opposite dynamics at country-level that somehow compensate at the aggregated level. Therefore, adding to the previous section devoted to an aggregated analysis, we explore in this section potential country-specificities in the relationship between GDP and CO2, all the more that, as previously emphasized, the CEE countries in our sample are characterized by heterogeneity. To better focus on such heterogeneities, we draw upon the AMG estimator, which conveniently filters common dynamic effects.

II.5.1. Results

Estimations that assume a cubic relationship between GDP and CO2 are reported in Table II.8. Interestingly, only in four countries (Croatia, Estonia, Poland, and Slovakia), the effects of the three polynomial terms in GDP are statistically significant. Besides, while in Croatia and Estonia results seem to suggest the presence of an *N*-curve, in Poland and Slovakia the estimated link seems to follow an inverted-*N* pattern.

Keeping these results in mind, we assume next a quadratic function for the remaining CEE countries. Estimations presented in Table II.9 show that the effect of the two GDP terms is statistically significant in Bulgaria, Czech Republic, Hungary, and Latvia, and only slightly not significant in Slovenia (the associated p-values equal 0.13 and 0.12). However, while in the Czech Republic and Hungary the relationship between GDP and CO2 seems to present an inverted-U shape, a U-shaped pattern seems to occur for Bulgaria and Latvia.

Finally, estimations in Table II.10, in which we assume a linear relationship for the remaining CEE countries, reveal a positive link in Lithuania, and the absence of a statistically-significant relationship between GDP and CO2 in Romania and Slovenia.

Table II.8: Country-specific estimates [cubic specification]

	Bulgaria	*Croatia*	Czech R.	*Estonia*	Hungary	Latvia	Lithuania	*Poland*	Romania	*Slovakia*	Slovenia
GDP	298.0	3102.4***	953.8	546.8**	520.6	11.5	-160.0	-225.6***	467.7	-476.7***	743.4
	(806.9)	(256.5)	(822.0)	(227.8)	(888.1)	(170.8)	(282.6)	(83.1)	(453.3)	(180.3)	(1151.6)
GDP^2	-32.27	-316.61***	-93.00	-55.73**	-51.87	-1.48	16.48	23.11***	-48.43	48.34***	-73.22
	(27.29)	(82.70)	(81.53)	(23.08)	(89.77)	(17.75)	(28.71)	(8.51)	(47.16)	(18.24)	(114.02)
GDP^3	1.165	10.769***	3.022	1.893**	1.723	0.060	-0.563	-0.789***	1.670	-1.633***	2.403
	(0.968)	(2.824)	(2.695)	(0.779)	(3.024)	(0.614)	(0.972)	(0.289)	(1.634)	(0.614)	(3.761)
Controls	Yes										
CDP	Yes										

Notes: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table II.9: Country-specific estimates [quadratic specification]

	Bulgaria	Czech R.	*Hungary*	*Latvia*	Lithuania	Romania	Slovenia
GDP	-8.914*	38.872**	33.573***	-5.184***	1.534	7.405	15.291
	(5.147)	(19.724)	(10.720)	(1.693)	(4.954)	(6.677)	(10.140)
GDP^2	0.488*	-1.920**	-1.684***	0.265***	-0.043	-0.378	-0.762
	(0.269)	(0.968)	(0.536)	(0.087)	(0.249)	(0.346)	(0.495)
Controls	Yes						
CDP	Yes						

Notes: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table II.10: Country-specific estimates [linear specification]

	Lithuania	Romania	Slovenia
GDP	0.802***	0.155	-0.055
	(0.095)	(0.211)	(0.214)
Controls	Yes		
CDP	Yes		

Notes: Common Dynamic Process (CDP) included as an additional regressor. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

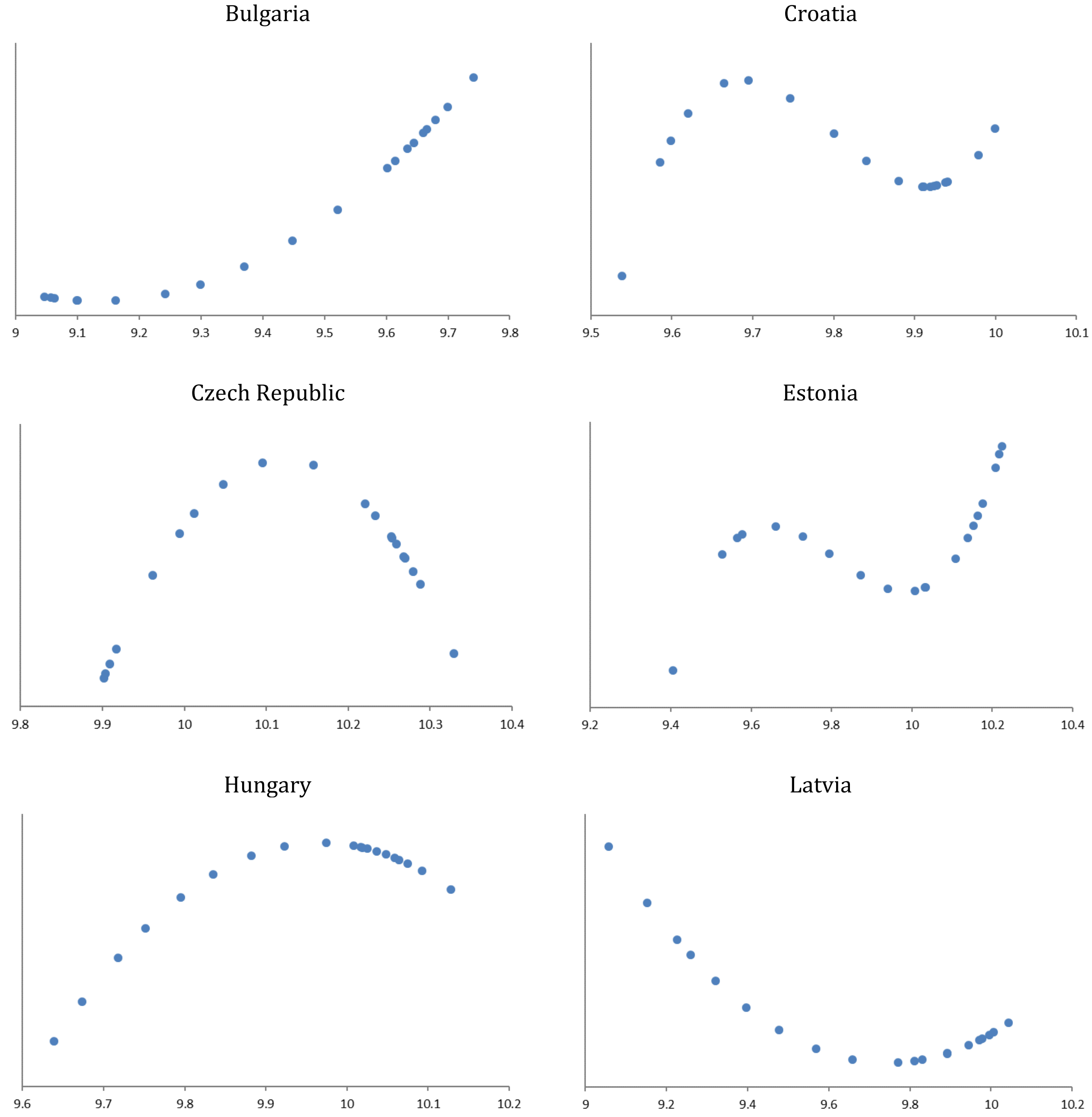
II.5.2. Patterns

Country-level results revealed differences among the eleven CEE countries in our panel. For a better view, Figure II.7 depicts the relationship between GDP and CO2 for the nine CEE countries in which a statistically-significant link was found.

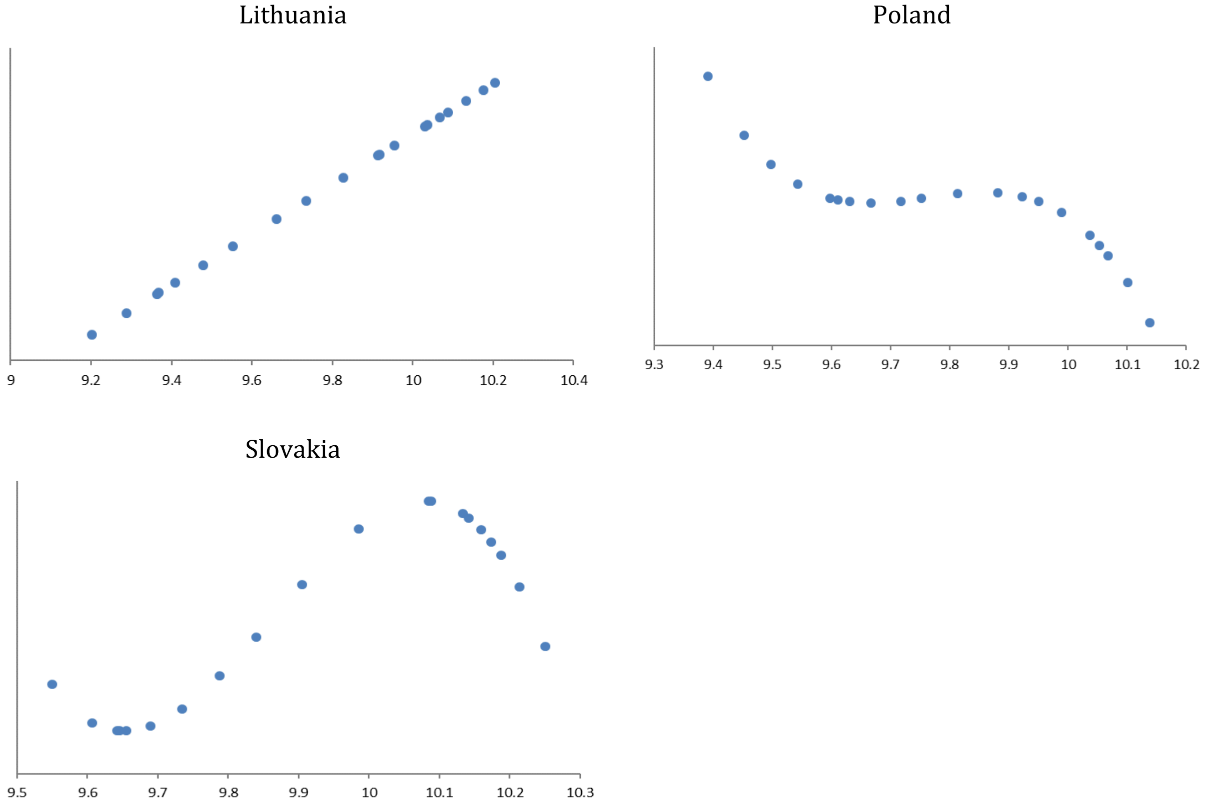
From a general perspective, these charts reveal important heterogeneities in the relationship between GDP and CO2 among the CEE countries in our panel, as several patterns emerge. First, Croatia and Estonia are characterized by an extended EKC *N*-shaped curve, suggesting that further economic development might be associated with an increase in CO2 emissions. Second, such an extended EKC was equally found in Poland and Slovakia, except that its shape is inverted-*N*. In these countries, further economic growth and lower CO2 emissions seem to be possible. Third, the Czech Republic and Hungary display traditional inverted-U EKC, in which further economic development might be associated with a decline in CO2 emissions. Fourth, on the contrary, in Bulgaria and Latvia the relationship follows a U-shape, suggesting that future economic growth might be associated with increasing CO2 emissions. Fifth, no threshold effects were found in Lithuania, in which the GDP-CO2 link is positive. Finally, in Romania and Slovenia our results suggest the absence of a clear-cut statistical relationship between GDP and CO2.

This multitude of shapes reveals the complexity of the relationship between GDP and CO2 in CEE countries. In particular, there is a striking difference with respect to the monotonously-increasing link emphasized for the entire sample. Taken together, these two findings suggest that adopting a policy that may seem appropriate at the aggregated level may result in unwanted consequences in some CEE countries.

Figure II.7: The estimated relationship between GDP and CO2 [country analysis]



(**Figure II.7:** continued)



II.5.3. Turning points

Turning points in the relationship between pollution and economic development received much attention in the related empirical literature, mainly with respect to the estimated values, while Bernard et al. (2015) provide an excellent analysis of their mere existence. Overall, there is hardly any consensus, as existing studies highlight that their exact values depend upon a large number of factors, such as e.g. the level of economic development, the variables used as a proxy for environmental quality, or the model employed (see e.g. Lopez-Menendez et al., 2014, or Sulemana et al., 2017, for recent studies emphasizing such differences in estimated GDP values related to CO2 emissions turning points).

In our analysis, the presence of different GDP values for turning points (see Table II.11) is somehow insulated from these sources of heterogeneity, since they are obtained using the same method (AMG estimator), for the same pollutant (CO2), and when controlling for the same domestic (energy consumption) and external (economic freedom) factors. Consequently, differences in these turning points may well reproduce structural heterogeneities among the CEE countries in our sample.

Table II.11: Turning points

Country	Cubic function	Quadratic function
Croatia	*peak*: 9.6866 ($16,100) trough: 9.9132 ($20,195)	
Estonia	*peak*: 9.6437 ($15,424) trough: 9.9836 ($21,668)	
Poland	trough: 9.6666 ($15,782) *peak*: 9.8593 ($19,135)	
Slovakia	trough: 9.6523 ($15,558) *peak*: 10.0778 ($23,809)	
Bulgaria		trough*:* 9.1327 ($9,253)
Czech R.		*peak:* 10.1216 ($24,875)
Hungary		*peak*: 9.9677 ($21,326)
Latvia		trough: 9.7467 ($17,098)

Notes: Local extrema are computed using the first derivative of CO2 with respect to GDP. All reported estimated GDP values associated with turning points are in the range of observed GDP values for each country.

According to Table II.11, the estimated GDP turning points are fairly different across countries. For example, considering the case in which no other turning point follows a peak, the peak in CO2 emissions is estimated at around (in thousands USD) 19 for Poland, 21 for Hungary, 24 for Slovakia, and 25 for the Czech Republic, namely a difference of up to around 30% among countries. In the same vein, considering the case in which no other turning point precedes a trough, the trough in CO2 emissions is estimated at around (in thousands USD) 9 for Bulgaria, 16 for Poland and Slovakia, 17 for

Latvia, namely a difference of up to around 80% between countries. Besides, after a peak at around 15 (16), Estonia (Croatia) experiences a trough at around 22 (20), namely before the peak of 25 in the Czech Republic. Similarly, following a trough at around 15, Poland experiences a peak at 19, namely before the trough of 20 in Latvia.

II.5.4. Discussion

The simple comparison of the shape of the CO2-GDP relationship and its turning points reveals important differences across countries. Although identifying such differences is a fairly complicated task, we can take a closer look at (i) the link between aggregated and disaggregated estimations and (ii) several important structural characteristics of the CEE countries, in search of some potential common patterns.

II.5.4.1. The link between aggregated and disaggregated estimations

We classify the countries in several subsamples in order to try to infer some additional results that may complete those at the panel level and country level. On the one hand, we distinguish between countries for which we identify tipping points Sub A1 (i.e. in which significant GDP3 or GDP2 coefficients lead to tipping points that are located inside the sample, namely, Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Poland, and Slovakia), and countries for which there were not tipping points Sub A2 (i.e. in which at most the coefficient of GDP was significant, namely, Lithuania, Romania, and Slovenia). On the other hand, we distinguish between countries for which the GDP-CO2 relationship is increasing for large GDP values Sub B1 (i.e. *N*-shaped in Croatia and Estonia, U-shaped in Bulgaria and Latvia, and monotonically-increasing in Lithuania), and decreasing for large GDP values Sub B2 (i.e. inverted-*N* shaped in Poland and Slovakia, and inverted-U shaped in the Czech Republic and Hungary). Tables II.12-13 below report the estimations for each of the four subsamples. Estimations show that, despite presenting the expected sign, the coefficient of the GDP terms is rarely significant when we consider cubic or square GDP polynomials. Consequently, even when looking at a more homogenous group of countries, it is not easy to identify a common relationship between GDP and CO2.

Table II.12: Aggregated estimates on subsamples [nonlinear versus linear]

Dependent variable	**CO2 (Sub A1)**	**CO2 (Sub A1)**	**CO2 (Sub A2)**	**CO2 (Sub A2)**
	(1) Nonlinear	**(1) Nonlinear**	**(2) Linear**	**(2) Linear**
GDP	69.418	-0.250	404.461	5.861
	(293.027)	(3.790)	(255.363)	(6.897)
GDP^2	-7.274	0.022	-40.543*	-0.269
	(29.726)	(0.191)	(25.241)	(0.348)
GDP^3	0.254		1.356*	
	(1.005)		(0.832)	
ENG	1.011***	0.991***	0.693**	0.677**
	(0.060)	(0.065)	(0.313)	(0.294)
ECFR	-0.026	0.034	-0.295***	-0.387***
	(0.055)	(0.098)	(0.098)	(0.109)
CDP	0.989***	1.136***	0.789***	0.786***
	(0.209)	(0.195)	(0.179)	(0.214)
Observations	160	160	60	60

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table II.13: Aggregated estimates on subsamples [increasing versus decreasing]

Dependent variable	**CO2 (Sub B1)**	**CO2 (Sub B1)**	**CO2 (Sub B2)**	**CO2 (Sub B2)**
	(3) Increasing	**(3) Increasing**	**(4) Decreasing**	**(4) Decreasing**
GDP	648.399	-1.294	95.454	3.698
	(565.656)	(5.220)	(217.108)	(5.542)
GDP^2	-66.395	0.070	-9.062	-0.164
	(57.647)	(0.267)	(21.434)	(0.274)
GDP^3	2.266		0.287	
	(1.958)		(0.705)	
ENG	0.927***	0.954***	0.632***	0.634***
	(0.170)	(0.163)	(0.101)	(0.132)
ECFR	-0.095	-0.154	0.020	0.047
	(0.190)	(0.239)	(0.100)	(0.121)
CDP	0.789**	0.870**	0.973***	1.040***
	(0.371)	(0.352)	(0.187)	(0.228)
Observations	100	100	80	80

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

II.5.4.2 Structural characteristics of the CEE countries

Regarding the important structural characteristics, after dropping countries in which the relationship between CO2 and GDP is not statistically significant (Slovenia and Romania), we split the remaining countries into two groups based on the sign of the relationship for large GDP values. Indeed, looking at large GDP values could provide information about the CO2 dynamics in the years to come, given that all countries in our sample present an upward trend in GDP during the studied period. The first group contains countries in which a higher GDP increases CO2 for large GDP values, namely: Croatia and Estonia (*N*-shaped), Bulgaria and Latvia (U-shaped), and Lithuania (monotonically increasing). The second group includes countries where a higher GDP reduces CO2 for large GDP values, namely: Poland and Slovakia (inverted-*N*), and the Czech Republic and Hungary (inverted-U). Then, we look at the relative ranking of the countries in the two groups with respect to the decreasingly-ordered variables included in columns (3)-(7) of Table II.6, namely: agriculture, industry, services, foreign direct investment, labor productivity, the economic complexity index, and the human development index (see Tables A-II.11-17 in the Appendix for further details).

The results can be summarized as follows. The first three countries with the highest share of agriculture—on average during the period 1996-2015—belong to the first group, while the two countries with the lowest share of agriculture are from the second group. Next, the clustering of countries is more pronounced if we consider the share of the industry: the first three (last four) countries with the highest average industry share in GDP belong to the second (first) group. In addition, the first (last) three countries with the highest (lowest) average share of services in GDP belong to the first (second) group. Therefore, the structure of the economy seems to matter, as further increases in GDP in the years to come may be associated with lower CO2 emissions in countries in which the agriculture and the services sectors are relatively weak, and the industry sector is relatively large. Assuming that the industry sector is the largest contributor to CO2 emissions, this finding may be related to the fact that CEE countries that present a relatively important industry sector are those that managed to transform their obsolete plants into newer plants that benefit of cleaner technologies.

Moreover, while no clear patterns seem to emerge with respect to the share of foreign direct investment, the first (last) three countries with the highest (lowest) labor productivity belong to the second (first) group. A possible explanation is that high labor productivity may go hand in hand with newer, and possibly less polluting, technologies. This can be all the more the case that allows the best identification of the two groups is the economic complexity index: the first four countries with the highest ECI belong to the second group, while the remaining five countries with the lowest ECI are part of the first group. Economic complexity can signal the presence of new and complex productive technologies, such as an increase in GDP may be associated with a reduction of CO2 emissions.

Finally, except for Estonia, the first five countries with high average levels of the human development index belong to the second group, and the four countries with the lowest HDI belong to the first group. This suggests that increases in GDP could be associated with lower CO2 emissions in countries with relatively high levels of HDI, probably because a large HDI is equally reflecting an important interest for a wide range of economic goals, including environmental quality.

II.6. Policy implications, and future research topics

We analyzed in this paper the relationship between CO2 and GDP in CEE countries. While at the aggregated level, an increase in GDP was found to be robustly associated with an increase in CO2 (whose magnitude depends on the GDP level), strong differences in the shape of this relationship were unveiled at the country level. These differences span from the absence of a statistically significant link to the presence of multiple thresholds and result in particular into strong heterogeneities regarding the turning points in the GDP-CO2 link in CEE countries.

Considering the overall findings, some important policy implications could be emphasized. Despite an aggregated upward trend of the CO2-GDP link, some CEE countries managed to secure both higher GDP and lower CO2 emissions. Drawing upon simple correlations that must be taken with much caution, we unveil that such a negative link between further GDP increases and lower CO2 emissions may occur in countries with a large and clean industry sector, in which high labor productivity supports complex techniques. Such countries should be analyzed more in detail, as they could provide useful insights on how to accommodate higher economic growth with a decrease in pollution, possibly complementing appropriate policies that are already known from the existing literature (e.g. the adoption of more environmentally-friendly policies, the internalization of externalities, or the adoption of regulations against pollution-havens).

From a more general perspective, our study's conclusions highlight the danger of a unique environmental policy at the EU level. Indeed, such a unique policy could differently affect CEE countries' economic activity, given the heterogeneities we emphasized in the link between pollution and economic activity at the country-level. Conversely, a policy that would account for country-differences, for example regarding the efforts that were already made to fight pollution or with respect to countries' individual CO2-GDP relationship, may outperform a unique policy in ensuring economic growth without damaging the environment.

Building on our conclusions, future work could draw upon more disaggregated country-level data to deepen our understanding of the heterogeneities we unveiled at a macroeconomic level in the pollution-growth nexus in CEE countries. In the same vein, it would be interesting to study the effect of (unexpected) changes in environmental regulation at the national level, and particularly the way firms adjust their activity to cope with such changes (possibly in relation to their production factors, and particularly research and development investment, see Alam et al., 2019). Finally, given that CEE countries are still emerging countries, a study of the population's perception of environmental goals and their integration in governments' welfare function, possibly from a political economy perspective, could foster our comprehension of motivations and challenges related to the promotion of environmental-friendly economic development.

Appendix

Table A - II.1: Variables' description

Variable	Description
CO2	CO2 per capita emissions totals of fossil fuel use and industrial processes. *Measurement unit*: tonnes *Source*: The European Commission. Janssens-Maenhout, Crippa, Guizzardi, Muntean, Schaaf, Olivier, Peters and Schure (2017) (http://edgar.jrc.ec.europa.eu/overview.php?v=booklet2017&dst=CO2pc)
GDP	GDP per capita based on purchasing power parity (PPP), constant 2011 prices. *Measurement unit*: USD *Source*: The World Bank, World Bank Indicators (http://data.worldbank.org/indicator)
ENG	Gross inland energy consumption per capita. *Measurement unit*: tonnes oil equivalent *Source*: Authors' computation based on Eurostat (gross inland energy consumption: http://ec.europa.eu/eurostat/statistics-explained/index.php?title=Consumption_of_energy) and World Bank Indicators data (population: https://databank.worldbank.org/data/home.aspx)
ECFR	The Index of Economic Freedom. *Measurement unit*: scale between 0 and 100, 0 designating the absence of economic freedom, and 100 the maximum degree of economic freedom. *Source*: The Heritage Foundation (https://www.heritage.org/index/)
GLOB	The Globalization Index. *Measurement unit*: scale between 0 and 100, 0 designating the lack of globalization, and 100 the maximum degree of globalization. *Source*: The KOF Swiss Economic Institute. Dreher (2006) and Gygli, Haelg, Potrafke and Sturm (2019) (https://www.kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html)
AGR	Agriculture, value added. *Measurement unit*: % of GDP *Source*: The World Bank, World Bank Indicators (https://databank.worldbank.org/data/home.aspx)
IND	Industry, value added. *Measurement unit*: % of GDP *Source*: The World Bank, World Bank Indicators (https://databank.worldbank.org/data/home.aspx
SERV	Services, value added. *Measurement unit*: % of GDP *Source*: The World Bank, World Bank Indicators (https://databank.worldbank.org/data/home.aspx
FDI	Foreign direct investment: Inward stock, annual. *Measurement unit*: % of GDP *Source*: The United Nations Conference on Trade and Development (https://unctadstat.unctad.org/EN/Index.html)
LABORPROD	Output per worker. *Measurement unit*: GDP constant 2011 international $ in PPP *Source*: The International Labour Organization (https://www.ilo.org/global/statistics-and-databases/lang--en/index.htm)
ECI	The Economic Complexity Index. *Measurement unit*: scale between roughly –3 and +3, with a higher value designating a higher economic complexity. *Source*: The Observatory of Economic Complexity. Haussman & Hidalgo (2009), Hausmann, Hidalgo, Bustos, Coscia, Chung, Jimenez, Simoes and Yildirim (2011) (http://chidalgo.org/Atlas/ComplexityAtlasFree.pdf, https://www.pnas.org/content/pnas/106/26/10570.full.pdf https://atlas.media.mit.edu/en/resources/methodology/)
HDI	The Human Development Index. *Measurement unit*: scale between 0 and 1, 0 designating the absence of human development, and 1 the maximum degree of human development. *Source*: The United Nations Development Programme (http://hdr.undp.org/en/content/human-development-index-hdi)

(**Table A - II.1:** continued)

Variable	**Description**
BIOCAP	Biocapacity per capita. *Measurement unit*: global hectares *Source*: The Global Footprint Network. National Footprint Accounts, 2019 Edition (http://data.footprintnetwork.org) Biocapacity captures the capacity of the biosphere to regenerate and provide natural resources and services for life.
ECOFT	Ecological Footprint per capita. *Measurement unit*: global hectares *Source*: The Global Footprint Network. National Footprint Accounts, 2019 Edition (http://data.footprintnetwork.org) The footprint captures the biologically productive land and water area an individual, population, or activity requires for producing produce all the resources it consumes, to accommodate its occupied urban infrastructure, and to absorb the waste it generates, using prevailing technology and resource management practices.
SO2	SO2 per capita emissions national total for the entire territory (based on fuel sold). *Measurement unit*: gigagrams *Source*: Authors' computation based on The European Environmental Agency (SO2 emissions: https://www.eea.europa.eu/data-and-maps) and World Bank Indicators data (population: https://databank.worldbank.org/data/home.aspx)

Table A - II.2: Descriptive statistics of the main variables

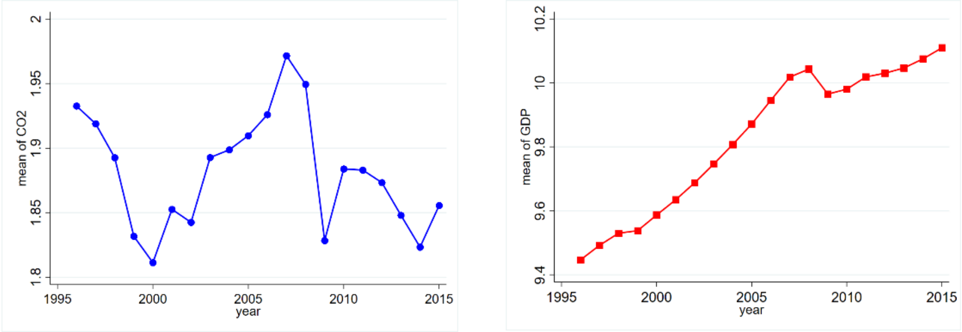
Country/Variable	**Statistic**	**CO2**	**GDP**	**ENG**	**ECFR**
Bulgaria	Min	5.88	8488.61	0.0022	45.70
	Max	7.54	17000.17	0.0027	66.80
	GR (1996-2015)	3.23	97.09	-6.2337	37.45
Czech Republic	Min	10.18	19962.96	0.0038	64.60
	Max	12.85	30605.42	0.0045	72.50
	GR (1996-2015)	-19.04	52.21	-4.0184	6.46
Croatia	Min	3.65	13886.61	0.0018	46.70
	Max	5.67	22014.71	0.0022	61.50
	GR (1996-2015)	21.67	49.49	21.6673	28.13
Estonia	Min	10.92	12144.59	0.0035	65.40
	Max	17.53	27549.58	0.0050	78.00
	GR (1996-2015)	34.31	126.85	11.4922	17.43
Hungary	Min	4.77	15347.79	0.0024	55.30
	Max	6.06	25034.45	0.0027	67.60
	GR (1996-2015)	-15.28	63.11	-2.0853	17.61
Latvia	Min	3.06	8575.31	0.0016	55.00
	Max	4.04	23018.82	0.0022	69.70
	GR (1996-2015)	2.37	168.43	18.8127	26.73
Lithuania	Min	3.32	9914.36	0.0020	49.70
	Max	4.80	27045.71	0.0029	74.70
	GR (1996-2015)	5.56	172.79	-7.8471	50.30
Poland	Min	7.54	11975.57	0.0023	56.80
	Max	9.53	25299.97	0.0026	68.60
	GR (1996-2015)	-20.84	111.26	-5.6601	18.69
Romania	Min	3.89	10264.00	0.0016	46.20
	Max	5.89	20545.08	0.0021	66.60
	GR (1996-2015)	-33.91	87.02	-22.7482	44.16
Slovakia	Min	6.62	14044.65	0.0029	53.80
	Max	8.54	28308.88	0.0035	70.00
	GR (1996-2015)	-22.11	101.56	-10.7916	16.67
Slovenia	Min	6.74	19091.07	0.0031	50.40
	Max	9.37	31137.78	0.0038	64.70
	GR (1996-2015)	-15.91	52.10	0.0946	19.64

Notes: GR (1996-2015) is the growth rate in 2015 compared with 1996.

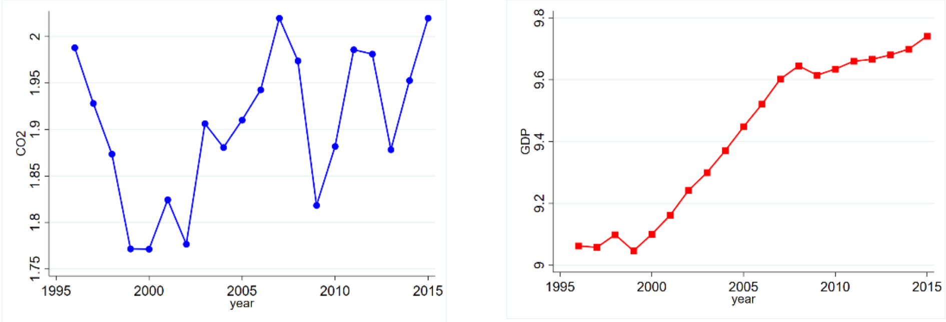
Figure A - II.1: CO2 and GDP evolution over 1996-2015

(a) CO2 **(b) GDP**

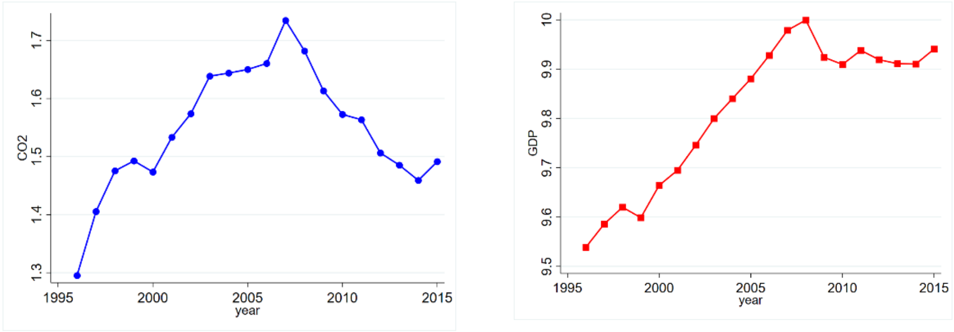
Full sample



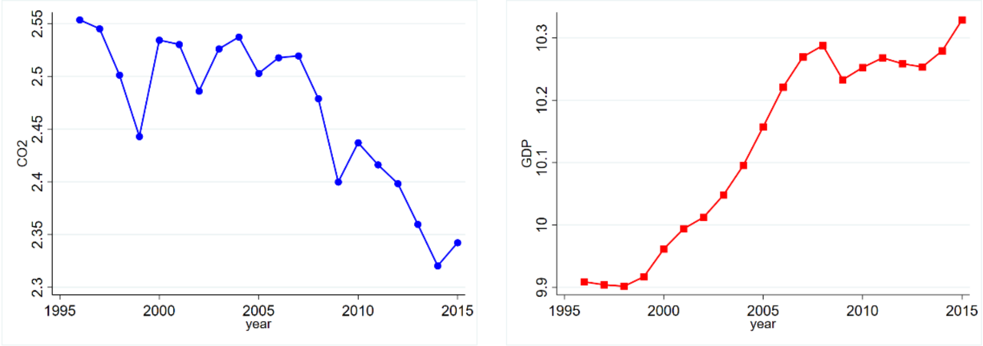
Bulgaria



Croatia



Czech Repubic

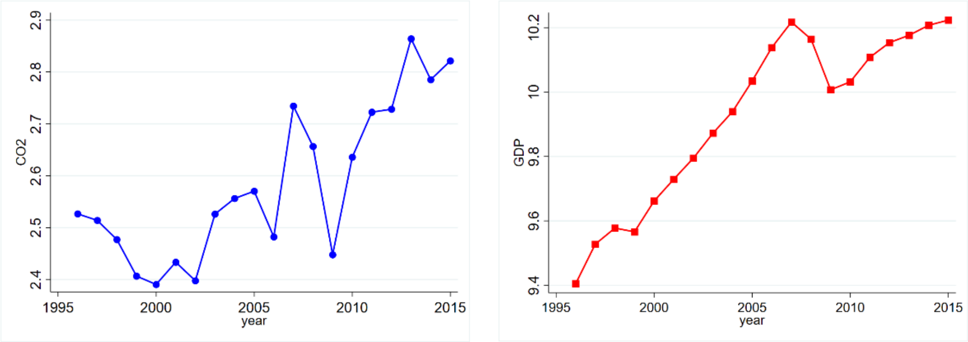


Notes: The plots refer to the natural logarithmic values of CO2 and GDP variable.

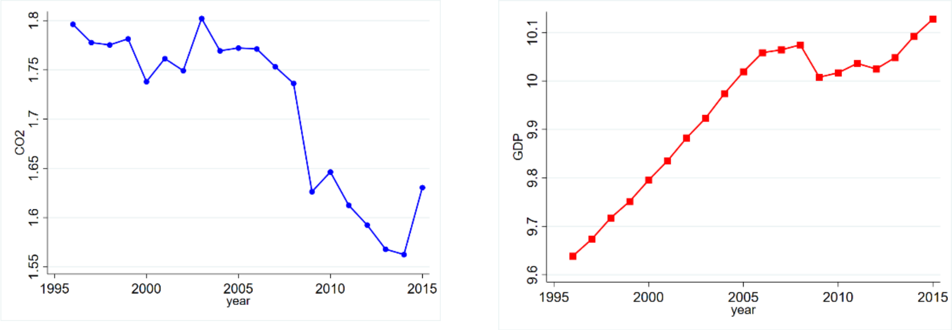
(**Figure A - II.1:** continued)

(a) CO2 **(b) GDP**

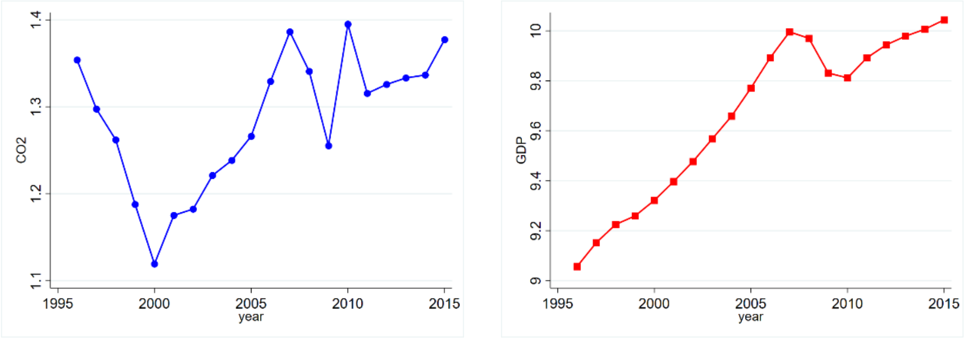
Estonia



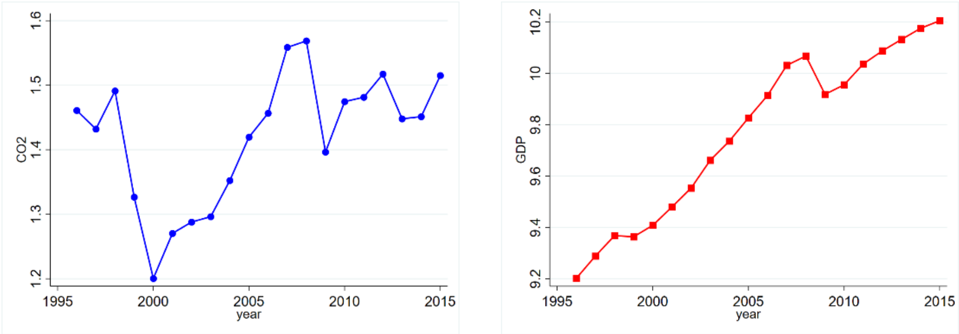
Hungary



Latvia



Lithuania

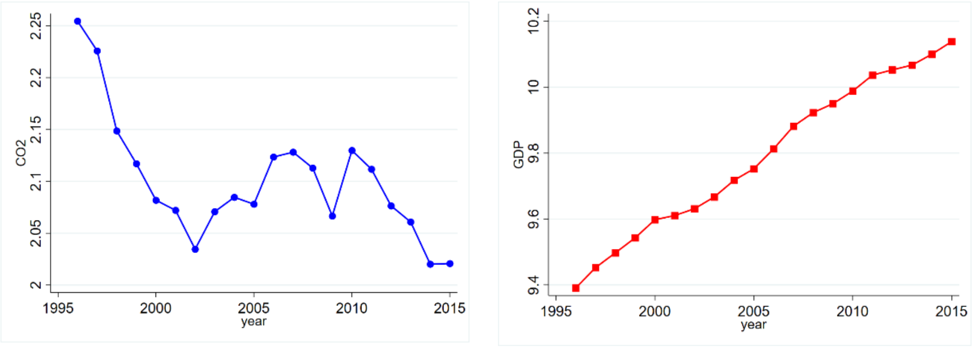


Notes: The plots refer to the natural logarithmic values of CO2 and GDP variable.

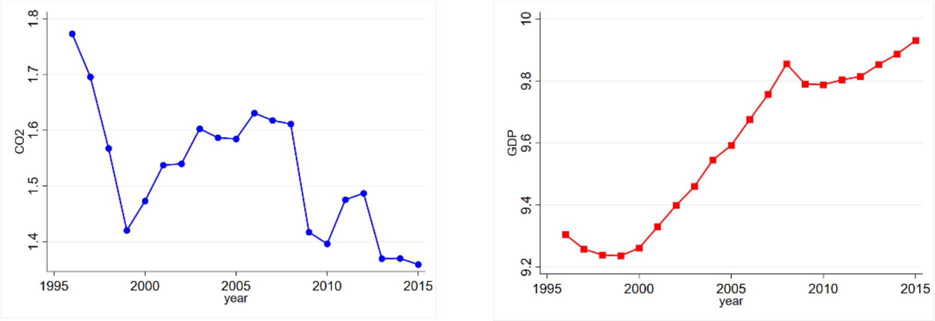
(**Figure A - II.1:** continued)

(a) CO2 **(b) GDP**

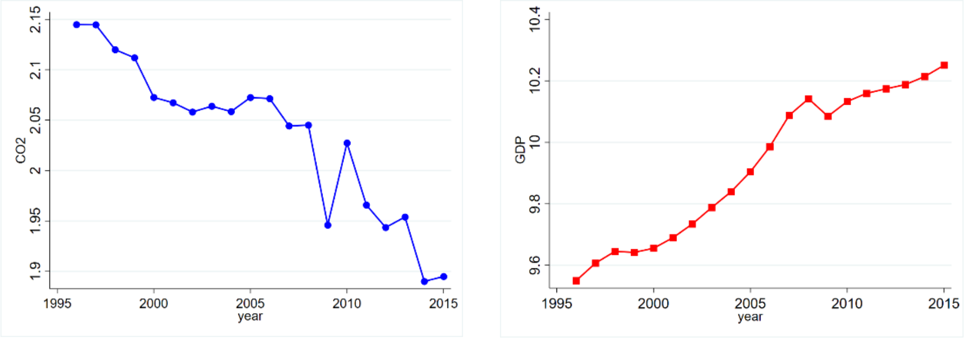
Poland



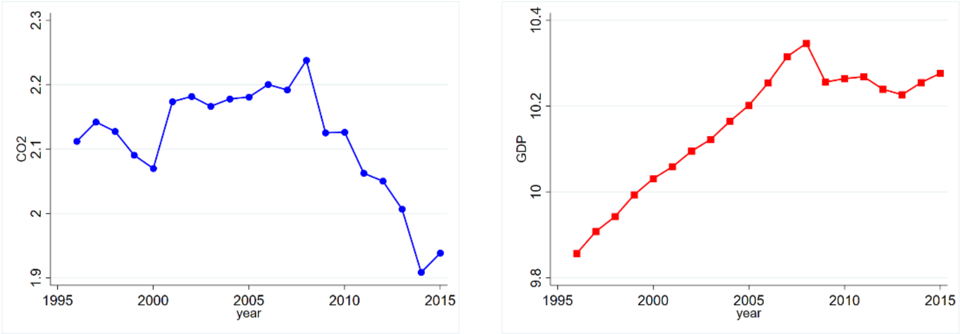
Romania



Slovakia



Slovenia



Notes: The plots refer to the natural logarithmic values of CO2 and GDP variable.

Table A - II.3: Panel ECM estimates

Dependent variable: ΔCO2			
	MG	**MG-FMOLS**	**AMG**
	(1)	**(2)**	**(3)**
ECT	**-0.837***** **(0.0814)**	**-0.208***** **(0.027)**	**-0.928***** **(0.051)**
ΔGDP	649.765** (295.844)	203.777*** (70.740)	396.562 (274.698)
ΔGDP^2	-65.528** (29.694)	-20.418*** (7.251)	-40.087 (27.932)
ΔGDP^3	2.204** (0.994)	0.683*** (0.247)	1.352 (0.947)
ΔENG	0.970*** (0.103)	1.005*** (0.036)	0.863*** (0.106)
ΔECFR	-0.152* (0.091)	-0.079* (0.048)	-0.142 (0.095)
CDP			0.745*** (0.186)
Observations	209	187	209

Notes: ECT stands for the error correction term and CDP is the common dynamic process. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - II.4: Aggregated estimates quadratic specification

Dependent variable: CO2			
	MG	**MG-FMOLS**	**AMG**
	(1)	**(2)**	**(3)**
GDP	0.277 (3.494)	0.012 (2.341)	5.829 (3.912)
GDP^2	-0.016 (0.177)	-0.002 (0.117)	-0.279 (0.197)
ENG	1.117*** (0.110)	1.126*** (0.051)	0.861*** (0.119)
ECFR	-0.171 (0.122)	-0.234*** (0.086)	-0.127 (0.132)
CDP			1.015*** (0.203)
Observations	220	209	220

Notes: Reported MG coefficients are unweighted averages across countries. Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - II.5: Aggregated estimates linear specification

Dependent variable: CO2			
	MG	**MG-FMOLS**	**AMG**
	(1)	**(2)**	**(3)**
GDP	-0.093	-0.104***	0.099
	(0.094)	(0.026)	(0.087)
ENG	1.140***	1.148***	1.007***
	(0.130)	(0.051)	(0.129)
ECFR	-0.211*	-0.211***	-0.186*
	(0.126)	(0.078)	(0.113)
CDP			0.798***
			(0.209)
Observations	220	209	220

Notes: Reported MG coefficients are unweighted averages across countries. Long-run covariances in MG-FMOLS are estimated using Bartlett kernel with Newey-West fixed bandwidth. Common Dynamic Process (CDP) included as an additional regressor in AMG, and reported coefficients are unweighted averages across countries. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - II.6: Panel ECM estimates with lagged values of the main variables

Dependent variable: ΔCO2									
	MG			**MG-FMOLS**			**AMG**		
	(1a)	**(1b)**	**(1c)**	**(2a)**	**(2b)**	**(2c)**	**(3a)**	**(3b)**	**(3c)**
ECT	**-0.985*** **	**-0.952*** **	**-1.084*** **	**-0.261*** **	**-0.313*** **	**-0.339*** **	**-1.126*** **	**-0.974*** **	**-1.062*** **
	(0.114)	**(0.083)**	**(0.104)**	**(0.058)**	**(0.052)**	**(0.058)**	**(0.073)**	**(0.066)**	**(0.107)**
ΔGDP	863.275***	713.084**	748.666**	148.976	151.169*	98.584	607.568**	506.264*	542.984*
	(336.836)	(336.059)	(316.775)	(119.179)	(93.781)	(96.684)	(282.991)	(305.091)	(306.614)
ΔGDP^2	-86.875***	-71.704**	-75.172**	-14.763	-15.049	-9.778	-61.023**	-50.963*	-54.651*
	(33.779)	(33.594)	(31.664)	(12.278)	(9.660)	(9.953)	(28.589)	(30.618)	(30.799)
ΔGDP^3	2.915***	2.404**	2.517**	0.488	0.501	0.324	2.044**	1.711*	1.834*
	(1.129)	(1.119)	(1.055)	(0.422)	(0.332)	(0.341)	(0.963)	(1.024)	(1.032)
ΔENG	0.934***	0.977***	0.958***	1.015***	1.007***	0.963***	0.819***	0.883***	0.857***
	(0.123)	(0.104)	(0.123)	(0.059)	(0.048)	(0.051)	(0.114)	(0.100)	(0.115)
ΔECFR	-0.218**	-0.161*	-0.175	-0.166**	-0.119*	-0.134**	-0.212*	-0.147*	-0.153
	(0.107)	(0.095)	(0.116)	(0.074)	(0.065)	(0.059)	(0.110)	(0.092)	(0.108)
$\Delta CO2_{(t-1)}$	0.076		0.143**	-0.038		-0.030	0.129**		0.096
	(0.049)		(0.061)	(0.038)		(0.036)	(0.054)		(0.065)
$\Delta GDP_{(t-1)}$		-0.042	-0.195***		-0.098**	-0.092**		-0.111*	-0.228***
		(0.059)	(0.075)		(0.045)	(0.047)		(0.058)	(0.069)
ΔCDP							1.017***	0.795***	0.829***
							(0.206)	(0.191)	(0.254)
Observations	198	198	198	176	176	176	198	198	198

Notes: ECT stands for the error correction term and CDP is the common dynamic process. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - II.7: Variables' description [globalization index]

Variable	Description	Source
GLOB_DF	Globalization index (de facto)	Savina, Haleg & Sturm (2018) Dreher (2006)
GLOB_DJ	Globalization index (de jure)	
GLOBEC	Economic globalization	
GLOBEC_DF	Economic globalization (de facto)	
GLOBECTR_DF	Trade globalization (de facto)	
GLOBECFF_DF	Financial globalization (de facto)	
GLOBEC_DJ	Economic globalization (de jure)	
GLOBECTR_DJ	Trade globalization (de jure)	
GLOBECFF_DJ	Financial globalization (de jure)	
GLOBSO	Social globalization	
GLOBSO_DF	Social globalization (de facto)	
GLOBSOIp_DF	Interpersonal globalization (de facto)	
GLOBSOIn_DF	Informational globalization (de facto)	
GLOBSOCu_DF	Cultural globalization (de facto)	
GLOBSO_DJ	Social globalization (de jure)	
GLOBSOIp_DJ	Interpersonal globalization (de jure)	
GLOBSOIn_DJ	Informational globalization (de jure)	
GLOBSOCu_DJ	Cultural globalization (de jure)	
GLOBPO	Political globalization	
GLOBPO_DF	Political globalization (de facto)	
GLOBPO_DJ	Political globalization (de jure)	

Table A - II.8: Aggregate estimates [de facto & de jure globalization index and economic globalization]

Dependent variable: CO2										
	MG[1]	**MG[2]**	**MG[3]**	**MG[4]**	**MG[5]**	**MG[6]**	**MG[7]**	**MG[8]**	**MG[9]**	**MG[10]**
GDP	764.535**	765.719**	825.594**	774.798**	658.224**	780.550*	607.519**	824.833**	851.021**	686.050*
	(329.586)	(327.483)	(382.523)	(357.585)	(262.758)	(420.091)	(267.967)	(380.245)	(390.476)	(399.781)
GDP^2	-77.127**	-77.103**	-83.380**	-78.247**	-66.655**	-79.029*	-61.454**	-83.338**	-85.871**	-69.935*
	(33.285)	(32.933)	(38.804)	(36.109)	(26.534)	(42.462)	(26.929)	(38.427)	(39.377)	(40.534)
GDP^3	2.594**	2.588**	2.807**	2.634**	2.250**	2.667*	2.072**	2.806**	2.888**	2.376*
	(1.120)	(1.104)	(1.312)	(1.215)	(0.893)	(1.430)	(0.902)	(1.294)	(1.323)	(1.369)
ENG	1.151***	1.160***	1.142***	1.166***	1.156***	1.073***	1.169***	1.147***	1.146***	1.120***
	(0.113)	(0.087)	(0.112)	(0.114)	(0.097)	(0.093)	(0.098)	(0.099)	(0.104)	(0.097)
ECFR	-0.131*	-0.244**	-0.165**	-0.184***	-0.238**	-0.083	-0.256***	-0.149**	-0.229***	-0.200**
	(0.074)	(0.118)	(0.075)	(0.061)	(0.119)	(0.085)	(0.074)	(0.076)	(0.074)	(0.093)
GLOB	-0.300									
	(0.240)									
GLOB_DF		0.158								
		(0.478)								
GLOB_DJ			-0.205							
			(0.187)							
GLOBEC				-0.078						
				(0.130)						
GLOBEC_DF					-0.020					
					(0.202)					
GLOBECTR_DF						-0.033				
						(0.143)				
GLOBECFF_DF							-0.000			
							(0.104)			
GLOBEC_DJ								-0.066		
								(0.076)		
GLOBECTR_DJ									-0.084*	
									(0.043)	
GLOBECFF_DJ										0.035
										(0.056)
Observations	220	220	220	220	220	220	220	220	220	220

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - II.9: Aggregated estimates [social globalization]

Dependent variable: CO2

	MG[11]	**MG[12]**	**MG[13]**	**MG[14]**	**MG[15]**	**MG[16]**	**MG[17]**	**MG[18]**	**MG[19]**
GDP	671.306**	593.027*	705.287**	646.531**	387.394	609.031**	705.287**	646.531**	448.261*
	(302.329)	(358.096)	(338.358)	(285.210)	(278.635)	(273.018)	(338.358)	(285.210)	(259.986)
GDP^2	-67.931**	-59.409*	-71.370**	-64.952**	-39.242	-61.460**	-71.370**	-64.952**	-45.069*
	(30.597)	(36.060)	(34.193)	(28.813)	(28.256)	(27.571)	(34.193)	(28.813)	(26.115)
GDP^3	2.291**	1.983*	2.407**	2.175**	1.325	2.067**	2.407**	2.175**	1.510*
	(1.032)	(1.211)	(1.151)	(0.970)	(0.955)	(0.928)	(1.151)	(0.970)	(0.874)
ENG	1.073***	1.123***	1.152***	1.142***	1.083***	1.129***	1.152***	1.142***	1.099***
	(0.111)	(0.110)	(0.108)	(0.121)	(0.113)	(0.114)	(0.108)	(0.121)	(0.102)
ECFR	-0.194***	-0.157**	-0.138***	-0.261**	-0.163***	-0.175***	-0.138***	-0.261**	-0.173**
	(0.065)	(0.071)	(0.046)	(0.103)	(0.057)	(0.058)	(0.046)	(0.103)	(0.073)
GLOBSO	-0.155								
	(0.294)								
GLOBSO_DF		0.004							
		(0.228)							
GLOBSOIp_DF			-0.103						
			(0.083)						
GLOBSOIn_DF				-0.301*					
				(0.184)					
GLOBSOCu_DF					0.078				
					(0.272)				
GLOBSO_DJ						-0.267***			
						(0.083)			
GLOBSOIp_DJ							-0.103		
							(0.083)		
GLOBSOIn_DJ								-0.301*	
								(0.184)	
GLOBSOCu_DJ									-0.108
									(0.069)
Observations	220	220	220	220	220	220	220	220	220

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

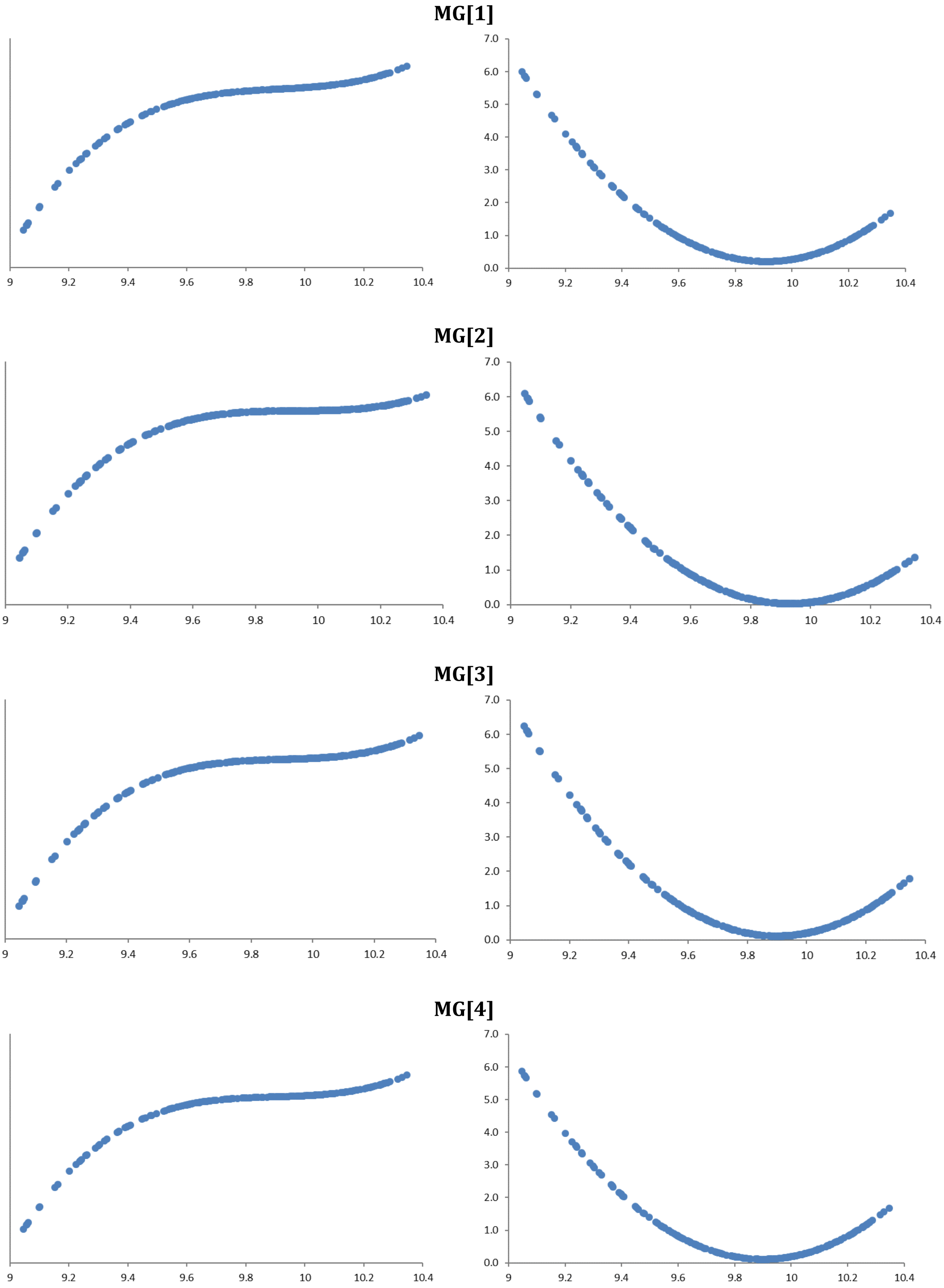
Table A - II.10: Aggregated estimates [political globalization]

Dependent variable: CO2			
	MG[20]	**MG[21]**	**MG[22]**
GDP	604.208*	660.146**	772.199**
	(311.963)	(321.565)	(346.207)
GDP^2	-61.163*	-66.727**	-78.091**
	(31.429)	(32.366)	(34.965)
GDP^3	2.064*	2.248**	2.632**
	(1.055)	(1.086)	(1.177)
ENG	1.148***	1.153***	1.158***
	(0.104)	(0.106)	(0.109)
ECFR	-0.180***	-0.169**	-0.156**
	(0.059)	(0.069)	(0.071)
GLOBPO	-0.179		
	(0.340)		
GLOBPO_DF		-0.259	
		(0.249)	
GLOBPO_DJ			-0.230
			(0.273)
Observations	220	220	220

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Figure A - II.2: The estimated relationship between GDP and CO2 [globalization control variables]

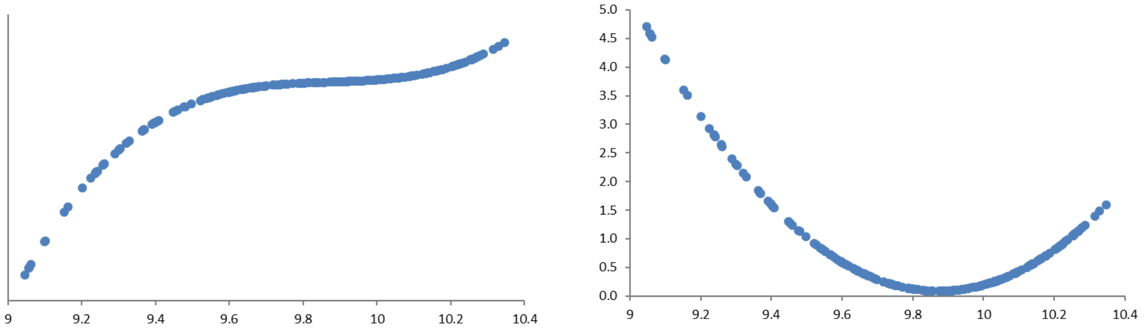
(a) the estimated relationship CO2/GDP (b) the derivative *dCO2/dGDP*



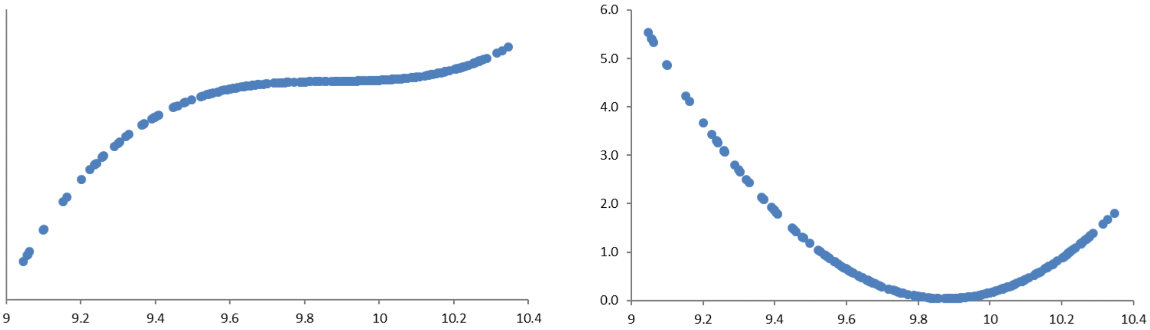
(**Figure A - II.2:** continued)

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

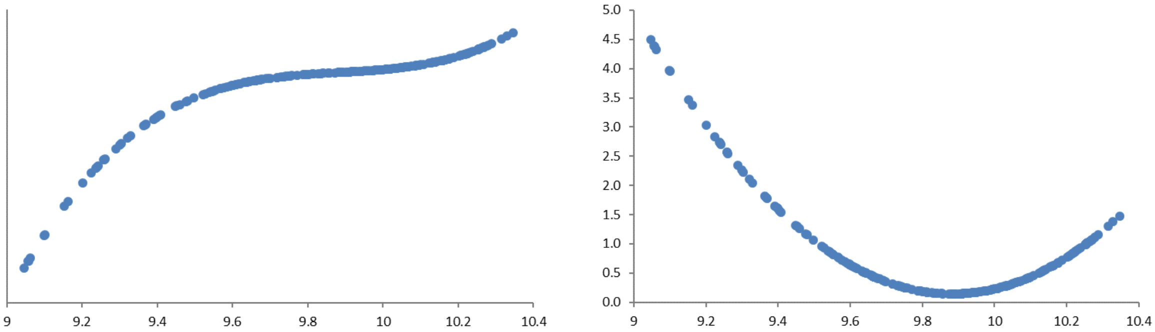
MG[5]



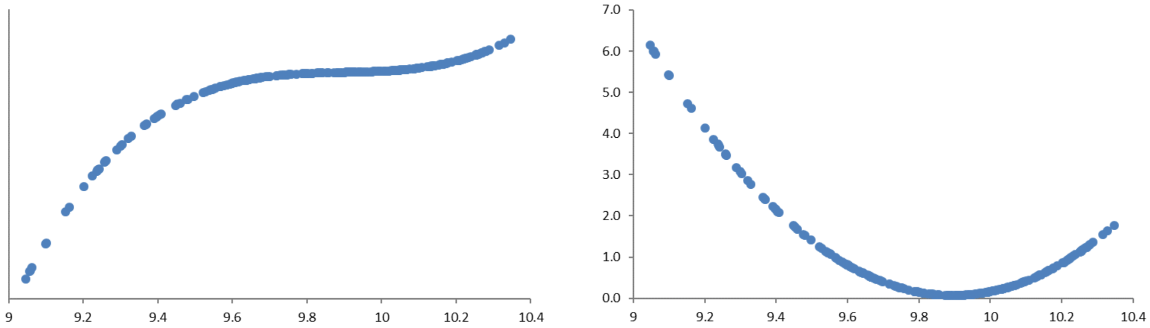
MG[6]



MG[7]



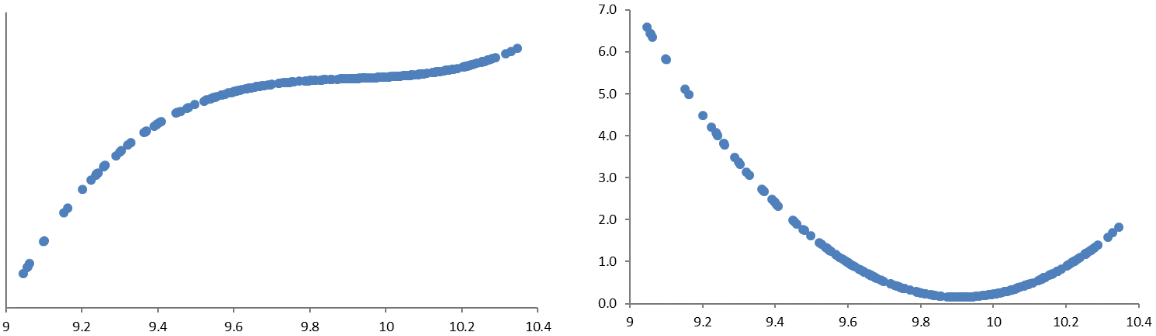
MG[8]



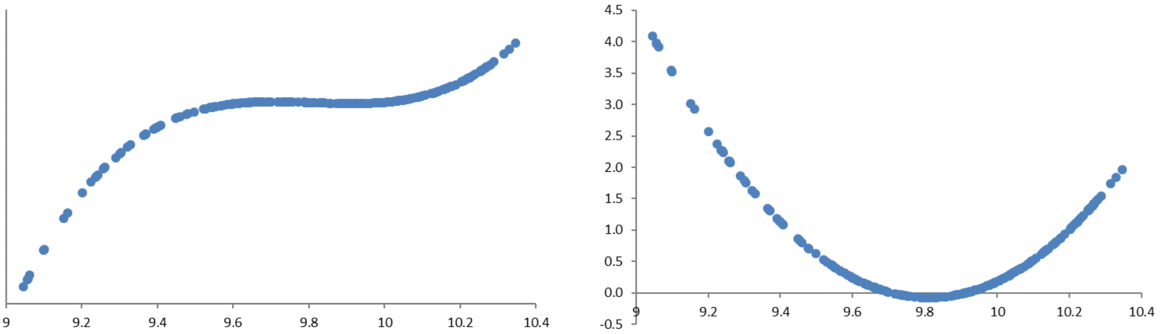
(**Figure A - II.2:** continued)

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

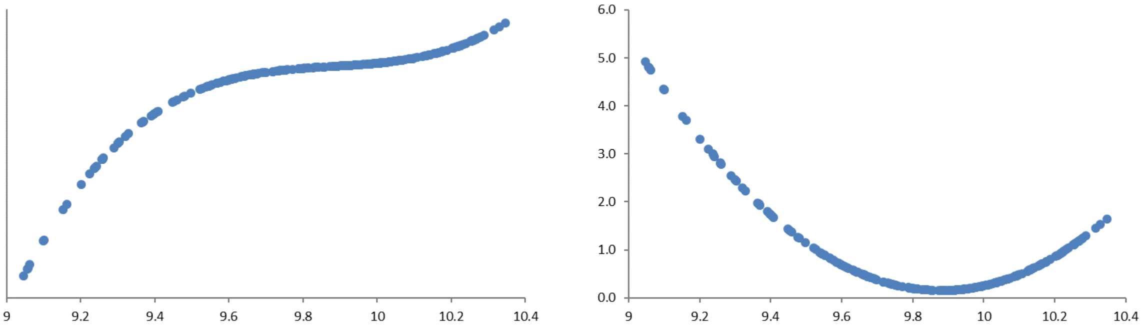
MG[9]



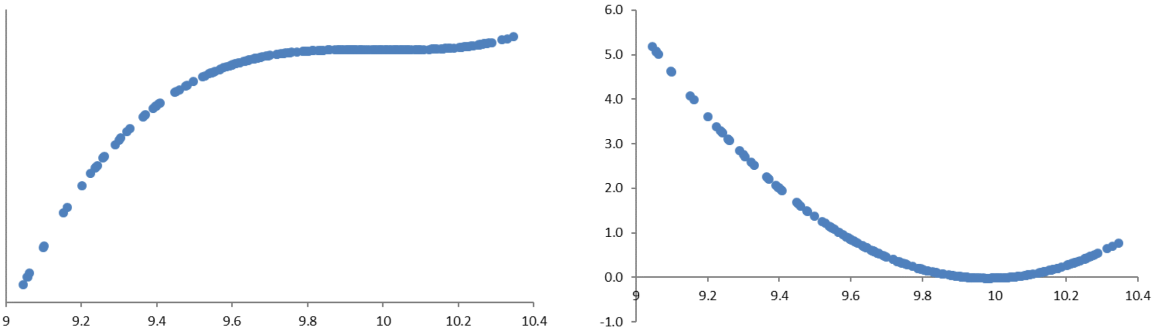
MG[10]



MG[11]



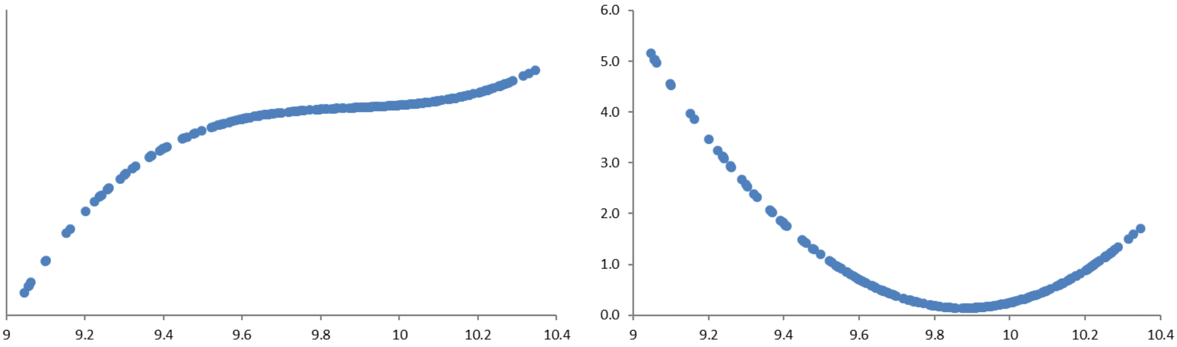
MG[12]



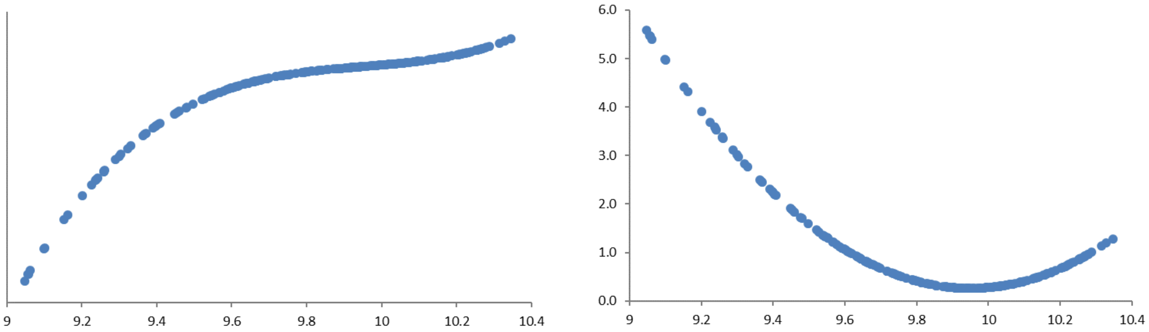
(**Figure A - II.2:** continued)

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

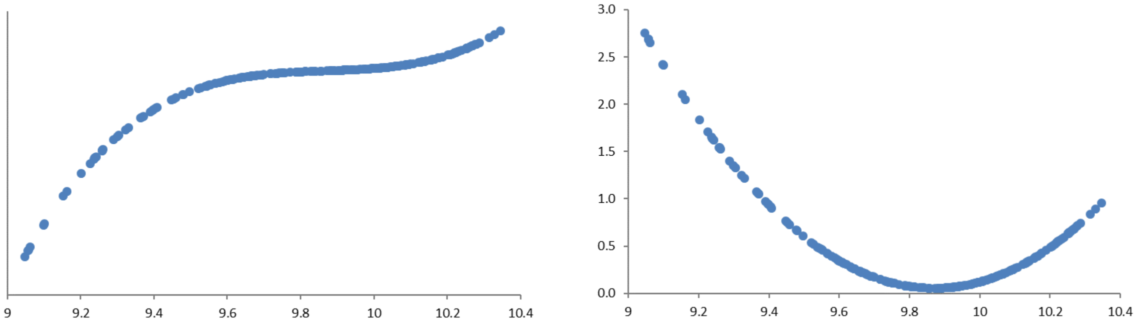
MG[13]



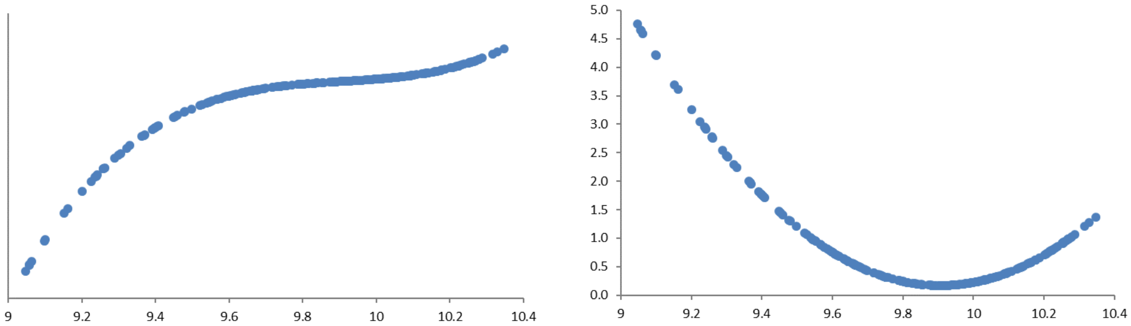
MG[14]



MG[15]



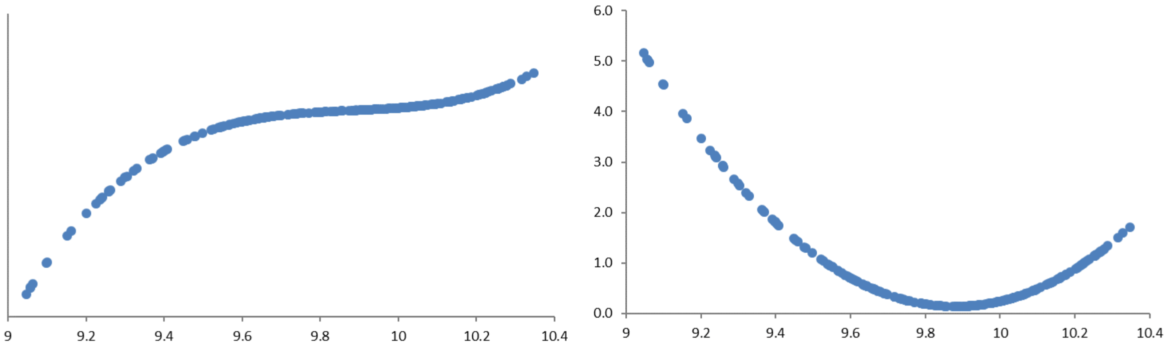
MG[16]



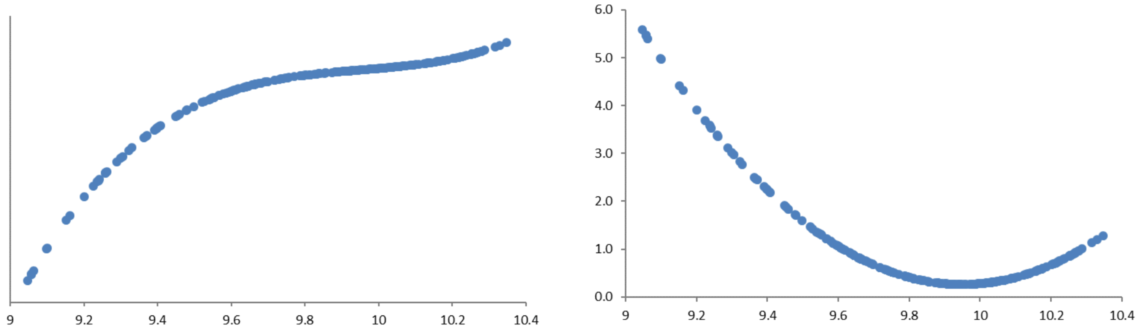
(**Figure A - II.2:** continued)

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

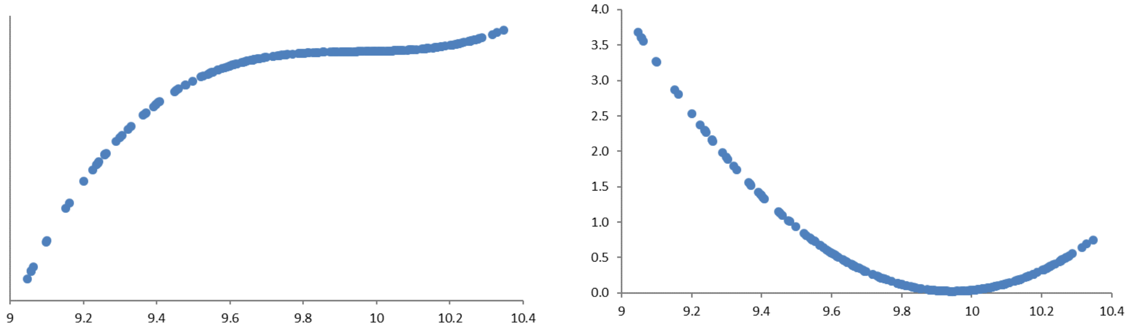
MG[17]



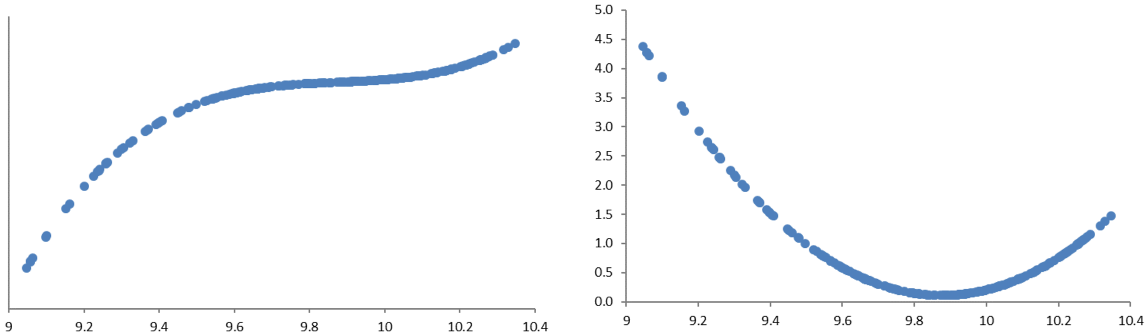
MG[18]



MG[19]



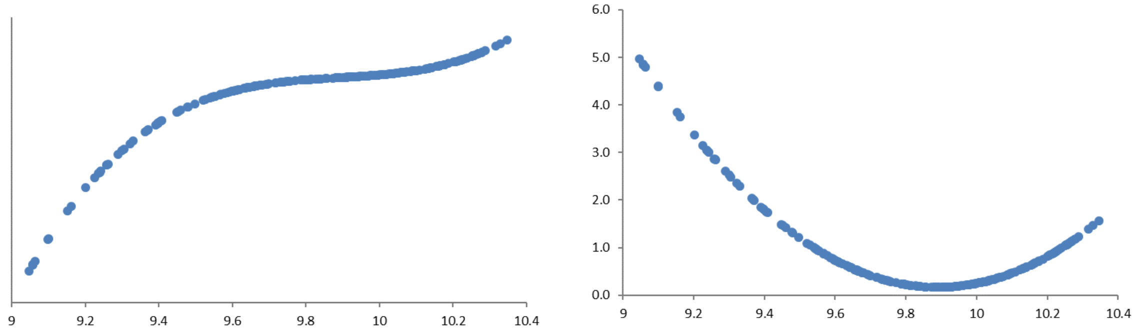
MG[20]



(**Figure A - II.2:** continued)

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

MG[21]



MG[22]

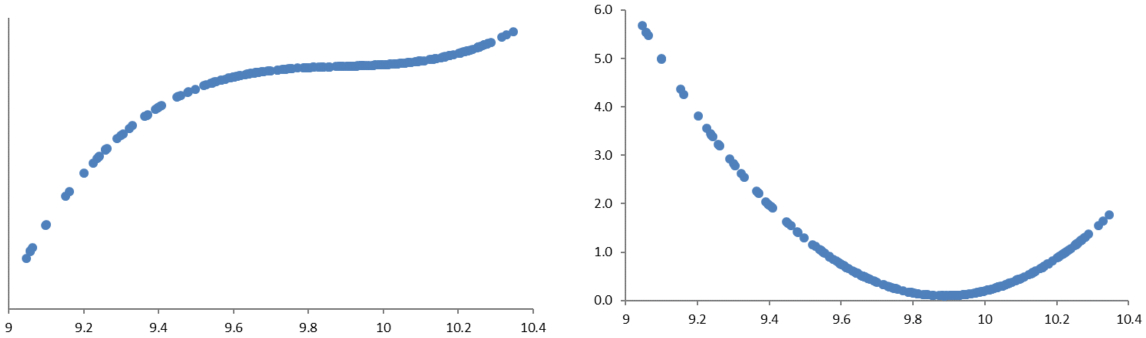
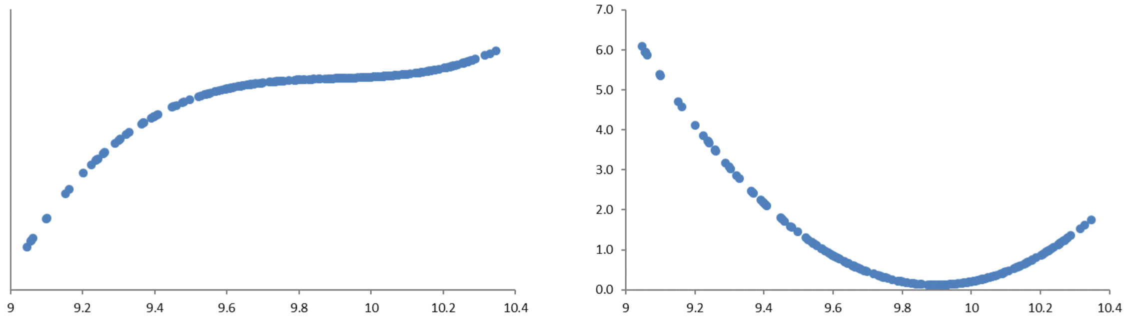


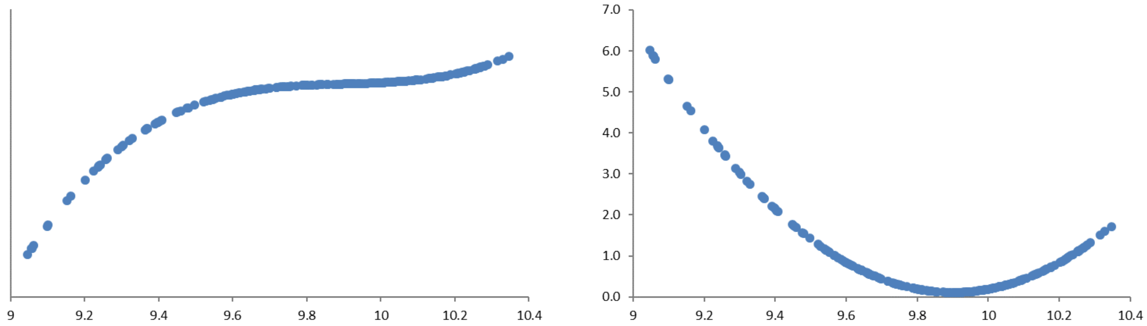
Figure A - II.3: The estimated relationship between GDP and CO2 [control variables]

(a) the estimated relationship CO2/GDP (b) the derivative $dCO2/dGDP$

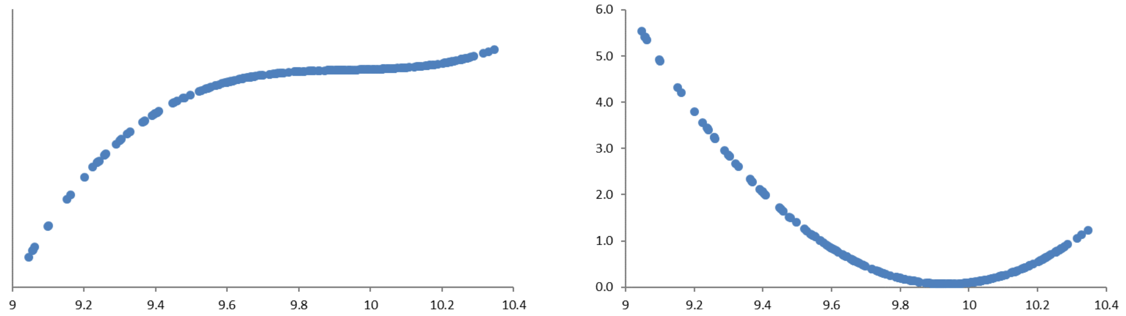
MG[3]



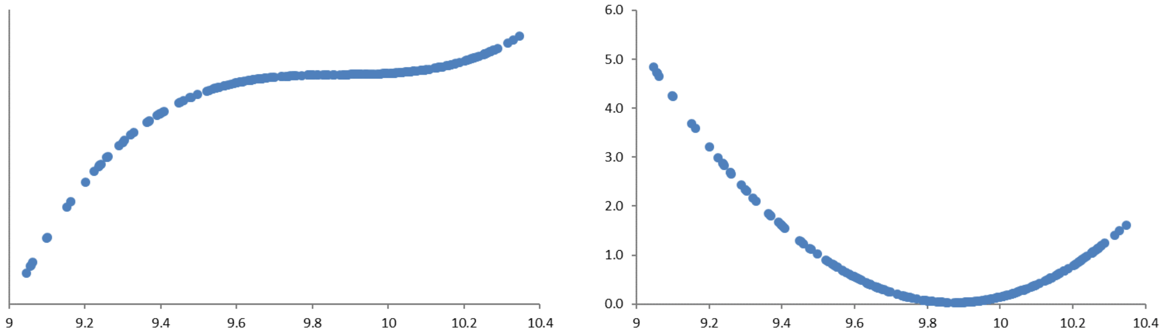
MG[4]



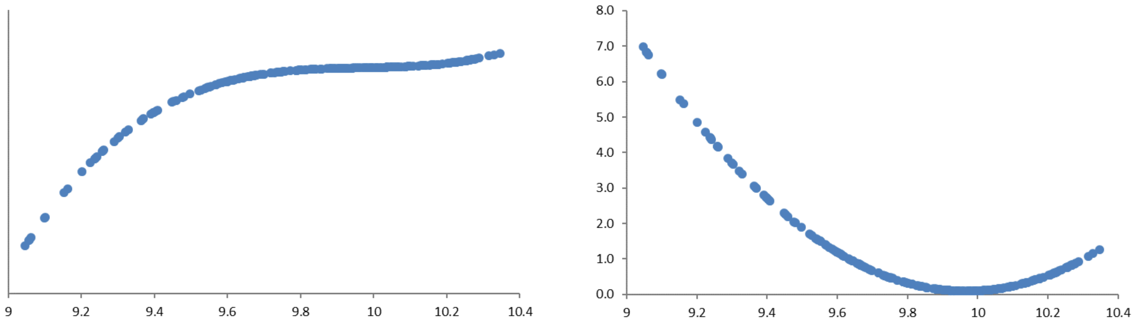
MG[5]



MG[6]



(**Figure A - II.3:** continued)



(a) the estimated relationship CO2/GDP (b) the derivative *dCO2*/*dGDP*

MG[7]

Table A - II.11: Countries' classification by agriculture average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_AGRI
1	[U-shaped]	Bulgaria	8.124
2	[M. increasing]	Lithuania	4.830
3	[*N*-shaped]	Croatia	4.294
4	[inverted-U shaped]	Hungary	4.293
5	[U-shaped]	Latvia	3.970
6	[inverted-*N* shaped]	Slovakia	3.768
7	[*N*-shaped]	Estonia	3.473
8	[inverted-*N* shaped]	Poland	3.043
9	[inverted-U shaped]	Czech Republic	2.488

Table A - II.12: Countries' classification by industry average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_IND
1	[inverted-U shaped]	Czech Republic	34.101
2	[inverted-*N* shaped]	Slovakia	32.058
3	[inverted-*N* shaped]	Poland	29.386
4	[M. increasing]	Lithuania	27.571
5	[inverted-U shaped]	Hungary	26.390
6	[*N*-shaped]	Estonia	25.470
7	[*N*-shaped]	Croatia	23.943
8	[U-shaped]	Bulgaria	23.720
9	[U-shaped]	Latvia	22.303

Table A - II.13: Countries' classification by services average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_SERV
1	[U-shaped]	Latvia	62.753
2	[*N*-shaped]	Estonia	59.241
3	[M. increasing]	Lithuania	57.207
4	[inverted-*N* shaped]	Poland	55.811
5	[*N*-shaped]	Croatia	55.601
6	[U-shaped]	Bulgaria	55.254
7	[inverted-U shaped]	Hungary	54.835
8	[inverted-*N* shaped]	Slovakia	54.430
9	[inverted-U shaped]	Czech Republic	54.038

Table A - II.14: Countries' classification by foreign direct investments average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_FDI
1	[*N*-shaped]	Estonia	63.769
2	[inverted-U shaped]	Hungary	59.219
3	[U-shaped]	Bulgaria	53.752
4	[inverted-*N* shaped]	Slovakia	46.928
5	[inverted-U shaped]	Czech Republic	46.211
6	[U-shaped]	Latvia	33.810
7	[*N*-shaped]	Croatia	33.603
8	[inverted-*N* shaped]	Poland	28.228
9	[M. increasing]	Lithuania	27.782

Table A - II.15: Countries' classification by labor productivity average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_ LABORPROD
1	[inverted-U shaped]	Hungary	53889.05
2	[inverted-U shaped]	Czech Republic	53611.70
3	[inverted-*N* shaped]	Slovakia	49465.90
4	[*N*-shaped]	Croatia	48414.20
5	[*N*-shaped]	Estonia	46148.30
6	[inverted-*N* shaped]	Poland	44853.50
7	[M. increasing]	Lithuania	42739.95
8	[U-shaped]	Latvia	37621.25
9	[U-shaped]	Bulgaria	31503.55

Table A - II.16: Countries' classification by economic complexity average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_ECI
1	[inverted-U shaped]	Czech Republic	1.545
2	[inverted-*N* shaped]	Slovakia	1.257
3	[inverted-U shaped]	Hungary	1.187
4	[inverted-*N* shaped]	Poland	0.929
5	[*N*-shaped]	Croatia	0.758
6	[*N*-shaped]	Estonia	0.638
7	[M. increasing]	Lithuania	0.422
8	[U-shaped]	Latvia	0.415
9	[U-shaped]	Bulgaria	0.397

Table A - II.17: Countries' classification by human development index average over 1996-2015

No.	CO2-GDP pattern	Country	Mean_HDI
1	[inverted-U shaped]	Czech Republic	0.832
2	[*N*-shaped]	Estonia	0.817
3	[inverted-*N* shaped]	Poland	0.809
4	[inverted-*N* shaped]	Slovakia	0.800
5	[inverted-U shaped]	Hungary	0.799
6	[M. increasing]	Lithuania	0.797
7	[*N*-shaped]	Croatia	0.781
8	[U-shaped]	Latvia	0.781
9	[U-shaped]	Bulgaria	0.751

«CHAPTER III»

Developing States and the Green Challenge. A Dynamic Approach[*]

Abstract: This paper studies the effects of output, urbanization, energy intensity, and renewable energy on aggregated and sector-specific CO2 emissions for a rich sample of developing states. We employ the recently developed GMM panel VAR technique, which allows us to tackle the potential endogeneity issue and capture both the current and future impact of indicators on CO2 via the impulse response analysis. On the one hand, robust to several alternative specifications, the findings indicate that output, urbanization, and energy intensity increase the aggregated CO2 emissions, while renewable energy exhibits an opposite effect. Moreover, regarding the CO2 responsiveness to output and urbanization shocks, the pattern may suggest that these countries are likely to attain the threshold that would trigger a decline in CO2 emissions. We also reveal heterogeneities related to both countries' economic development and Kyoto Protocol ratification/ascension status. On the other hand, the sectoral analysis unveils that the transportation, buildings, and non-combustion sector tend to contribute more to increasing the future CO2 levels. Overall, our study may provide useful insights concerning environmental sustainability prospects in developing states.

Keywords: CO2 emissions; urbanization; energy efficiency; renewable energy; developing countries; environmental Kuznets curve.

JEL Codes: Q01, Q53, Q56, O13

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[*] A version of this *Chapter* was published as Purcel, A.-A. (2020). Developing states and the green challenge. A dynamic approach. *Romanian Journal of Economic Forecasting*, *23*, 173-193.

III.1. Introduction

As a global and stock pollutant with the highest share in greenhouse gasses (GHG), carbon dioxide (CO2) emissions are considered the main driving force of environmental degradation. According to Olivier et al. (2017) report, developing countries such as Indonesia and India have recorded the highest absolute increase in CO2 emissions in 2016 (6.4% and 4.7% respectively), followed closely by Malaysia, Philipines, and Ukraine.

Indeed, having the fastest-growing economies, most developing countries experience complex structural changes that reflect in the mix of various socio-economic processes such as industrialization and urbanization. For example, according to the United Nations (UN) World Urbanization Prospects (2014)[1], the urban population in 2014 accounted for 54% of the total world population, and it is expected to rise at about 66% by 2050. Additionally, considering the worldwide ongoing urbanization process, Asia and Africa seem to exhibit the fastest urbanization rate. Overall, these changes strongly connected with the industrialization process also imply an intensification and a shift of economic activities towards urban conglomerates, demanding more energy resources, which in turn may reflect in higher pollution.

Consequently, some of the key factors that can help mitigate pollution include the gradual replacement of classic fossil fuels with more carbon-neutral alternatives, the increase of renewable sources in the energy mix, and energy efficiency improvements. In this regard, the renewable energy and energy efficiency projects implemented between 2005 and 2016 in developing economies, and supported at the international level, are expected to reduce GHG emissions by 0.6 gigatons of CO2 per year by 2020 (UN Environment Programme, 2017).[2] Likewise, based on the same report, approximately 75 developing or emerging economies have implemented policies or programs that incorporate renewable energy and energy efficiency technologies.

Looking at developing countries' positions vis-à-vis the global environmental challenges and the main related tools designed to address them, they differ in certain features from developed countries. On the one hand, developing states being Non-Annex I parties of the Kyoto Protocol do not have binding commitments to reduce or limit their

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[1] https://population.un.org/wup/publications/files/wup2014-highlights.pdf.

[2] https://wedocs.unep.org/bitstream/handle/20.500.11822/22149/1_Gigaton_Third%20Report_EN.pdf?sequence=1&isAllowed=y.

emissions, compared to their industrialized counterparts. Nonetheless, they may voluntarily comply, and the advanced economies that choose to support them in fighting global warming may also benefit in terms of the fulfillment of their commitments. For example, the Kyoto Protocol's well-known Clean Development Mechanism (CDM) is designed to jointly involve developing and developed economies in fighting climate change by implementing various green projects.[3] On the other hand, following the Paris Agreement's adoption under the umbrella of the UN Framework Convention on Climate Change (UNFCCC), both developing and developed economies are required to put the efforts and fight together against the imminent threats of climate change. As such, the Paris Agreement may represent one of the most powerful instruments adopted so far concerning developing countries and their active role in combating and mitigating the harmful effects of global warming.

Taking stock of the above mentioned, this paper aims to assess CO2 emissions' responsiveness following external disturbances to output and urbanization, assuming a transmission channel that incorporates two of the key elements used in mitigating environmental degradation, namely the renewable energy and energy efficiency. In doing so, we employ the recently-developed generalized method of moments (GMM) panel vector autoregression (VAR) approach of Abrigo & Love (2016), which allows us to explore the essential dynamics and tackle the potential endogeneity between indicators. The technique is applied for a comprehensive group of developing countries, within a modified Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) framework, which along with the Environmental Kuznets Curve (EKC) hypothesis[4], helps us to provide the necessary economic foundation for the assumed innovations' transmission mechanism required to identify the key structural shocks. Furthermore, opposite to a sizeable empirical strand of literature that independently examines the nexus between CO2 and growth (urbanization) via the classical (urbanization-related) EKC hypothesis, we jointly test these two well-known hypotheses. Indeed, building on the general belief that a vast majority of developing economies have

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[3] As a result of the CDM green projects (i.e. projects aimed at reducing emissions) implemented in developing countries, the Annex I parties can buy Certified Emission Reduction (CER) units, which in turn help them to meet some of their commitments of emission reduction (Carbon Trust, 2009).

[4] The classical EKC hypothesis states that the relationship between environmental degradation and economic growth follows a bell-shaped pattern (Grossman & Krueger, 1991).

not yet reached the maximum level of growth (urbanization) that would ensure a decrease in pollution, this approach via the computation of impulse response functions (IRFs) allows us to assess whether this will be feasible or not in the future. As well, motivated by the ongoing structural changes that developing countries experience, we focus on aggregated and sector-specific CO2, as they may provide us with complementary insights.

Our findings can be summarized as follows. First, although output and urbanization shocks trigger a rise in the current and future levels of CO2, the effect may reverse, and in the long-run, a bell-shaped pattern seems to be at work in terms of the CO2 responsiveness. Moreover, the green actions that developing countries have taken in the last decades, particularly those related to renewable energy sources, seem to reduce the cumulated CO2 emissions both on the short- and long-term horizon. However, considering that the positive disturbances to energy intensity are associated with an increase in CO2, more attention should be paid to energy efficiency by attracting and implementing more related projects. Also, while the results confirm the persistence in CO2, a positive, permanent shock to its dynamics causes only a small increase in the future emissions levels.

Second, we examine the robustness of these findings by changing the order of variables into the transmission channel, altering the sample in several ways concerning both N and T dimensions, and controlling for an extensive set of exogenous factors. According to IRFs, the shocks to output, urbanization, energy intensity, and CO2 have the same cumulated increasing effect on CO2, opposite to positive disturbances to renewables that trigger a cumulated decrease in CO2. Likewise, the CO2 response to GDP and urbanization shocks tends to exhibit a bell-shaped pattern in the long-run, indicating that the related EKC hypothesis may be validated.

Third, we find that the results are sensitive to both countries' level of development and the Kyoto Protocol ratification/ascension status. On the one hand, overall, the IRFs show that low income economies might experience a more moderate increase in pollution in the long-run than lower-middle income states. Besides, in low income states, the results seem to be compatible with the EKC hypothesis, especially for urbanization. One possible, optimistic explanation could be given by the fact that less developed countries could benefit from the experience of a larger number of countries. Thus, they may have a higher probability of implementing exactly those environmental strategies that have proven to be the most effective and also build on their predecessors' mistakes. Not to mention that, over time, pollution control techniques and methods have been evolving significantly, while previous ones become more accessible, increasing the chances of obtaining favorable results much faster. On the other hand, the countries that ratified or acceded to the Kyoto Protocol before it entered into force may also be those which have been more actively engaged in combating pollution, given that both output and urbanization are more likely to display a threshold effect on CO2 (i.e. validate the EKC hypothesis in the long-run). Indeed, this may also suggest that these states faced the effects of increasing pollution earlier and, thus, decided to become more actively involved in combating climate change sooner than their counterparts.

Finally, despite the positive response of aggregate CO2 to output and urbanization shocks, when the sectoral components of CO2 are taken into account, the findings appear to be much more diverse. In particular, we find opposite results for the other industrial combustion and power industry sectors, namely external disturbance to both GDP and urbanization, leading to a cumulated decrease in associated CO2. Thus, overall, the disaggregated CO2 analysis indicates that transportation followed by construction[5] and non-combustion sectors is more prone to increase future CO2 pollution in our group of developing economies.

The remainder of the paper is organized as follows. Section 2 reviews the related empirical literature. Section 3 provides the STIRPAT framework, discusses the research methodology, and describes the data used in the analysis. Section 4 presents the baseline empirical findings. Section 5 examines the robustness of these findings. Section 6 explores their sensitivity. Section 7 analyzes the sector-specific CO2 dynamics following exogenous shocks to other system variables, and the last section presents the concluding remarks.

III.2. Literature review

In the light of the vast body of empirical literature on the environmental degradation determinants, this section aims to review some of the most recent empirical studies that tackle the impact of output, urbanization, (non)renewable energy, among other

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[5] In this chapter, the terms “construction” and “buildings” are used with the same connotation.

explanatory factors, on environmental degradation. More precisely, we mainly focus on works that explore this nexus for developing[6] economies in the context of STIRPAT and/or EKC hypothesis (both the classical and urbanization related ones). As well, given that the output appears in almost all studies as one of the main determinants of environmental degradation, we split the literature into two main parts, namely the (i) output-urbanization-environmental degradation nexus, and (ii) output-(non) renewables-environmental degradation nexus.[7]

First, we further split the studies into two subcategories regarding the impact of economic growth and urbanization on environmental pollution. Thus, the first strand of literature tackles the papers that extend the baseline STIRPAT equation and/or EKC hypothesis to capture the urbanization process's effects. In this fashion, researchers such as Lin et al. (2009), Li et al. (2011), Wang et al. (2013), Wang & Lin (2017), among others, using time-series data on China reveal that, overall, both urbanization and economic growth exacerbate the environmental degradation. The authors employ techniques such as ridge regression, partial least-squares regression, or VAR model. Likewise, the findings of Talbi (2017) for Tunisia and Pata (2018) for Turkey show that urbanization increases CO2 pollution, while economic growth exhibits a nonlinear effect on CO2, validating the EKC hypothesis.

Furthermore, making use of STIRPAT framework, several works (see e.g. Poumanyvong & Kaneko, 2010; Liddle, 2013; Iwata & Okada, 2014; Sadorsky, 2014a; Wang et al., 2015; among others) examine the effects of growth and urbanization on environmental degradation, using either samples of developing countries or mixed samples comprising both developing and developed economies. However, in most cases, the findings unveil that both variables positively affect environmental degradation. Also, it is worth noted that concerning economic growth, Liddle (2013) and Wang et al. (2016) find evidence in favor of the EKC hypothesis. Also, scholars such as Li et al. (2016), Awad & Warsame (2017), Joshi & Beck (2018), among others, study the relationship between pollution and growth in the context of the EKC hypothesis, while controlling for the effects

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[6] The term "developing" is used with double connotation, meaning that it refers to both developing and emerging countries.

[7] We note that the studies that comprise, along with the output, both urbanization and (non)renewable energy as explanatory factors of environmental degradation, are included in the category that we consider most suitable.

of the urbanization process. The authors apply either parametric or semiparametric panel data techniques, and, most frequently, environmental degradation is proxied by CO2 emissions. Overall, the findings seem to be mixed with respect to the EKC hypothesis's validity, whereas urbanization tends to increase the pollution levels.

The second strand of literature focuses on testing the urbanization-related EKC hypothesis, whether or not this is done within the STIRPAT context. In this manner, the findings provided by Martínez-Zarzoso & Maruotti (2011) support the urbanization-pollution EKC for 88 developing states span over 1975-2003. Opposite, Zhu et al. (2012) and, more recently, Wang et al. (2016) find little evidence in favor of the urbanization-CO2 and urbanization-SO2 EKC hypothesis. Besides, employing the panel VAR analysis, Lin & Zhu (2017) study the dynamic relationship between industrial structure, urbanization, energy intensity, and carbon intensity for 30 provinces of China span over 2000-2015. Concerning the carbon intensity response following external shocks to the other variables, the IRFs reveal that both urbanization and industrial structure decrease the carbon intensity, while energy intensity disturbances increase (decrease) on impact (after three years) its levels. According to twenty-year horizon FEVDs' results, only urbanization exhibits a bell-shaped pattern on carbon intensity. Also, the findings provided by Chen et al. (2019) and Xie & Liu (2019) show that urbanization exhibits nonlinear effects on CO2 for 188 Chinese prefecture-level cities and 30 Chinese provinces, respectively.

Second, the present study is also related to the body of literature investigating the effects of economic growth, nonrenewable energy (especially energy intensity), and/or renewable energy on environmental degradation. In this regard, Shahbaz et al. (2015) investigate for 13 Sub Saharan African states the link between energy intensity and CO2 while also testing the EKC hypothesis. On the one hand, the long-run panel findings unveil that the energy intensity has a positive impact on CO2, while a bell-shaped pattern characterizes the CO2-GDP nexus. On the other hand, the country-specific long-run results reveal that energy intensity significantly increases CO2 in Botswana, Congo Republic, Gabon, Ghana, South Africa, Togo, and Zambia. Besides, an inverted-U shaped (U-shaped) relationship between CO2 and GDP is found in South Africa, the Congo Republic, Ethiopia, and Togo (Senegal, Nigeria, and Cameroon). Antonakakis et al. (2017) employ the panel VAR approach to investigate the dynamic interrelationship between output, energy consumption (and its subcomponents, namely electricity, oil, renewable, gas, and coal) and CO2. In doing so, the authors concentrate on a large panel of 106 states over the period 1971-2011. Overall, for low income group, the findings (based on cumulative generalized IRFs) reveal that CO2 respond significantly and positively only to output and oil consumption shocks. On the contrary, for lower-middle income countries, the CO2 seems to react significantly and positively to output, aggregated energy consumption, electricity consumption, and oil consumption. Likewise, Naminse & Zhuang (2018) examine for China the link between economic growth, energy intensity (in terms of coal, oil, gas, and electricity), and CO2, span over 1952-2012. The results based on the IRFs analysis show that coal, electricity, and oil consumption positively impact the future levels of CO2. In contrast, gas consumption seems to decrease future levels of CO2. The regression analysis also indicates an inverted-U shaped relationship between growth and CO2, in line with EKC. Charfeddine & Kahia (2020) also investigate the impact of renewable energy and financial development on both CO2 emissions and growth for 24, the Middle East, and North Africa (MENA) states. The computed IRFs unveil a cumulative negative effect of renewables on CO2, suggesting that renewable energy sources may reduce CO2 pollution.

Moreover, some authors assess the impact of (non)renewable energy consumption and output on CO2 pollution using the EKC framework for European Union (EU) states. As such, the results of Bölük & Mert (2014) for a sample of 16 EU countries indicate that renewables consumption has a positive impact on CO2 emissions, while the EKC hypothesis is not validated. Conversely, based on a sample of 27 developing and developed EU states, the findings of López-Menéndez et al. (2014) show, on the one hand, that renewables have a negative effect on GHG emissions. On the other hand, the results suggest that the EKC hypothesis may work for those economies that exhibit high intensity concerning renewable energy sources. Likewise, for a sample of EU economies, Dogan & Seker (2016) show that renewable (nonrenewable) energy decreases (increases) the CO2 emission, and the EKC hypothesis is supported. As an empirical methodology, the authors employ panel data techniques robust in the presence of cross-sectional dependence.[8]

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[8] These findings are also partially supported by the more recent study of Inglesi-Lotz & Dogan (2018) for a sample that comprises the top 10 electricity generators states from Sub-Saharan Africa. Specifically, the results show that renewable (nonrenewable) decreases (increases) the CO2, but the validity of the EKC hypothesis over 1980-2011 is not supported.

Bearing in mind the present study's objective, we previously review some studies that directly or indirectly tackle the effects of output, urbanization, and (non)renewable energy, among others, on environmental degradation. However, given that we aim at addressing the potential endogenous behavior between variables and, thus, consistent with the recursive order that we impose among them (see subsection 4.2 for details), the study could also be linked with the strand of research that examines the relationship between (i) output and urbanization (see e.g. Brückner, 2012; Bakirtas & Akpolat, 2018; among others), (ii) output and (non)renewable energy (see e.g. Sadorsky, 2009; Salim & Rafiq, 2012; Liu, 2013; Apergis & Payne, 2015; Doğan & Değer, 2018), (ii) urbanization and (non)renewable energy (see e.g. Shahbaz & Lean, 2012; Sadorsky, 2014b; Wang, 2014; Kurniawan & Managi, 2018; among others), and as well the papers that focus on efficiency of (non)renewable energy (see e.g. Aldea et al., 2012; Jebali et al., 2017; Gökgöz et al., 2018; among others).

III.3. STIRPAT framework, methodology, and data

III.3.1. STIRPAT framework

STIRPAT is an analytical framework introduced in the literature by Dietz & Rosa (1994, 1997) as the stochastic counterpart of IPAT identity proposed by Ehrlich & Holdren (1971, 1972), and also discussed in Holdren & Ehrlich (1974). According to the I=PAT accounting equation, the environmental impacts denoted by (I) are determined in a multiplicative way by demographic-economic forces such as population (P), affluence (A), and technology (T). Nonetheless, over the years, to meet the needs of different research questions the baseline IPAT and STIRPAT model has encountered many alternative specifications (see for instance Kaya, 1990; Schulze, 2002; Waggoner & Ausubel, 2002; Xu et al., 2005; Martínez-Zarzoso et al., 2007; Lin et al., 2009; Shaifei & Salim, 2013; among others).

First, the classical IPAT equation written for panel data with $i = \overline{1,N}$ observed countries over the period $t = \overline{1,T}$ takes the following for

$$I_{it} = \alpha \cdot P_{it}^{\beta 1} \cdot A_{it}^{\beta 2} \cdot T_{it}^{\beta 3} \cdot \varepsilon_{it} \tag{1}$$

Second, the above accounting identity's stochastic counterpart is obtained by applying natural logarithm on equation (1). Also, along with this transformation, we approximate the environmental impacts I with a well-known global pollutant, namely the CO2 emissions. Likewise, we proxy P with the share of the urban population in total (URB), A with the gross domestic product (GDP), while T it is captured through both energy intensity (EINT) and the share of renewable energy (RENG). Subsequently, our modify STIRPAT model can be specified as follows

$$CO2_{it} = \alpha_i + \beta_1 GDP_{it} + \beta_2 URB_{it} + \beta_3 EINT_{it} + \beta_4 RENG_{it} + \varepsilon_{it}. \tag{2}$$

In the above equation, all the variables are expressed in log form while α_i and ε_{it}captures the potential country-specific fixed effects and the error term, respectively. Moreover, given that the affluence term is usually expressed via GDP, its square (cubic) term into the equation allows for testing the well-known EKC hypothesis in its traditional (extended form). Indeed, the same holds for any explanatory factor, namely adding higher-order polynomial terms, allows for testing a potential nonlinear effect of the respective variable on environmental degradation (e.g. the urbanization-EKC hypothesis).

III.3.2. Methodology

We draw upon the novel panel VAR methodology to explore the CO2 responsiveness to other system variables shocks. In this regard, we follow the work of Love & Zicchino (2006) and Abrigo & Love (2016) and estimate a homogeneous panel VAR model using the generalized method of moments (GMM) approach. Indeed, this technique gives us the possibility to treat all the variables endogenously and account for the unobserved individual heterogeneity.

The specification of a homogeneous panel VAR with individual fixed effects can be written as follows

$$Y_{it} = W^{\bullet} + Y_{it-1}W_1 + Y_{it-2}W_2 + \cdots + Y_{it-p}W_p + \nu_i + \varepsilon_{it}, \tag{3a}$$

or considering its reduced-form

$$Y_{it} = W^{\bullet} + W(L)Y_{it} + \nu_i + \varepsilon_{it}, \tag{3b}$$

with $i \in \{1, 2, \dots, N\}$ and $t \in \{1, 2, \dots, T\}$.

In equations (3a)-(3b), Y_{it} represents the vector of our four stationary endogenous variables (i.e. GDP, URB, EINT, RENG, and CO2), which, in particular, can be specified in the following form

$$Y_{it} = \begin{bmatrix} GDP_{it} \\ URB_{it} \\ EINT_{it} \\ RENG_{it} \\ CO2_{it} \end{bmatrix}.$$

$W(L)$ stands for associated matrix polynomial in the lag operator (i.e. the autoregressive structure), while $W^{\bullet}$ is the vector of constants. Likewise, v_i and ε_{it} denotes the vector of unobservables country-specific characteristics and idiosyncratic errors, respectively. The unobservables may capture the cultural, institutional, and historical individual country characteristics that are time-invariant. As in Abrigo & Love (2016), we assume that the vector of idiosyncratic errors ε_{it} possesses the following features: $E[\varepsilon_{it}] = 0$, $E[\varepsilon_{it}'\varepsilon_{it}] = \sum$ and $E[\varepsilon_{it}'\varepsilon_{is}] = 0$, $\forall\, t > s$. Put differently, the innovations have zero first moment values, constant variances, and do not exhibit individual serial and cross-sectional correlation.

Furthermore, in line with Holtz-Eakin et al. (1988), the panel VAR model described above assumes that the parameters are common across all panel members (Abrigo & Love, 2016). Indeed, this seems to be quite a strong restriction that may not hold when working with a large number of countries, which are prone to exhibits certain particularities. Thus, the country-specific fixed effects are introduced into the model to overcome the parameters' homogeneity assumption. In this regard, the model may be estimated via the fixed effects or ordinary least squares approach, but the coefficients are likely to suffer from Nickell's bias (Nickell, 1981)—when estimating dynamic panels, the fixed-effects are correlated with the regressors, given the lags of endogenous variables (Abrigo & Love, 2016). To alleviate this issue, we use the Helmert procedure described in Arrelano & Bover (1995), and remove the mean of all future available country-time observations, by applying forward mean-differencing (orthogonal deviations).

Let us consider a generic variable y_{it} with $i \in \{1, 2, \dots, N\}$ and $t \in \{1, 2, \dots, T\}$, whose mean with respect to time dimenssion T, for country i is computed as follows

$$\bar{y}_i = \frac{1}{T}\sum\nolimits_{t=1}^{T} y_{it}. \tag{4a}$$

By applying the Helmert transformation to variable y_{it}, we obtain the new variable

$$y_{it}^{*} = \sqrt{\frac{T-t}{T-t+1}} \times \left(y_{it} - \frac{1}{T-t} \sum_{j=t+1}^{T} y_{ij} \right). \tag{4b}$$

In this manner, we refrain from eliminating the orthogonality between transformed variables and lagged regressors. Consequently, the coefficients are consistently estimated by GMM, using instruments the lags of independent variables (Abrigo & Love, 2016).

III.3.3. Data

The study concentrates on 68 countries classified by World Bank (2017) as economies with low and lower-middle income. The list of countries included in the analysis, grouped by geographic region, is displayed in Table A-III.1 in the Appendix. Moreover, the data are annual and cover the period from 1992 to 2015, while the sample is constructed according to data availability and in such a way to omit to deal with missing observations for the main variables. Also, by focusing on this period, we avoid the instabilities triggered by the fall of the Communist Bloc and the end of the Cold War, which may equally distort our analysis.

On the one hand, our primary data source is the World Bank, given that four out of five variables included in the empirical analysis come from World Bank Indicators (WDI, 2018). These variables are the *GDP* (constant 2011 international $, purchasing power parity), *EINT* (energy intensity of GDP), *URB* (urban population as % of the total population), and *RENG* (renewable energy consumption as % of total final energy consumption).

On the other hand, the data for *CO2* emissions (kton per year) are collected from Janssens-Maenhout et al. (2017), Emissions Database for Global Atmospheric Research (EDGAR). For the baseline model, we use the aggregate CO2 emissions, computed as the sum of emissions from transport, other industrial combustion, buildings, non-combustion, and power industry sector. Nonetheless, in the heterogeneity section, we estimate each sector's model separately, using disaggregated CO2 emissions. Furthermore, to capture the overall dynamics' magnitude between variables (especially between CO2 and GDP), we refrain from working with their per capita versions. Indeed, this allows us to further investigate, in the robustness section, if potential changes in the population alter the baseline findings. Also, for modeling purposes, all the variables are express in natural logarithm. Tables A-III.2-3 in the Appendix illustrates the variables' definition and their descriptive statistics before applying any transformation.

III.4. Empirical results

This section is devoted to the preliminary analysis of data, identification strategy, and the VAR model's estimation.

III.4.1. Some preliminary data evaluations

Prior to modeling the dynamic relationship between variables, we check some univariate properties of our data, such as the cross-sectional dependence, the critical assumption of stationarity required by a stable VAR model, and the potential cointegration of variables.

First, we check the presence of cross-sectional dependence by employing the Breusch-Pagan (1980) LM, Pesaran (2004) scaled LM, Pesaran (2004) CD, and Baltagi et al. (2012) Bias-Corrected (BC) scaled LM test. The findings depicted in Table III.1 show that all variables are characterized by cross-sectional dependence.

Second, taking into account the presence of cross-sectional dependence and the large dimension of N compared to T (i.e. N=68 and T=24), we use, on the one hand, the Harris-Tzavalis (1999) panel unit root test. In particular, this test allows us to alleviate the effects of cross-sectional dependence by subtracting the cross-sectional means from the variables while imposing small-sample adjustment to T. On the other hand, bearing in mind that unit root/stationarity tests are usually sensitive to the number of lags included in the equation, we also consider the Pesaran's (2003) CADF test. Specifically, we employ the test by augmenting the equation with one and two lags, respectively. Moreover, regarding both tests, we include in the equation a constant and a trend for the variables in levels, whereas only the constant for their first difference. Tables III.2-3 show the associated results. Overall, we can observe that all variables are stationary on their first difference and integrated of order one in levels, with the notable exception of URB and CO2 for Pesaran's (2003) test augmented by one lag.

Third, given that the stationarity analysis suggests mixed results, especially for URB and CO2 variable, and to be sure that variables do not exhibit a long-term relationship, we check for a potential cointegration between variables. Indeed, if the variables are cointegrated in levels, only taking their first difference to satisfy the VAR model's stationarity condition would eventually bias the estimates. To this end, we employ the error-based panel cointegration tests of Westerlund (2007), which allow us to control for the presence of cross-sectional dependence via the bootstrap procedure. The findings depicted in Table III.4 illustrate that the null hypothesis of no cointegration is strongly accepted across all four tests when using both 100 and 800 replications for the bootstrap procedure. Consequently, estimating the panel VAR by differencing the data seems to be the most appropriate decision in our case, as the model will be consistent, and the inference will hold. Besides, taking the first difference of the log data facilitates modeling between variables by allowing them to work with their growth rates.

Table III.1: Cross-sectional dependence tests

Test/Variable	**CO2**	**GDP**	**EINT**	**RENG**	**URB**
Breusch-Pagan LM	34483.67*** (0.000)	44405.60*** (0.000)	19907.45*** (0.000)	18059.67*** (0.000)	43539.82*** (0.000)
Pesaran scaled LM	477.134*** (0.000)	624.129*** (0.000)	261.184*** (0.000)	233.808*** (0.000)	611.303*** (0.000)
Pesaran CD	141.464*** (0.000)	202.439*** (0.000)	55.523*** (0.000)	59.380*** (0.000)	110.153*** (0.000)
BC scaled LM	475.655*** (0.000)	622.651*** (0.000)	259.705*** (0.000)	232.330*** (0.000)	609.824*** (0.000)

Notes: The Breusch-Pagan (1980) LM, Pesaran (2004) scaled LM, Pesaran (2004) CD, and Baltagi et al. (2012) Bias-Corrected (BC) scaled LM test. H0 is "no cross-section dependence (correlation)". P-values in brackets. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

Table III.2: Stationarity analysis I

Test/ Variable	**Harris-Tzavalis test**			
	Level (cons & trend)		**Δ (cons)**	
	rho	*p-value*	*rho*	*p-value*
GDP	0.748	(0.983)	0.235***	(0.000)
URB	0.853	(1.000)	0.839**	(0.033)
EINT	0.685	(0.258)	-0.007***	(0.000)
RENG	0.675	(0.145)	-0.056***	(0.000)
CO2	0.686	(0.271)	0.004***	(0.000)

Notes: We remove cross-sectional means and apply small-sample adjustment to T. H0 is "panels contain unit roots". P-values in brackets. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

Table III.3: Stationarity analysis II

Test/ Variable	**Pesaran's CADF test**							
	Level (cons & trend)		**Δ (cons)**		**Level (cons & trend)**		**Δ (cons)**	
	Augmented by one lag (average)				**Augmented by two lags (average)**			
	t-bar	*p-value*	*t-bar*	*p-value*	*t-bar*	*p-value*	*t-bar*	*p-value*
GDP	-2.263	(0.663)	-2.819***	(0.000)	-1.969	(0.999)	-2.139***	(0.000)
URB	-2.620***	(0.003)	-1.674	(0.740)	-2.325	(0.446)	-1.965**	(0.034)
EINT	-2.185	(0.865)	-2.962***	(0.000)	-1.866	(1.000)	-2.114***	(0.001)
RENG	-1.884	(1.000)	-3.017***	(0.000)	-1.740	(1.000)	-2.036***	(0.008)
CO2	-2.597***	(0.005)	-3.234***	(0.000)	-2.166	(0.899)	-2.630***	(0.000)

Notes: H0 is "all series are nonstationary". P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table III.4: Panel cointegration tests

	Westerlund (2007)			
Statistic	**Z-value**	**Robust p-value**	**Z-value**	**Robust p-value**
	bootstrap with 100 replications		*bootstrap with 800 replications*	
Gt	0.669	0.271	0.669	0.271
Ga	13.271	1.000	13.271	1.000
Pt	10.714	0.591	10.714	0.591
Pa	9.670	0.684	9.670	0.684

Notes: H0 is "no cointegration". The equation includes the constant term, one lag, and one lead. The width of the Bartlett kernel window is set to three. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

III.4.2. Identification and estimation of the structural panel VAR model

III.4.2.1. Identification

A crucial aspect of the VAR approach involves the assumptions imposed to consistently estimate the associated system of simultaneous equations. Indeed, converting the classical VAR into a structural VAR (SVAR) approach by setting specific restrictions, allow us to achieve the necessary causal inference, and have a meaningful economic interpretation of the parameters. In other words, the identification in SVAR of all structural parameters requires that some theory-based economic restrictions are imposed. In doing so, we draw upon a recursive panel SVAR model, meaning that we do not impose any restriction on the matrix that captures the impact effects[9], i.e. we use exclusion restrictions. Effectively, this can be done by imposing a particular causal order between variables, which plays a vital role in the computation of both the Cholesky decomposition of the innovations' variance-covariance matrix and the IRFs (Abrigo & Love, 2016). Correspondingly, we further detail the rationale behind the causal ordering we impose on the systems' variables.

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[9] The matrix of impact effects or impact multipliers matrix stands for the matrix that contains the variables' immediate responses following a structural shock.

First, according to the EKC hypothesis and STIRPAT framework, we argue that the GDP exhibits the highest levels of exogeneity, while CO2 the highest level of endogeneity. More specifically, we consider that CO2, namely the variable ordered last into our transmission channel, responds more quickly following exogenous shocks to economic activity. Thus, the exogenous structural disturbances to output have both a contemporaneously and lagged impact on the CO2. Opposite, the GDP being ordered first into the system may have only a delayed response to any exogenous shocks to CO2 (i.e. is restricted to respond within the period).

Second, the three remaining variables, namely the urbanization, energy intensity, and renewable energy, enter the transmission channel at the right- (left)-side of the GDP (CO2). The reasoning for this choice is straightforward. On the one hand, as previously mentioned, the related literature ranks these factors among the most important determinants of CO2 emission. On the other hand, regarding the sample's particularities (discussed more is detailed in the Introduction section), they may easily explain the ongoing urbanization process, along with the efforts made by developing economies to combat climate change. In this manner, for example, the active involvement in the CDM of the Kyoto Protocol may mirror some of the countries' efforts aiming to reduce environmental degradation. However, what remains ambiguous so far, is the causal ordering of these factors in the transmission channel, given that it may influence our results. Indeed, we may have less information than the underlying economic foundation of CO2-GDP nexus, but the economic intuition could equally help us in this regard.

Subsequently, we assume that any exogenous shocks to output may impact the urbanization degree, which may further influence the energy intensity, renewable energy share, and the CO2. The same logic is preserved for the other variables, namely the external disturbances to energy intensity may affect renewables, which may reflect the CO2 emissions levels. Thus, the CO2 emissions are ultimately allowed to react within the period to any exogenous shocks to the other system's variables. In contrast, all the variables respond within the period following positive exogenous shocks to output.

Overall, our previous economic rationale may be linked with the fast growth rates of developing economies, which may impact the urbanization process scale. As a result, we expect that the intensification of economic processes to increase the energy use, but at the same time, at least from a sustainability perspective, to foster the advance in energy efficiency and renewables. Notably, we postulate that efforts to promote energy efficiency and the renewable energy share are a by-product of the pressures caused by urbanization and, in any case, economic activity. Indeed, these efforts may also suggest the countries' willingness to get involved in pollution mitigation activities.

Nonetheless, the Granger (1969) causality Wald test can also help us verify the underlying economic reasoning. In this regard, we note that the associated results depicted in Table A-III.5 in the Appendix overwhelmingly endorse the assumed transmission channel between variables. Specifically, the findings show that each factor separately Granger-causes the CO2 (except the renewable energy), while all four variables jointly Granger-cause the CO2. Besides, GDP, along with all the excluded variables taken together, Granger-cause the equation variable. Also, as a counterfactual, the causality towards the GDP runs only from the renewable energy share, but its statistical significance is considerably low.

III.4.2.2. Estimation

A key primary step in estimating the panel SVAR involves setting the optimal lag length of the model. Therefore, we choose the appropriate order of our panel SVAR, according to moment and model selection criteria (MMSC) proposed by Andrews & Lu (2001) based on Hansen's (1982) *J* statistic. Table A-III.6 in the Appendix presents the associated results. Overall, the MMSC statistics indicate that the first-order panel SVAR is the most suitable, compared with the other two alternatives, namely the second- and third-order specifications.[10]

Accordingly, we estimate the first-order panel SVAR model through the GMM estimator. The results displayed in Table A-III.8 in the Appendix show the following.[11] On the one hand, the output has a significant positive one-lag impact on itself, urbanization, and CO2, while a negative impact on energy intensity and renewable energy. On the other

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[10] Along with MMSC (i.e. Bayesian, Akaike, and Hannan-Quinn information criterion) also the overall coefficient of determination (CD), which shows the share of the variation explained by the model, and Hansen's (1982) *J* statistic of over-identifying restrictions, are reported (see Abrigo & Love, 2016). However, we rely predominantly on MMSC in choosing the optimal lag length, given that the Hansen's (1982) *J* statistic has no correction for the degrees of freedom and, thus, may provide biased results. We also mention that the chosen model accepts Hansen's overidentification restriction at a 1% level of significance.

[11] Post estimation, we examine the stability condition of the panel SVAR-GMM model. As such, we note that all eigenvalues lie inside the unit root circle, proving that the model is correctly specified and exhibits a high accuracy (see Table A-III.7 and Figure A-III.1 in the Appendix).

hand, urbanization, renewable energy, and CO2 respond positively and significantly to a one-lag impact of urbanization. Moreover, the energy intensity seems to have a significant increasing delayed effect only on CO2 emissions. Also, given that renewable energy displays a significant negative one-lag impact on GDP, there is a negative feedback effect at work between the indicators.

The first-order panel SVAR-GMM findings give us an original resolution on the dynamic behavior between variables. Indeed, it also represents the leading basis for the crucial IRFs and forecast-error variance decompositions (FEVDs), which may be retrieved following its multivariate estimation. However, before discussing the associate findings, some methodological aspects regarding the choice of presenting the orthogonalized cumulative IRFs should be considered. On the one hand, we note that the simple IRFs are built on the assumption that the shocks are contemporaneously uncorrelated since they illustrate the response following an external shock (impulse) by holding all other impulses constant. Thus, using the Cholesky decomposition of the positive definite variance-covariance matrix, based, of course, on the recursive structure previously imposed, we can capture the isolated response of CO2 following disturbances to the other variables via the orthogonalized version of the IRFs.

On the other hand, the cumulative IRFs may provide us a broader perspective regarding the evolution of the dynamic relationship between variables, given that they show the cumulative response of CO2 in the aftermath of a permanent shock to the other factors of the system. Besides, recalling that our variables are expressed in growth rates (i.e. the first difference of their logs), the computation of cumulative IRFs is even more appropriate and ease the interpretation of the results. Indeed, the simple orthogonalized IRFs may also be useful in evaluating the overall stability of our model. In this regard, Figure A-III.2 in the Appendix shows that the CO2 responses move towards zero over time, supporting both the variables' stationarity condition and the model's overall stability.

Consequently, being mainly interested in the CO2 response following shocks to other system variables, let us now discuss the associated orthogonalized cumulative IRFs and FEVDs, both generated based on 1000 Monte Carlo simulations, and depicted in Figure III.1 and Table III.5, respectively. First, the IRFs indicate that one standard deviation exogenous positive shock to GDP triggers a persistent increase in CO2 emissions, both immediately and cumulated over the twenty-year horizon. More specifically, the CO2 increases by about two percent on impact, following a positive shock to output. Although it shows a smooth evolution over time, the upward trend seems to be slightly bent to the right. Likewise, its magnitude almost triples in the long-run, reaching and even exceeding five percent. From an economic perspective, these findings suggest that developing countries under examination are situated on the EKC's growing side. However, the results may suggest that they are likely to reach the crucial GDP turning point in the long-run sooner or later, depending on their economic context. Overall, these findings are expected, considering that the developing countries exhibit among the highest GDP growth rates, which are often incompatible with lower levels of environmental pollution. For example, a positive exogenous technology shock may induce the well-known phenomena of "catch-up growth" and trigger the intensification of industrial processes, which would eventually reflect at first in higher pollution. Indeed, as the nations' economic welfare grows, they can more easily acquire advanced green technologies, which, along with the increase in household income, may equally promote environmental sustainability. Thus, over time these may help in flattening the pollution curve. In this fashion, judging from the perspective of a future potential validity of EKC, our findings may complement the work of Liddle (2013), Shahbaz et al. (2015), Dogan & Seker (2016), Li et al. (2016), Wang et al. (2016), Talbi (2017), Naminse & Zhuang (2018), and Pata (2018), among others.

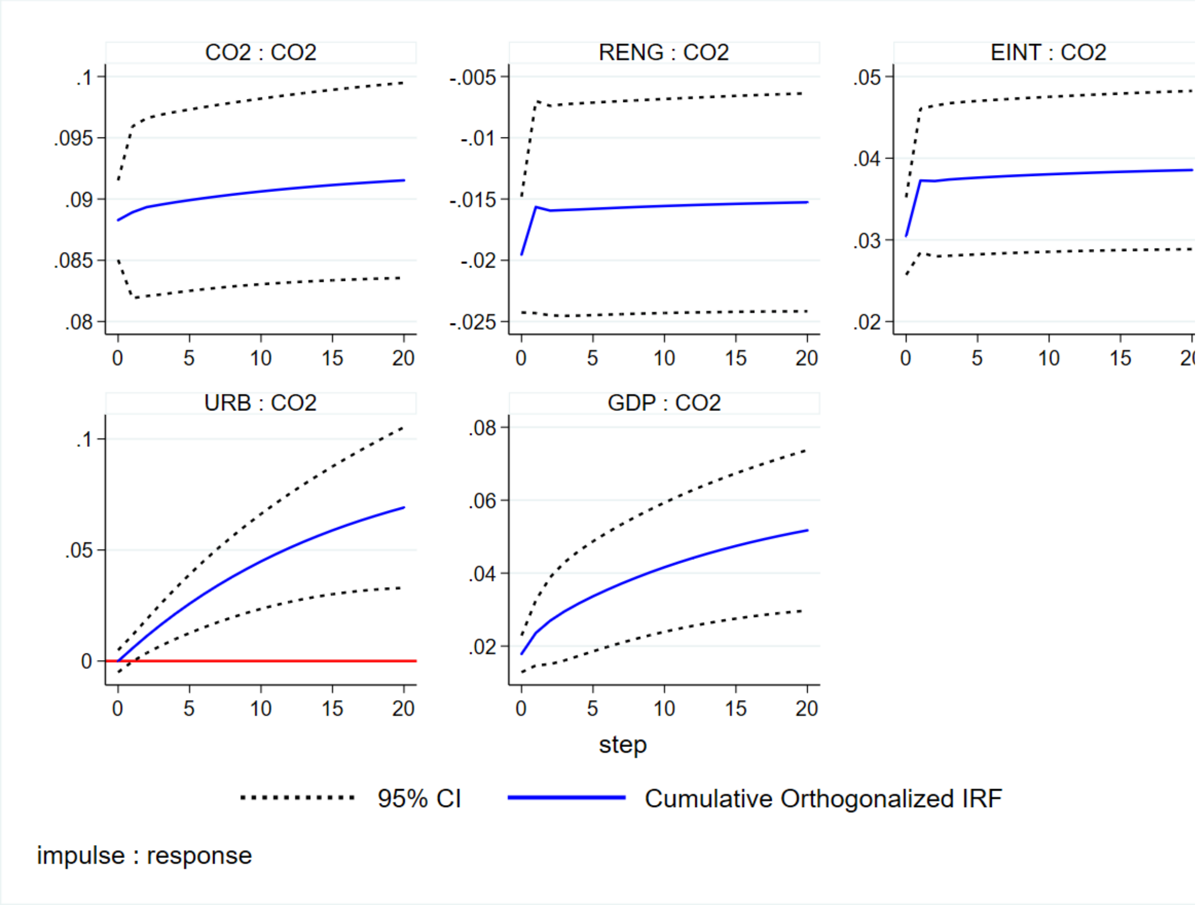
Second, one standard deviation permanent positive shock to urbanization triggers an increase in CO2, which may attain almost seven percent after twenty years from impact. Also, we note that the cumulated effect becomes statistically significant only after two years. This may imply that the urbanization process's adverse effects are not reflected immediately on the environment, but rather with a delay. Additionally, the overall pattern of the CO2 response seems to mirror the CO2 response to GDP shocks to a certain extent, suggesting that states will be able to reach the urbanization threshold that would lead to a decrease in CO2 in the future. In this regard, the results are similar to studies that unveil a bell-shaped pattern between urbanization and environmental degradation (see e.g. Martínez-Zarzoso & Maruotti, 2011; Lin & Zhu, 2017; Chen et al., 2019).

Third, a positive one standard deviation shock to energy intensity raises the CO2 by about three percent on impact. As well, the cumulate CO2 response exhibits a sharp increase over roughly the first one year and a half, then stabilizes and very slowly increases until it reaches nearly four percent following a permanent shock to energy intensity. This result is in line with the study of Sadorsky (2014a), Shahbaz et al. (2015), and Naminse & Zhuang (2018), but opposes the one of Martínez-Zarzoso & Maruotti (2011).

Fourth, in terms of the overall pattern displayed, the response of CO2 following a positive exogenous shock to renewables seems quite similar to the cumulate effect produced by an exogenous shock to energy intensity. However, one standard deviation positive shock to RENG induces an opposite effect, namely a decrease of about two percent in CO2 at the moment of the impact. Moreover, the cumulated magnitude of the negative response diminishes significantly after the initial impact, and then stabilizes and gravitates around the same value for the rest of the period. We note that the permanent shock, projected twenty years ahead, still causes a drop in CO2, even if the magnitude is slightly lower (i.e. around one and a half percent). These findings corroborate the ones of López-Menéndez et al. (2014), Dogan & Seker (2016), and Charfeddine & Kahia (2020) while contrasting those of Bölük & Mert (2014).

Finally, the CO2 increases by about nine percent in the aftermath of a permanent positive exogenous shock to itself. However, the cumulative response increasing is almost imperceptible in the long-run, pointing out a low magnitude of CO2 persistence (see the top-left plot in Figure III.1). Overall, this finding supports the one of Martínez-Zarzoso & Maruotti (2011), Sadorsky (2014a), and Acheampong (2018), among others, who find persistence effects in CO2 emissions.

Figure III.1: Cumulative orthogonalized IRFs



Observations: 1428 • Groups: 68

Notes: Considering two generic variables A and B, "A: B" denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

Concerning FEVDs, on the one hand, as expected, the largest share of the variables' variation is explained by their dynamics (see the principal diagonal of Table III.3). Furthermore, energy intensity seems to explain, twenty years ahead, about 9.90% of the variation in CO2, followed by output (4.08%), renewable energy (4.03%), and urbanization (2.69%). Indeed, the findings seem to uphold the energy as the primary contributor of CO2 in our group of developing economies. The results also indicate that the renewables explain about the same share of variation in CO2 as the output, and a more significant one compared to urbanization. Overall, this is a quite exciting and promising result, which may suggest, yet again, that these states have made substantial efforts to switch towards more environmentally friendly energy sources and, among others, that the CDM related projects have had the desired outcomes. Likewise, this result is also supported by the large share of renewable energy variation, following shocks to energy intensity.

On the other hand, we remark that the external shocks to output explain, twenty years ahead, a large share of variation in the other macro factors. These findings are also somehow expected, considering that the exogenous disturbances propagate first through output an then to its related macro components. Besides, it seems that any exogenous shocks to the remaining column variables do not exhibit a large magnitude in explaining the fluctuations in the row variables.

Table III.5: Forecast-error variance decompositions

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2
GDP	99.28	0.29	0.19	0.19	0.02
URB	12.89	86.96	0.02	0.01	0.10
EINT	21.59	0.16	78.12	0.04	0.07
RENG	0.89	0.41	8.16	90.42	0.08
CO2	4.08	2.69	9.90	4.03	79.27

Notes: Considering a twenty-year horizon, the numbers (in percentages) show the variation in the row variable that is explained by the column variables.

III.5. Robustness

We assess the robustness of our baseline SVAR specification in several ways. Also, we focus on reporting the associated findings with respect to the crucial IRFs, retrieved after running the panel SVAR-GMM model.

III.5.1. Alternative ordering

Given that we use a recursive ordering strategy to achieve identification in our SVAR, we check the underlying economic rationale's stability by implementing alternative transmission schemes. On the one hand, we check our economic intuition's soundness behind the ordering of the factors positioned at the right-side (left-side) of GDP (CO2) within the transmission scheme, namely URB, EINT, and RENG. In this manner, we switch their initial position by running a five-time rotation between them, until we consider all available options. On the other hand, we order each of these three factors at the top of the transmission channel, namely before the output. Therefore, we can observe if changing the variable, which exhibits the highest level of exogeneity, alters the baseline findings. It should also be mentioned that these new restrictions imposed among the system variables are even more consistent with the literature that positions urbanization, energy intensity, and renewables as the main determinants of CO2.

As shown by Figure A-III.3 in the Appendix, using distinct ordering scenarios does not qualitatively alter the baseline findings. Indeed, as expected, small changes in the magnitude of the responses are present. In this fashion, we note that a more visible difference is at work for CO2 response following external shocks to EINT, especially in the model where EINT is ordered first into the transmission channel. In particular, the cumulative response of CO2 due to a positive shock to EINT seems to follow a downward trend after reaching the peak, that is, approximately after one year and a half after the impact. One possible explanation could be related to the fact that manifesting the highest level of exogeneity, the impact of energy intensity on CO2, does not also capture the effect of disturbances to GDP and urbanization. As such, the energy intensity may appear much lower, thus, having a lower impact on CO2.

III.5.2. Altering the sample

To check whether our baseline findings are robust under certain economic or political distress conditions, we account for some well-known related events which can be seen in relation to both *T* and *N* dimensions of our sample. First, to control the global financial crisis's potential (delayed) effects, we restrict the analysis period to (1992-2010) 1992-2008. Furthermore, the exclusion of the period following 2008 coincides with the starting point of the Kyoto Protocol's first commitment phase (i.e. 2008-2012). Thus, if there were specific changes in developed countries' environmental behavior due to potential pressures to achieve their binding targets, we would expect them to reflect on developing countries as well. Second, we drop the period immediately following the end of the Cold War, namely 1992-1996, since the economies affected by this quite prominent geopolitical distress could have encountered difficulties in economic recovery. Indeed, if our assumption holds, the fluctuations in their primary macro aggregates may alter the baseline findings. Third, having in mind the Arab Spring, which involves several developing states, we also check whether its effects are reflected in our results. In doing so, we drop from the sample all the economies affected to some extend by this major political unrest episode. Finally, it is generally recognized that the petroleum industry has major implications for the environment. In this fashion, we exclude all states ranked by the Central Intelligence Agency (CIA)[12] among the top thirty economies regarding the

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[12] For more details see https://www.cia.gov/library/publications/the-world-factbook/fields/262rank.html.

crude oil exports. Overall, the associated cumulative IFRs, depicted in Figure A-III.4 in the Appendix, shows that independent of the sample's restriction, the baseline results are preserved both in terms of pattern and statistical significance.

III.5.3. Exogenous control factors

We exogenously introduce, along with the main SVAR endogenous variables, several additional explanatory factors into the model to control for a potential bias caused by omitted variables. These variables are related to changes in the size of the economy[13] (population), sectoral output composition (agriculture, industry, and services as % of GDP), trade (trade as % of GDP), environmental prospects (forest rents as % of GDP), external financing (remittances in % GDP), and private sector financial conditions (domestic credit to the private sector as % GDP) (see Tables A-III.2-3 in the Appendix for variables definition and descriptive statistics, respectively). Also, to maintain the stability conditions of the SVAR model and consistency between variables, we transformed them into growth rates by taking the first difference of their log-transformed values. Overall, the cumulative IRFs illustrated by Figure A-III.5 in the Appendix indicate that the findings are comparable with those of the baseline model, especially judging based on the significance and long-term trajectory of CO2 response due to different innovations shocks.

III.6. Heterogeneity

This section explores the sensitivity of CO2 responses following external shocks to other factors, depending on the income level group and the ratification or ascension date of states to the Kyoto Protocol.

III.6.1. The level of economic development

The economic development stages that a country crosses imply that different effects such as scale, structural, or technological, are at work during different periods and may cause substantial fluctuations in environmental conditions (see e.g. Grossman & Krueger, 1991). Thus, to explore the possible difference of CO2 responses with respect to countries'

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[13] With respect to possible changes in countries' population, we estimate two alternative models using (i) GDP and CO2 in per capita terms, and (ii) GDP, EINT, and CO2 in per capita terms (i.e. their growth rates in per capita terms, computed as the difference of log-transformed values). As shown by the panel (e)-(f) in Figure A-III.4 in the Appendix, the cumulative IRFs are almost identical to those revealed by the baseline model.

income level, we construct two subsamples of low and lower-middle income economies, based on the World Bank classification (2017) (see Table A-III.4 in the Appendix for summary statistics). Panel (a) and panel (b) in Figure A-III.6 in the Appendix depicts the cumulative IRFs for both income subsamples.

First, as expected, following external shocks, the GDP exhibits a positive effect on CO2 but with a higher magnitude in lower-middle income economies. Moreover, the cumulated CO2 response over the first two years displays a sharp increase in lower-middle income states than the low income ones. Likewise, the increasing long-run trajectory seems to be more accentuated in wealthier countries.

Second, CO2 emissions significantly and positively react due to innovations shocks to urbanization only in low income countries, and with a delay of around four years. Besides, the CO2 response path tends to display a bell-shaped pattern in the long-term, supporting the urbanization-EKC hypothesis. Conversely, the lack of significance in the lower-middle income countries may suggest that the urbanization process is at a more advanced stage, leading to a more abundant flow of sophisticated ecological practices that help in combating pollution.

Third, following a positive shock to energy intensity (renewables), the CO2 emissions respond positively (negatively) in both income subgroups. As well, the cumulated effect shows a sharp increase after the impact in both subsamples (except CO2 response following renewables shocks in low income states, where the increase seems to be smoother and lower in magnitude). However, starting approximately with the second year, the IRFs indicate that the cumulated effect stabilizes and preserves its positive linear trajectory up to twenty years in low income states. In contrast, it follows a monotonically increasing pattern in lower-middle income ones. On the whole, this may confirm that in countries where the industrialization process is more pronounced, it also becomes more challenging to maintain low levels of pollution.

Finally, an exogenous positive shock to CO2 leads to an increase in its levels, and the magnitude of impact seems to be comparable in both subgroups. Nonetheless, in low income countries, the cumulated response starts to decline after the impact, and then quickly readjust (after about two years) to a linear path that remains stable in the long-run. Conversely, in lower-middle income economies, the cumulated response keeps an increasing trajectory over the twenty-year horizon.

III.6.2. The Kyoto Protocol status

We split the main sample taking into account the date of the ratification/accession of individual states to the Kyoto Protocol based on the UN Treaty Collection[14] (see Table A-III.12 in the Appendix for details). Thus, the first subsample (Kyoto Protocol group A) comprises the nations which ratified or acceded before the year in which it entered into force (i.e. 2005), while in the second subgroup (Kyoto Protocol group B), we include the remaining countries for which the ratification/accession date is 2005 onwards (see Table A-III.4 in the Appendix for summary statistics). The cumulative IRFs are illustrated by panels (c) and (d) in Figure A-III.6 in the Appendix.

On the one hand, the findings indicate that for the states which ratified or acceded to the Kyoto Protocol before 2005, the evolution of cumulated CO2 response following output and urbanization shocks seems to switch its increasing trend in the long-run. In particular, this suggests that this group of countries may attain the peak in CO2 more rapidly and for lower levels of GDP and URB, compared to the economies which ratified/acceded to the Protocol after it entered into force. As such, the traditional and urbanization-EKC hypothesis seems to be more realistic for the Kyoto Protocol group A. Moreover, for the Kyoto Protocol group A states, the urbanization exhibits a delayed cumulated effect on CO2. In contrast, for the members of group B, the effect loses its significance in the long-term.

On the other hand, an exogenous increase in energy intensity (renewables) triggers a cumulated positive (negative) effect on CO2 in both subgroups of economies. However, at the moment of the impact, the magnitude of CO2 response is higher due to energy intensity (renewable energy) disturbances for the states which ratified/acceded to the Kyoto Protocol before (after) it entered into force. Also, in the next two years after the impact, the cumulated magnitude of CO2 response following both energy intensity and renewables shocks increases sharply, but then stabilizes and raises very slowly for the group A economies. For the group B states, the cumulated response of CO2 (i) raises

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[14] https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en.

abruptly after the impact due to EINT disturbances, but then stabilizes to a new high and follows a linear path until the end of the period, (ii) remains roughly at the same level recorded at the time of the impact following renewable energy shocks. Besides, a positive one standard deviation shock to CO2 has a positive effect on its levels for both subgroups. However, the cumulated effect increases (decreases) slowly over the years across the Kyoto Protocol group A (B) states. Overall, the findings may suggest that the states which ratified or acceded to the Protocol before 2005 are the ones that have undergone significant changes in their economic development (e.g. have experienced a more intense process of industrialization and urbanization, among others). Thus, they were committing much faster in actions to counteract the potential adverse effects on the environment.

III.7. Sectoral CO2 emissions

To have a more in-depth look at the potential changes in pollution dynamics in the relationship with our macro indicators, we substitute aggregated CO2 with its sector-specific counterparts (see Tables A-III.2-3 in the Appendix for variables' definition and summary statistics, respectively).[15] In doing so, we estimate the GMM-SVAR model considering the CO2 related to each of the following sectors: transport, buildings, other industrial combustion, non-combustion, and power industry. Figure III.2 displays the CO2 sector-specific cumulative orthogonalized IRFs, while Table A-III.12 in the Appendix depicts the CO2 sector-specific FEVDs.

First, considering the presumed differences in the magnitude, an external shock to output and urbanization has a cumulative significant positive effect on CO2 from transport, buildings, and non-combustion sector—with the notable exception of CO2 from buildings which do not significantly respond to urbanization disturbances. Besides, the significant positive cumulated paths over the twenty-year horizon suggest that the related EKC hypothesis may be at work in the very long-run, both for output and urbanization. Also, in line with the baseline findings, the CO2 emissions respond with a delay of about two years following urbanization shocks. On this last point, given that the construction industry has a substantial contribution to the urbanization process, the lack of

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[15] We test the cross-sectional dependence and stationarity properties of CO2 sector variables using the same tests as for the baseline model. The findings confirm the presence of cross-sectional dependence, while the unit root test shows that variables are stationary in levels (see Tables A-III.9-11 in the Appendix). However, in empirical analysis, we use the first difference of the variables to work with growth rates and have all the system variables at the same level.

significance of the buildings-related CO2 response following external shocks to urbanization may indicate that a substantial number of green projects are implemented in this sector, thus, helping to reduce the associated pollution.

Second, an exogenous shock to output and urbanization reduce the CO2 from other industrial combustion and power industry sector both on impact and cumulated over twenty years. However, industrial combustion- and power industry-related CO2 emissions do not respond immediately to output shocks, but rather with roughly ten and eighteen years of delay. Moreover, regarding the disturbances to urbanization, they seem to induce a U-shaped pattern in cumulative CO2 emissions' evolution, opposite to the bell-shaped pattern postulated by the traditional EKC hypothesis.

Third, the CO2 related to each of the five sectors react positively (negatively) to one standard deviation energy intensity (renewables) shocks, both on impact and cumulated over the twenty years, thus, backing up the baseline findings. However, the effect of renewables on CO2 from non-combustion and power industry is not statistically significant. Indeed, these two similar results may go hand in hand, given that access to energy in developing countries is a significant issue, mainly alleviated, among others, by the transition to off-grid renewable energy systems [International Renewable Energy Agency (IRENA), 2015]. More precisely, the off-grid renewables technologies (e.g. solar, micro-hydro, wind, biomass, among others), whose leading market is concentrated in developing economies, represent the more environmentally-friendly and cost-effective alternative to classical nonrenewable energy sources, such as the fossil fuels used for electricity generation via combustion processes [see e.g. IRENA, 2015; Renewable Energy Policy Network for the 21st Century (REN21), 2015]. Additionally, the results also corroborate with the negative effect of output and urbanization on power industry-related CO2.

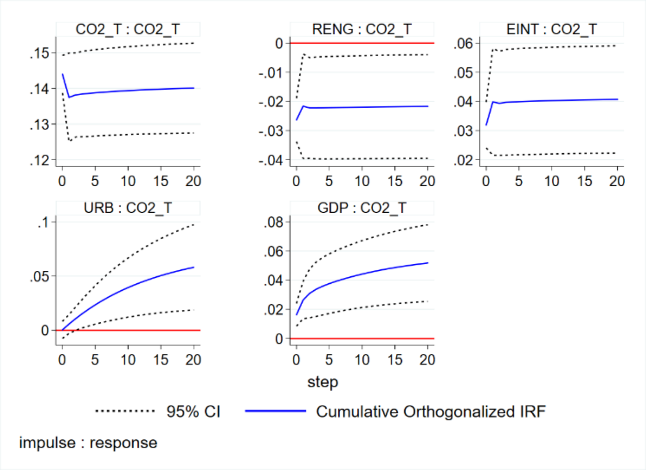
Fourth, an external increase in the sector-specific CO2 emissions triggers a statistically significant increase in its levels. At the same time, the magnitude at the moment of impact ranges from about fourteen and a half percent (CO2 from transport) to thirty percent (CO2 from other industrial combustion). Furthermore, the cumulated effect starts to decay immediately after the impact (except CO2 associated with other industrial combustion), and then quickly stabilizes and follows an almost linear path until the end of the analyzed period. In particular, the results may highlight, yet again, the inertial behavior of CO2 pollution levels.

Regarding the FEVDs (see Table A-III.12 in Appendix), similar to the aggregated results, variables' dynamics contribute to explaining their largest share of variation. Also, considering a twenty-year horizon, energy intensity explains the largest share in CO2 from transport (4.66%) and buildings (3.99%), while urbanization the largest share in CO2 related to other industrial combustion (5.36%), non-combustion (5.17%), and power industry (3.68%) sector. Moreover, the GDP contributes more in explaining the variation in CO2 from non-combustion (2.36%), buildings (2.11%), and transport (1.79%), than to other industrial combustion (0.62%) and power industry (0.51%) sector. Likewise, renewables have the most significant contribution to variation in CO2 related to transport (3.08%) and buildings (2.29%) sector. However, its contribution to the remaining sectors is relatively lower (0.99% for other industrial combustion, and 0.21% for the power industry), or almost insignificant (0.01% for non-combustion). Indeed, these results suggest that the most polluting sectors (i.e. transport and buildings) are also those in which the vast majority of renewable energy projects are implemented.

Overall, the findings illustrate, on the one hand, the complexity of the relationship between sector-specific CO2 and the several related key economic aggregates, highlighting which sector is more likely to be associated in the future with higher pollution levels. On the other hand, the results strengthen the vital role of non-combustion energy sources and energy efficiency projects (e.g. the rapidly growing off-grid renewable systems, the use of sustainable technologies in the construction industry, among many others) in promoting green growth and urbanization, and ultimately in reducing the environmental degradation.

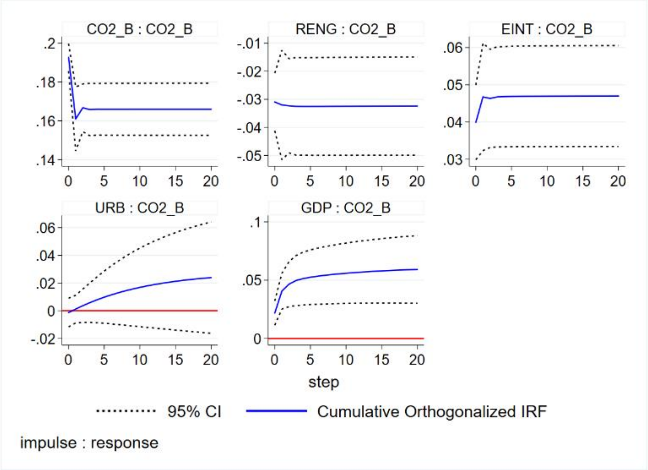
Figure III.2: Cumulative orthogonalized IRFs: sectoral CO2 emissions

(a) CO2 from transport



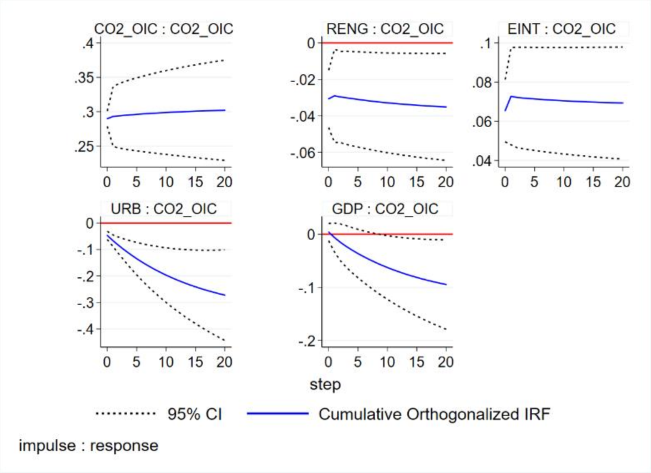
Observations: 1428 • Groups: 68

(b) CO2 from buildings



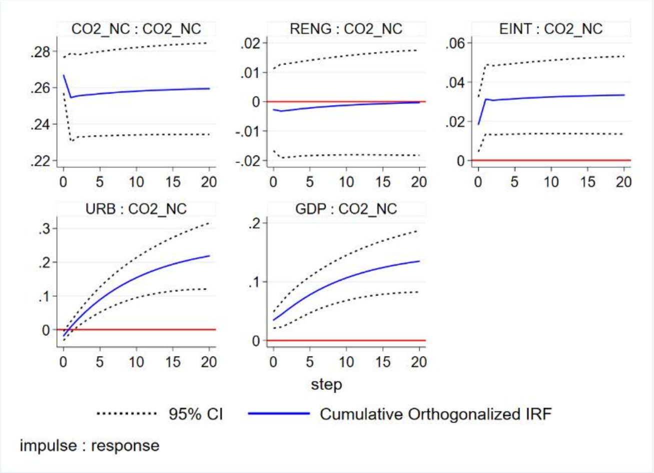
Observations: 1428 • Groups: 67

(c) CO2 from other industrial combustion



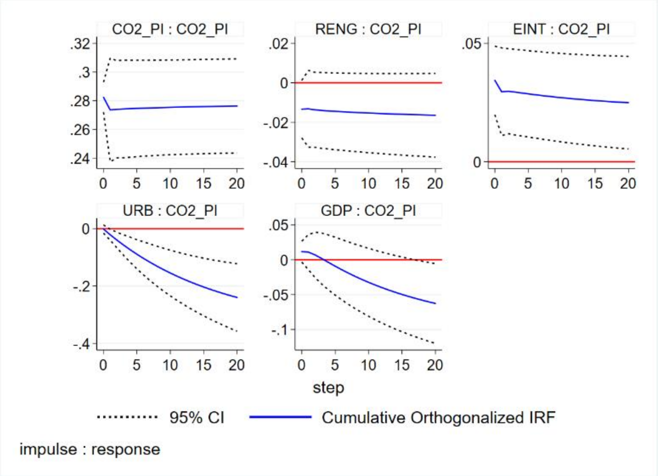
Observations: 1405 • Groups: 67

(d) CO2 from non-combustion



Observations: 1428 • Groups: 68

(e) CO2 from power industry



Observations: 1422 • Groups: 68

Notes: Considering two generic variables A and B, “A: B” denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

III.8. Conclusion, and policy implications

The fast-growing process of development and urbanization are two of the main features that differentiate between developing economies' economic system and that of developed nations. From a sustainable development standpoint, over the last two decades, the progressive active involvement of developing countries in fighting climate change has been achieved mainly by implementing numerous green projects, aimed at increasing both the use of renewable energy and energy efficiency.

This paper explored the impact of external changes in output, urbanization, energy intensity, and renewable energy on aggregated and sector-specific CO2, within a modified STIRPAT analytical framework. To this end, motivated by the potential endogenous behavior between variables, we employed the novel panel GMM-VAR technique for a rich sample of 68 developing states over 1992-2015. On the one hand, the results showed that an exogenous increase in output, urbanization, energy intensity and CO2 led to a significant increase in CO2, both on impact and cumulated over the twenty-year horizon. Besides, the CO2 response following disturbances to output and urbanization suggested that a threshold effect, compatible with the classical and urbanization EKC hypothesis, might be at work in the long-run for our group of countries. Conversely, we found that a positive shock to renewables cumulatively and significantly decreases the current and future levels of CO2. In sum, these findings may imply that in the context of rapid industrialization and urbanization, renewable energy is one of the most powerful tools in mitigating environmental degradation.

Nonetheless, more considerable attention must also be paid to energy efficiency, especially as increasing it can further enhance renewable energy's beneficial effects on the environment. These results are supported by several robustness tests, including an alternative Cholesky ordering of variables, when altering the sample, and controlling for a series of exogenous factors. On the other hand, the findings were sensitive concerning both countries' level of development and their Kyoto Protocol ratification/ascension status. Besides, the disaggregated CO2 analysis unveiled essential differences regarding various sectors' contribution to the overall CO2 pollution. In particular, the results may suggest that the CO2 emissions related to transportation, construction, and non-combustion sector are more likely to increase in the future, compared to other industrial combustion and power industry sector.

The findings could be transposed in some valuable policy recommendations. First, developing countries should pay more attention to the implications that the process of urbanization, as well as the growth-promoting policies, have on CO2 pollution. Moreover, the urban planning and development policy requires an appropriate design to accommodate better any potential negative impacts on the quality of the environment. Second, although countries make outstanding efforts to invest as much as possible in renewable energy sources and minimize energy dependency, these investments should be continuously adapted to cope with their particular economic environment dynamics. Likewise, adequate monitoring during project implementation may increase their efficiency and signal beforehand any potential nonconformities. Third, to counterbalance and mitigate the overall pollution, additional efforts should be directed towards the sectors where CO2 emissions are more likely to increase. Finally, the ongoing international cooperation and assistance from developed nations may represent a central pillar in ensuring environmental sustainability in developing economies. Future work could consider a more detailed breakdown of energy sources in assessing their impact on CO2 (see e.g. Antonakakis et al., 2017; Naminse & Zhuang, 2018). However, this is strictly conditioned by data availability, especially for this group of developing economies. As well, an analysis of the impact of various types of crises on CO2, by making use of complementary techniques such as the local projection method (see e.g. Jalles, 2019), could provide additional insights regarding the future behavior of CO2 emissions.

Appendix

Table A - III.1: List of countries

Geographic region		
East Asia and Pacific (10)	**Europe and Central Asia (6)**	**Latin America and Caribbean (5)**
Indonesia	Armenia	Bolivia
Kiribati	Georgia	El Salvador
Lao PDR	Kyrgyz Republic	Guatemala
Mongolia	Tajikistan	Honduras
Myanmar	Ukraine	Nicaragua
Papua New Guinea	Uzbekistan	
Philippines		
Solomon Islands		
Vanuatu		
Vietnam		
Middle East and North Africa (5)	**South Asia (6)**	**Sub-Saharan Africa (36)**
Egypt, Arab Rep.	Bangladesh	Angola
Jordan	Bhutan	Benin[⸙]
Morocco	India	Burkina Faso[⸙]
Tunisia	Nepal[⸙]	Burundi[⸙]
Yemen, Rep.	Pakistan	Cabo Verde
	Sri Lanka	Cameroon
		Central African Republic[⸙]
		Chad[⸙]
		Comoros[⸙]
		Congo, Dem. Rep.[⸙]
		Congo, Rep.
		Côte d'Ivoire
		Ethiopia[⸙]
		Gambia[⸙]
		Ghana
		Guinea[⸙]
		Guinea-Bissau[⸙]
		Kenya
		Lesotho
		Liberia[⸙]
		Madagascar[⸙]
		Malawi[⸙]
		Mali[⸙]
		Mauritania
		Mozambique[⸙]
		Nigeria
		Rwanda[⸙]
		Senegal[⸙]
		Sierra Leone[⸙]
		Sudan
		Swaziland
		Tanzania[⸙]
		Togo[⸙]
		Uganda[⸙]
		Zambia
		Zimbabwe[⸙]

Notes: [⸙] denotes that the respective country belongs to the low income group.

Table A - III.2: Variables' definition

Variable	**Defintion**	**Source**
CO2	CO2 emissions totals of fossil fuel use and industrial processes (ktonnes)	The European Commission, Joint Research Centre (EC-JRC)/Netherlands Environmental Assessment Agency (PBL). Emissions Database for Global Atmospheric Research (EDGAR), release EDGARv4.3.2_FT2016 (1970-2016). Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Olivier, J.G.J., Peters, J.A.H.W., Schure, K.M., Fossil CO2 and GHG emissions of all world countries, EUR 28766 EN,Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-73207-2, doi:10.2760/709792, JRC107877 (http://edgar.jrc.ec.europa.eu/overview.php?v=booklet2017&dst=CO2emi)
CO2_T	CO2 emission from transport	
CO2_B	CO2 emission from buildings	
CO2_OIC	CO2 emission from other industrial combustion	
CO2_NC	CO2 emission from non-combustion	
CO2_PI	CO2 emission from power industry	
GDP	GDP based on purchasing power parity (PPP) (constant 2011 international $)	The World Bank, World Bank Indicators (https://databank.worldbank.org/data/home.aspx)
URB	Urban population (% of total population)	
RENG	Renewable energy consumption (% of total final energy consumption)	
EINT	Energy intensity level of primary energy computed as total primary energy supply over GDP measured in constant 2011 US dollars at PPP (MJ/$2011 PPP GDP)	
POP	Total midyear population	
AGRI	Agriculture, value added (% of GDP)	
IND	Industry, value added (% of GDP)	
SERV	Services, value added (% of GDP)	
TRADE	Trade (% of GDP)	
FRENTS	Forest rents (% of GDP)	
CREDIT	Domestic credit to private sector (% of GDP)	
GDPc	GDP per capita based on purchasing power parity (PPP) (constant 2011 international $)	
REM	Migrant remittance inflows (nominal US$ million)	The World Bank staff calculation based on data from IMF Balance of Payments Statistics database and data releases from central banks, national statistical agencies, and World Bank country desks (https://www.worldbank.org/en/topic/labormarkets/brief/migration-and-remittances)
CO2c	CO2 per capita emissions totals of fossil fuel use and industrial processes (ktonnes)	Authors' computation based on The European Commission, Joint Research Centre (EC-JRC)/Netherlands Environmental Assessment Agency (PBL) (CO2 emissions: http://edgar.jrc.ec.europa.eu/overview.php?v=booklet2017&dst=CO2emi) and World Bank Indicators data (population: https://databank.worldbank.org/data/home.aspx)
EINTc	Energy intensity level of primary energy per capita computed as total primary energy supply over GDP measured in constant 2011 US dollars at PPP (MJ/$2011 PPP GDP)	Authors' computation based on the World Bank Indicators data (energy intensity level of primary energy and population: https://databank.worldbank.org/data/home.aspx)

Table A - III.3: Descriptive statistics [full-sample]

Variable/Statistic	Mean	Std. dev	Median	Min	Max	Observations
Baseline analysis						
GDP	1.54e+11	5.49e+11	2.52e+10	1.43e+08	7.54e+12	1632
URB	36.97067	15.85659	35.3225	6.288	83.679	1632
EINT	8.732009	6.978321	6.149098	1.91032	57.98816	1632
RENG	59.00502	29.2848	63.37218	0.600592	98.34261	1632
CO2	45506.02	185879.9	4161.842	20.6217	2419637	1632
Robustness analysis						
GDPc	2815.427	2185.772	2085.198	180.4062	12152.17	1632
CO2c	0.0008181	0.0012382	0.0003974	0.0000311	0.012404	1632
EINTc	3.02e-06	7.44e-06	6.84e-07	3.61e-09	0.000069	1632
POP	4.17e+07	1.38e+08	1.03e+07	74769	1.31e+09	1632
AGRI	23.93044	12.40996	22.88478	2.706677	79.04237	1559
IND	24.93198	10.76102	24.15961	2.073173	77.41367	1540
SERVI	45.03406	9.706143	45.77348	12.43525	77.02007	1485
TRADE	72.59632	32.94223	67.26805	0.1674176	311.3553	1565
FRENTS	4.593966	6.052195	2.429323	0.0000	40.42677	1616
REM	2072.407	6065.007	204.5626	0.0095628	70388.64	1340
CREDIT	21.92812	18.57499	15.66249	0.4103563	114.7235	1521
CO2 sector-specific analysis						
CO2_T	7117.286	20936.74	1244.581	15.26836	257301.2	1632
CO2_B	5187.247	17222.53	561.6689	0.407881	180733.1	1632
CO2_NC	5724.411	18873.11	476.8578	0.046156	206595.6	1632
CO2_OIC	10202.23	42005.12	636.099	0.0000	529105.3	1608
CO2_PI	17424.87	91486.77	608.0745	0.0000	1245902	1632

Table A - III.4: Descriptive statistics [subsamples]

Variable/Statistic	Mean	Std. dev	Median	Min	Max	Observations
Low income economies						
GDP	1.97e+10	2.16e+10	1.36e+10	5.13e+08	1.53e+11	576
URB	29.17297	11.52414	30.2355	6.288	59.632	576
EINT	11.83926	8.449231	9.401523	1.91032	57.98816	576
RENG	81.83385	14.57414	86.66449	40.46676	98.34261	576
CO2	2391.314	2914.064	1306.94	45.36593	18988.19	576
Lower-middle income economies						
GDP	2.27e+11	6.71e+11	4.27e+10	1.43e+08	7.54e+12	1056
URB	41.22395	16.2794	40.0925	12.977	83.679	1056
EINT	7.037145	5.31305	5.425794	1.992982	38.33533	1056
RENG	46.55294	27.75466	51.01571	.600592	95.85808	1056
CO2	69023.13	227689	8254.396	20.6217	2419637	1056
Kyoto Protocol status group A						
GDP	1.90e+11	6.53e+11	2.88e+10	1.43e+08	7.54e+12	1104
URB	38.34527	17.04287	36.327	6.288	83.679	1104
EINT	8.284522	6.528194	5.964056	1.91032	57.98816	1104
RENG	53.47162	30.03119	57.21445	.600592	97.29142	1104
CO2	59523.13	222856.2	5533.39	20.6217	2419637	1104
Kyoto Protocol status group B						
GDP	7.91e+10	1.77e+11	2.00e+10	6.37e+08	9.47e+11	528
URB	34.09649	12.56938	33.7425	9.585	65.526	528
EINT	9.667664	7.759983	6.990818	2.056564	50.13474	528
RENG	70.57486	23.83922	78.07493	5.554171	98.34261	528
CO2	16197.52	41380.69	2583.84	43.01915	227542	528

Table A - III.5: Panel SVAR-Granger causality Wald test

[Equation] \ Excluded variable	**chi2**	**df**	**prob > chi2**
[GDP]			
URB	1.083	1	(0.298)
EINT	1.531	1	(0.216)
RENG	2.812*	1	(0.094)
CO2	0.469	1	(0.493)
ALL	5.921	4	(0.205)
[URB]			
GDP	10.608***	1	(0.001)
EINT	0.167	1	(0.683)
RENG	2.247	1	(0.134)
CO2	1.989	1	(0.158)
ALL	16.152***	4	(0.003)
[EINT]			
GDP	22.044***	1	(0.000)
URB	0.149	1	(0.699)
RENG	0.563	1	(0.453)
CO2	0.805	1	(0.370)
ALL	23.092***	4	(0.000)
[RENG]			
GDP	11.287***	1	(0.001)
URB	5.934**	1	(0.015)
EINT	2.131	1	(0.144)
CO2	1.273	1	(0.259)
ALL	23.727***	4	(0.000)
[CO2]			
GDP	4.828**	1	(0.028)
URB	15.787***	1	(0.000)
EINT	6.179**	1	(0.013)
RENG	1.313	1	(0.252)
ALL	22.787***	4	(0.000)

Notes: H0 is ''Excluded variable does not Granger-cause equation variable'', while according to H1 ''Excluded variable Granger-causes equation variable. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

Table A - III.6: Panel SVAR selection order criteria

Lag	**CD**	**J**	**J p-value**	**MBIC**	**MAIC**	**MQIC**
1	0.988	70.449	0.019	-270.824	-25.550	-117.853
2	0.988	48.099	0.033	-179.417	-15.900	-77.435
3	0.988	17.601	0.345	-96.156	-14.398	-45.166
Observations	1224					
Panels	68					

Notes: Model and moment selection criteria are computed using the first four lags of variables.

Table A - III.7: Model stability condition

Eigenvalue		
Real	*Imaginary*	*Modulus*
0.940	0	0.940
0.372	0	0.372
-0.081	0	0.081
-0.045	0	0.045
0.022	0	0.022

Notes: All the eigenvalues lie inside the unit circle. The GMM panel SVAR model satisfies stability condition.

Figure A - III.1: Inverted roots of AR characteristics polynomial [GMM-SVAR]

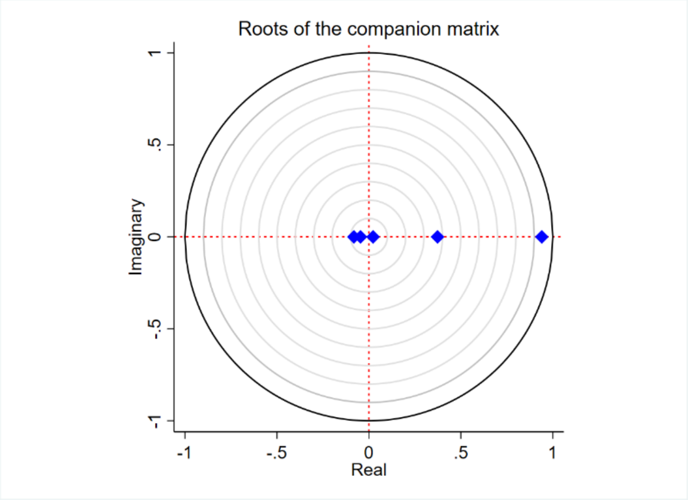
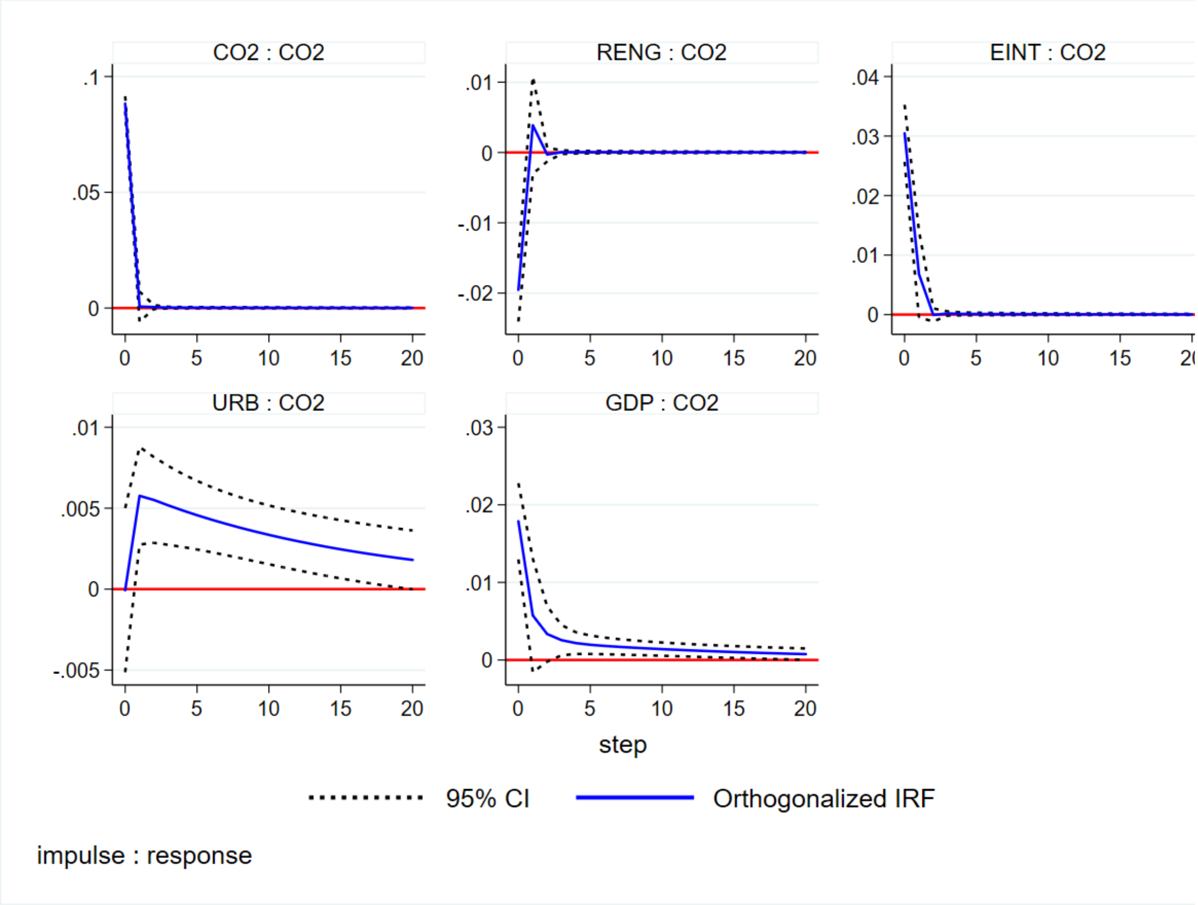


Table A - III.8: First-order panel SVAR-GMM estimates

	Response to				
Response of	GDP$_{(t-1)}$	URB$_{(t-1)}$	EINT$_{(t-1)}$	RENG$_{(t-1)}$	CO2$_{(t-1)}$
GDP	0.3746***	-0.2343	0.0190	-0.0292*	0.0083
	(0.0436)	(0.2251)	(0.0154)	(0.0174)	(0.0122)
URB	0.0066***	0.9398***	0.0002	0.0010	0.0011
	(0.0020)	(0.0241)	(0.0007)	(0.0007)	(0.0007)
EINT	-0.2868***	0.1219	-0.0517	0.0271	0.0246
	(0.0610)	(0.3158)	(0.0427)	(0.0362)	(0.0274)
RENG	-0.1375***	0.4409**	-0.0481	-0.0618	-0.0263
	(0.0409)	(0.1810)	(0.0329)	(0.0497)	(0.0233)
CO2	0.1628**	1.9181***	0.1078**	0.0536	0.0072
	(0.0741)	(0.4827)	(0.0433)	(0.0468)	(0.0367)
Observations (N × T)	1428				
Countries	68				

Notes: The five-variable one lag panel SVAR is estimated by GMM, using first four lags of the variables as instruments. The country-specific fixed effects are removed during estimation via the Helmert transformation. Reported numbers display the coefficients of regressing the row variables on first lag of the column variables. Standard errors robust to heteroskedasticity and serial correlation in brackets. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

Figure A - III.2: Orthogonalized IRFs

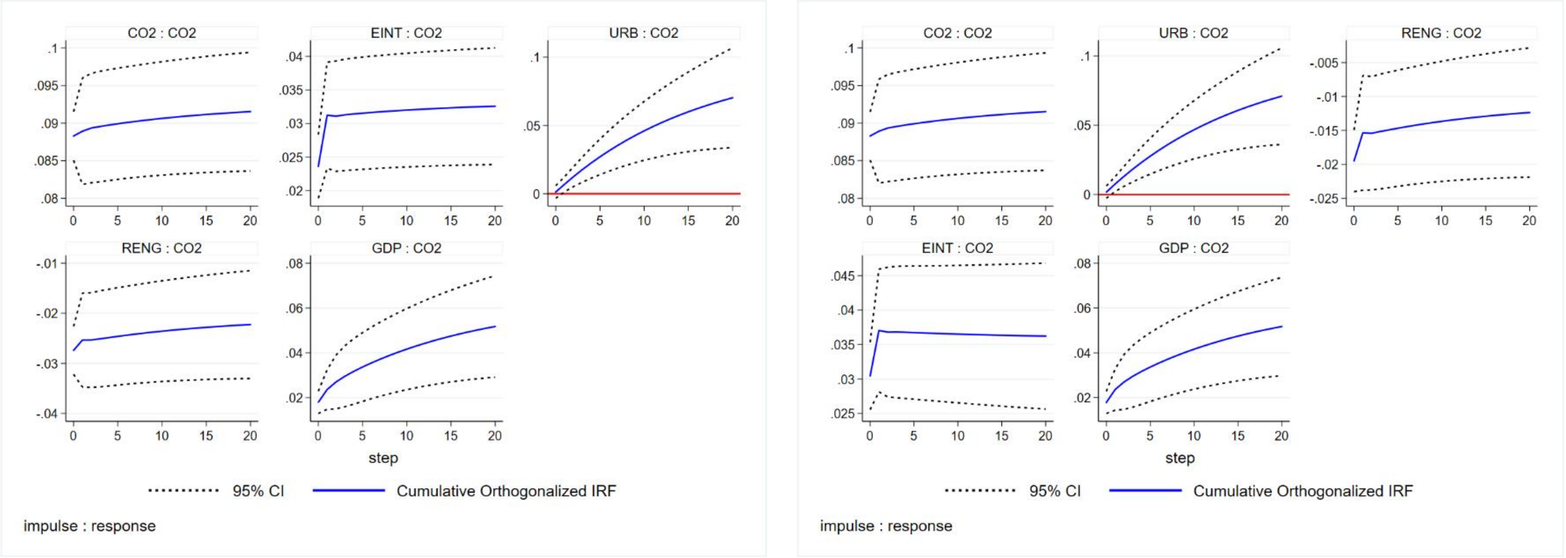


Observations: 1428 • Groups: 68

Notes: Considering two generic variables A and B, “A: B” denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

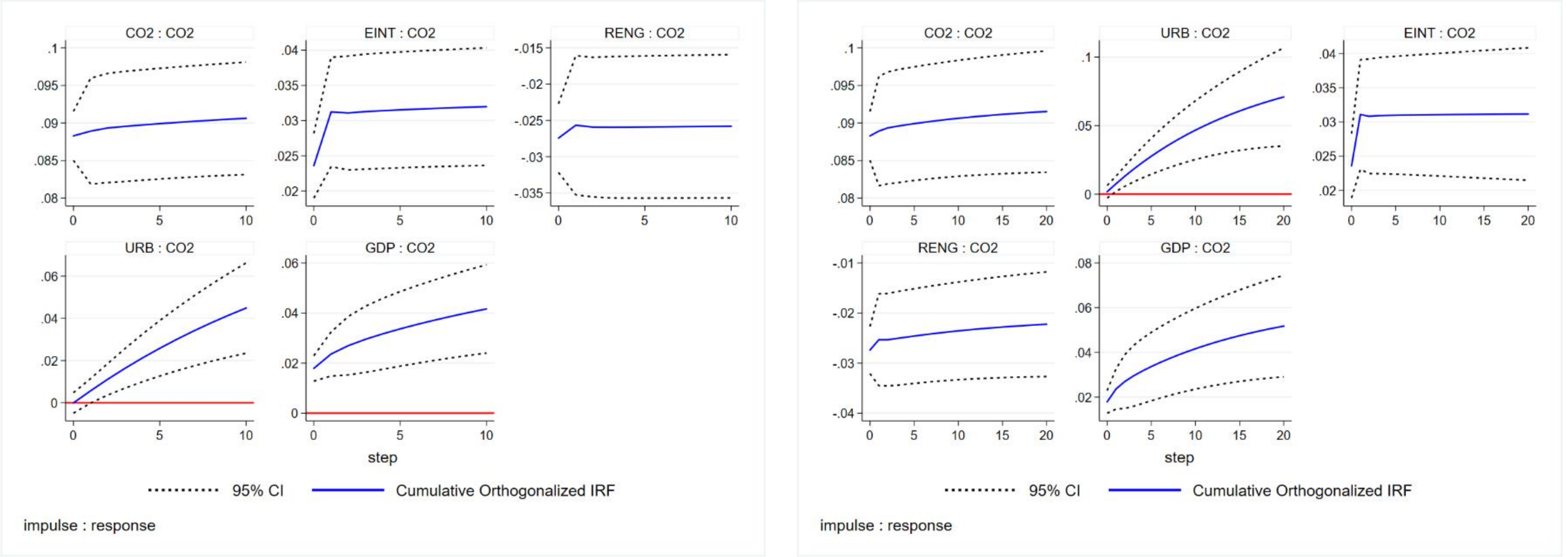
Figure A - III.3: Cumulative orthogonalized IRFs: robustness [alternative ordering]

(a) (**GDP → RENG → URB → EINT → CO2**) **(b)** (**GDP → EINT → RENG → URB → CO2**)



Observations: 1428 • Groups: 68 Observations: 1428 • Groups: 68

(c) (**GDP → URB → RENG → EINT → CO2**) **(d)** (**GDP → RENG → EINT → URB → CO2**)

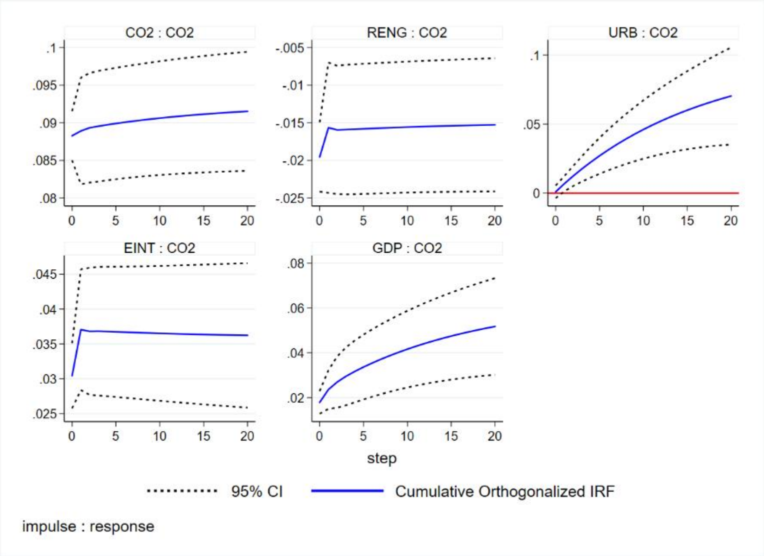


Observations: 1428 • Groups: 68 Observations: 1428 • Groups: 68

Notes: Considering two generic variables A and B, "A: B" denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

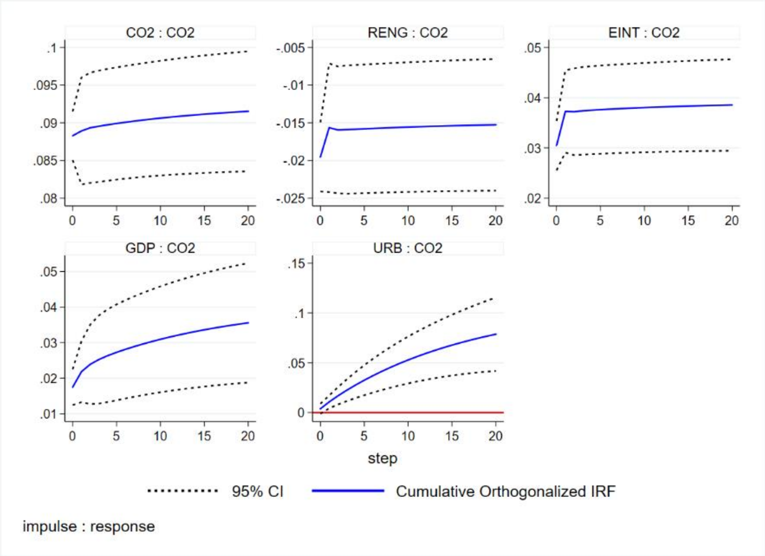
(**Figure A - III.3:** continued)

(e) (**GDP → EINT → URB → RENG → CO2**)



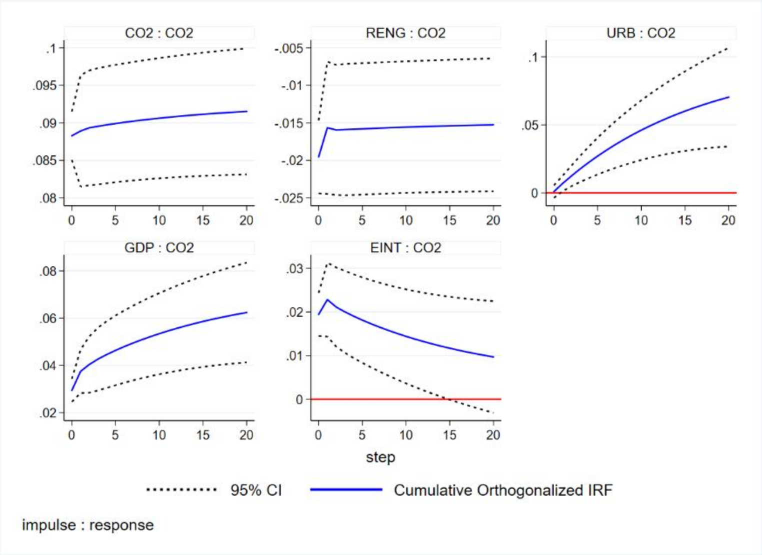
Observations: 1428 • Groups: 68

(f) (**URB → GDP → EINT → RENG → CO2**)



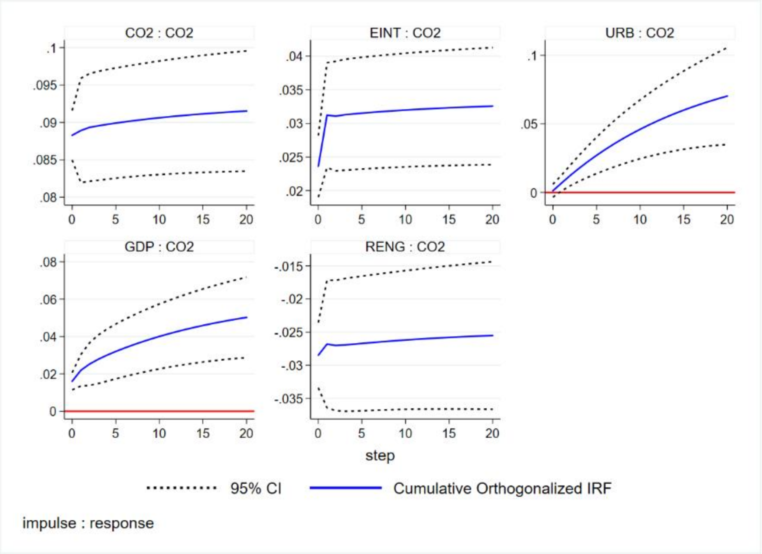
Observations: 1428 • Groups: 68

(g) (**EINT → GDP → URB → RENG → CO2**)



Observations: 1428 • Groups: 68

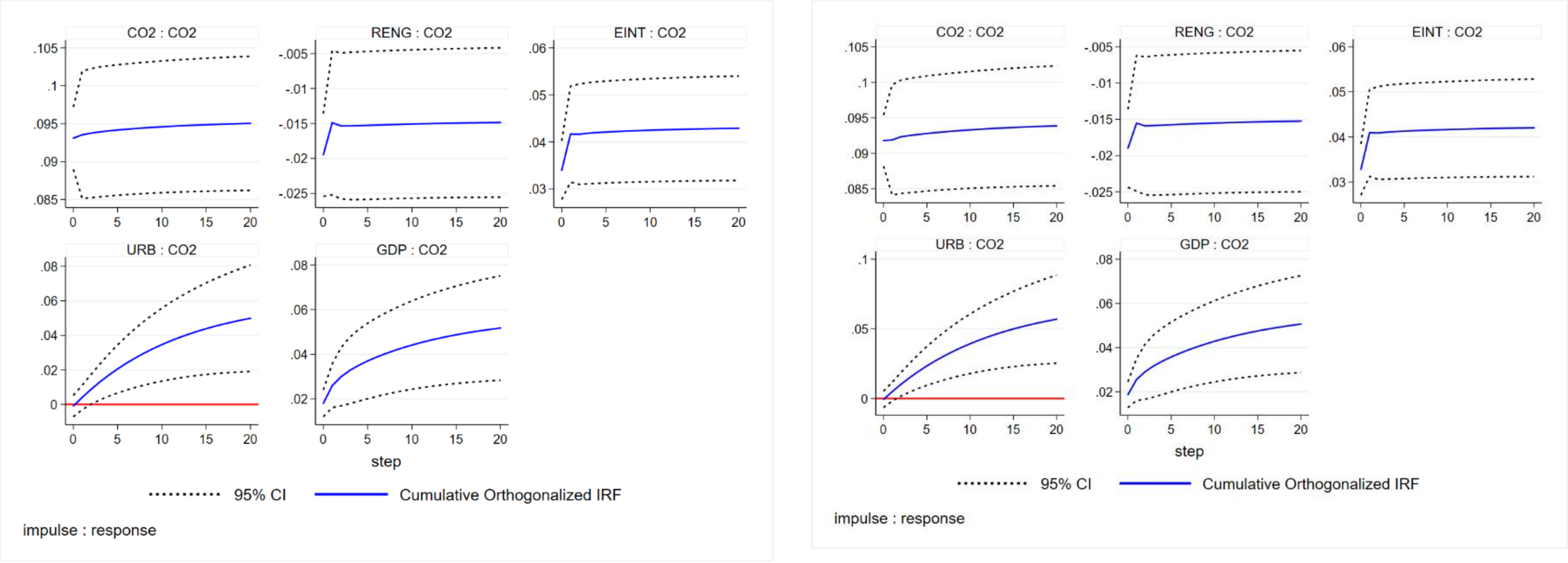
(h) (**RENG → GDP → URB → EINT → CO2**)



Observations: 1428 • Groups: 68

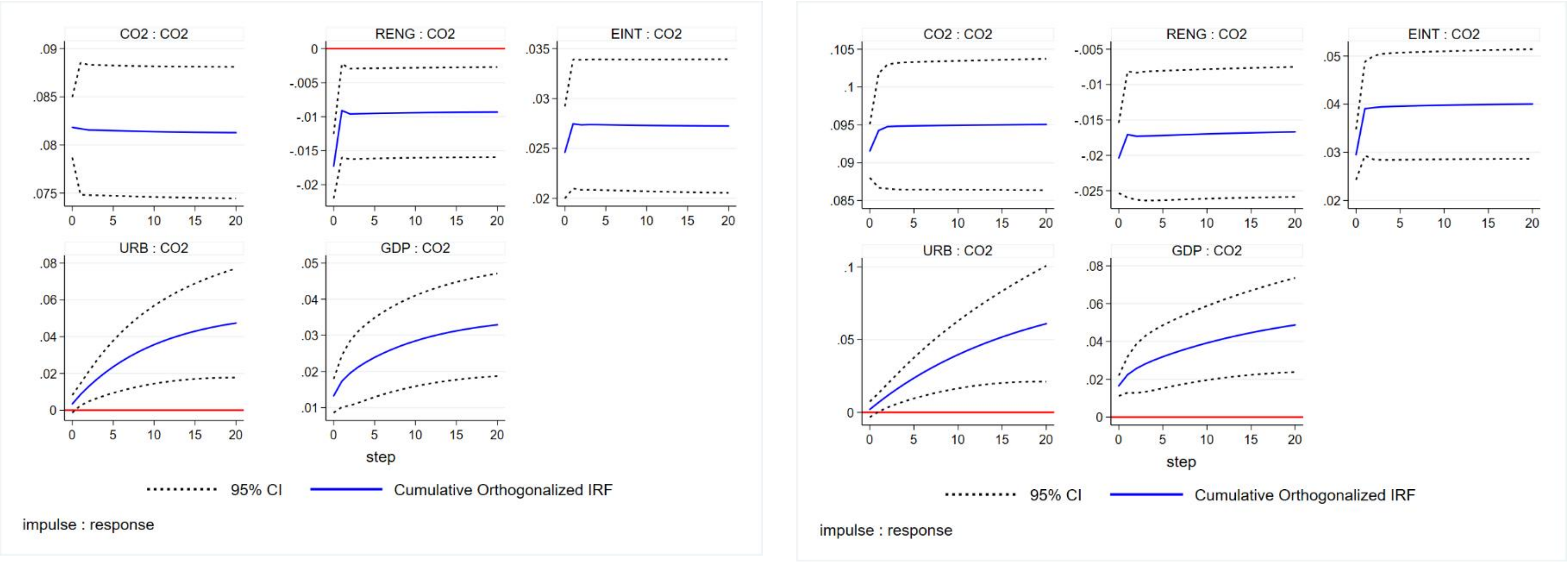
Notes: Considering two generic variables A and B, "A: B" denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

Figure A - III.4: Cumulative orthogonalized IRFs: altering the sample & CO2, GDP and EINT in per capita terms


(a) period: 1992-2008 **(b) period: 1992-2010**

Observations: 1020 • Groups: 68

Observations: 1156 • Groups: 68


(c) period: 1996-2015 **(d) without: Egypt, Jordan, Mauritania Morocco, Sudan, Tunisia, and Yemen**

Observations: 1292 • Groups: 68

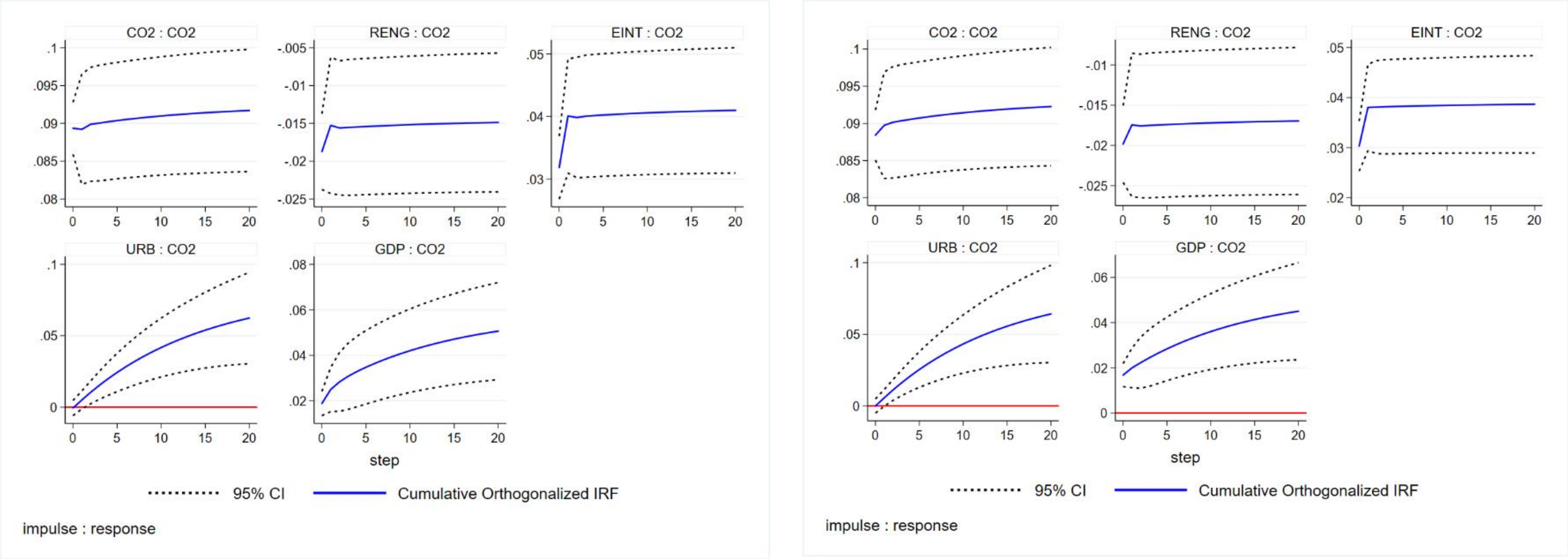
Observations: 1281 • Groups: 61

Notes: Considering two generic variables A and B, “A: B” denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

(**Figure A - III.4:** continued)

(d) without: Angola, Congo Rep., Egypt, Indonesia, Nigeria, and Vietnam

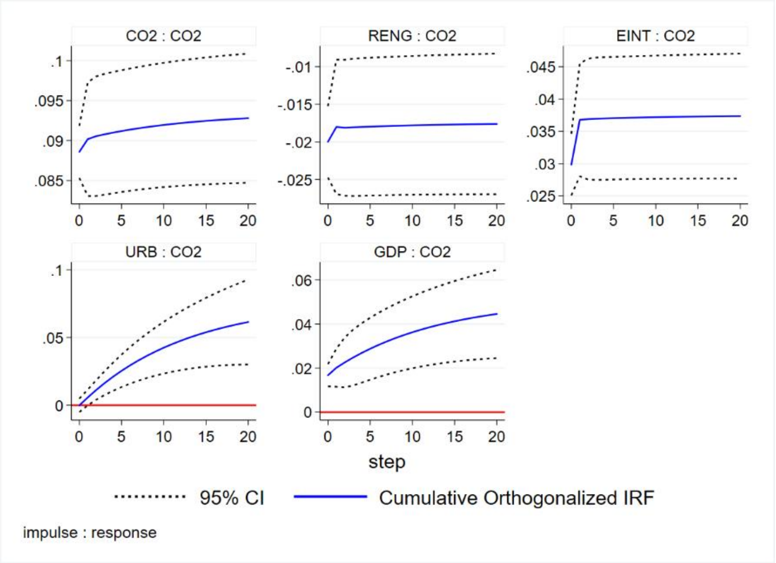
(e) GDP and CO2 in per capita terms



Observations: 1302 • Groups: 62

Observations: 1428 • Groups: 68

(f) GDP, EINT, and CO2 in per capita terms

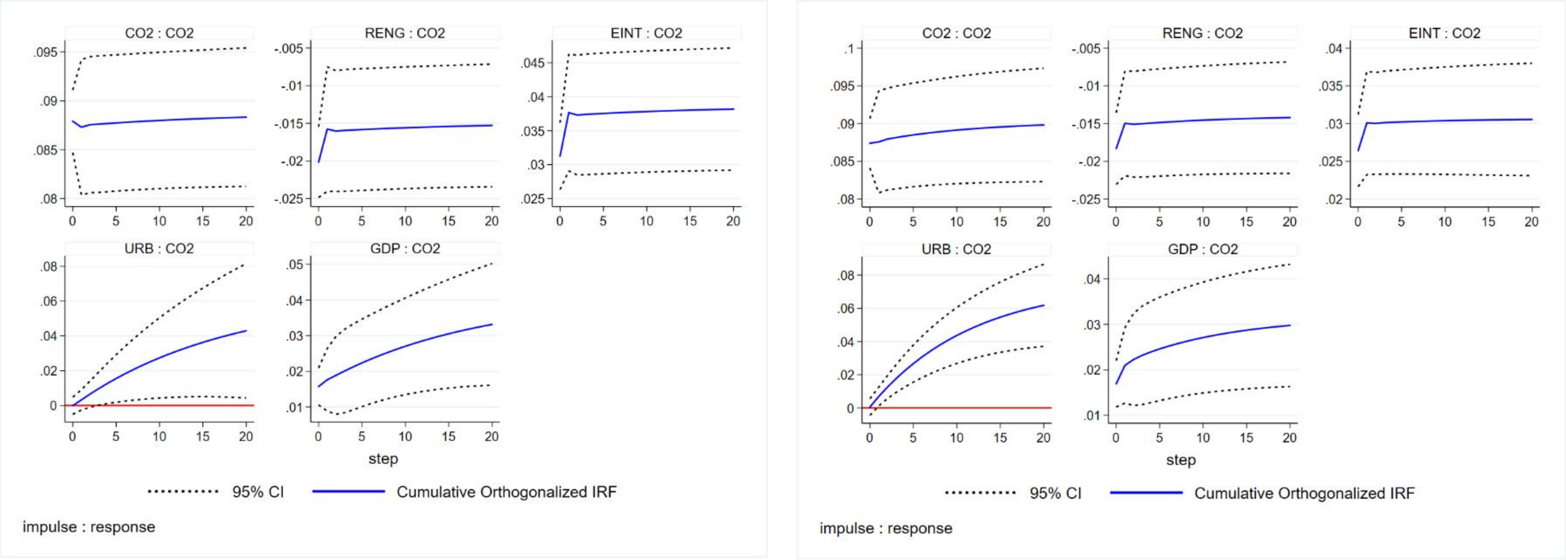


Observations: 1428 • Groups: 68

Notes: Considering two generic variables A and B, "A: B" denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

Figure A - III.5: Cumulative orthogonalized IRFs: exogenous additional controls

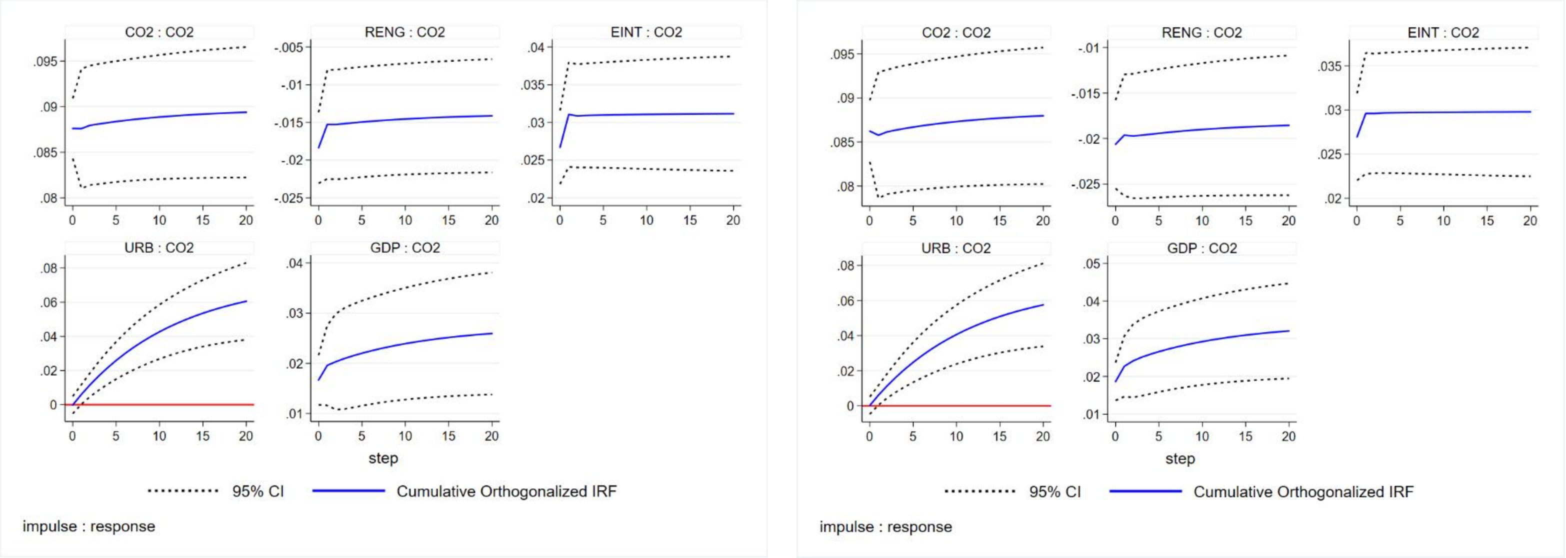
(a) population **(b) agriculture**



Observations: 1428 • Groups: 68

Observations: 1361 • Groups: 68

(c) industry **(d) services**

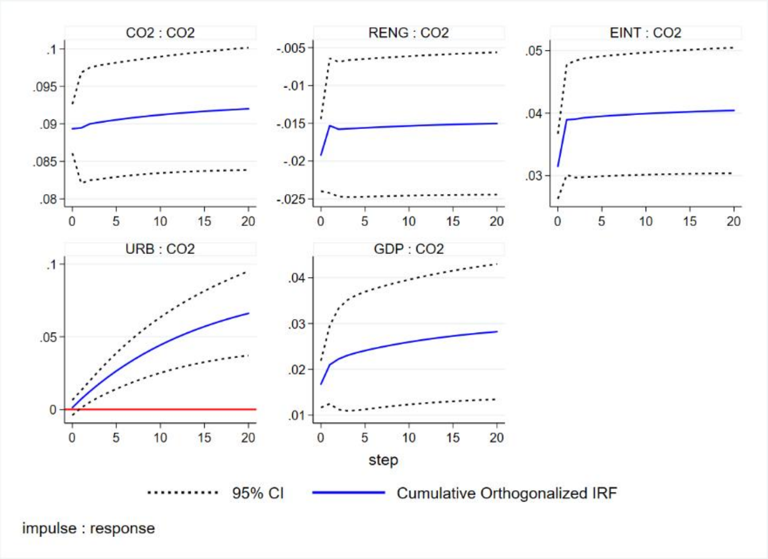


Observations: 1344 • Groups: 68

Observations: 1269 • Groups: 68

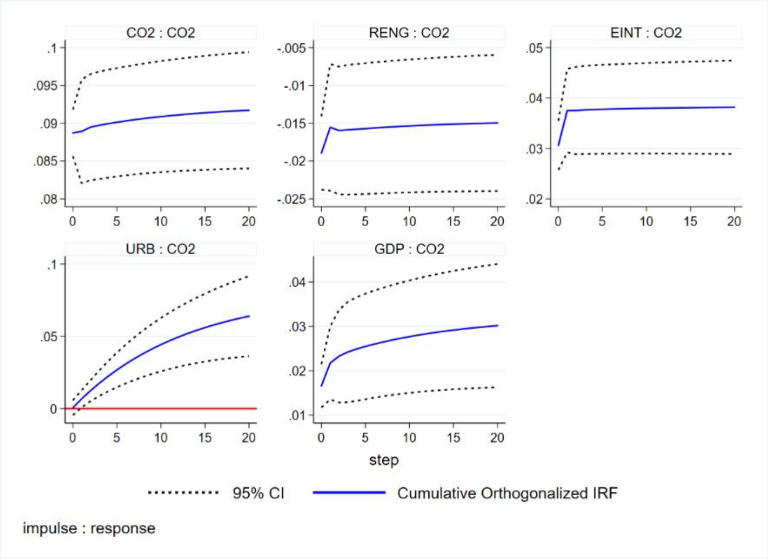
Notes: Considering two generic variables A and B, “A: B” denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

(**Figure A - III.5:** continued)



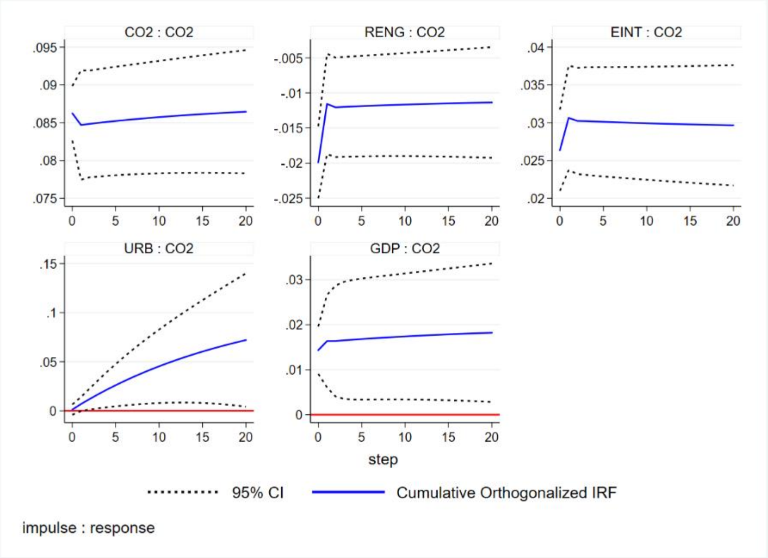
(e) trade

Observations: 1365 • Groups: 68



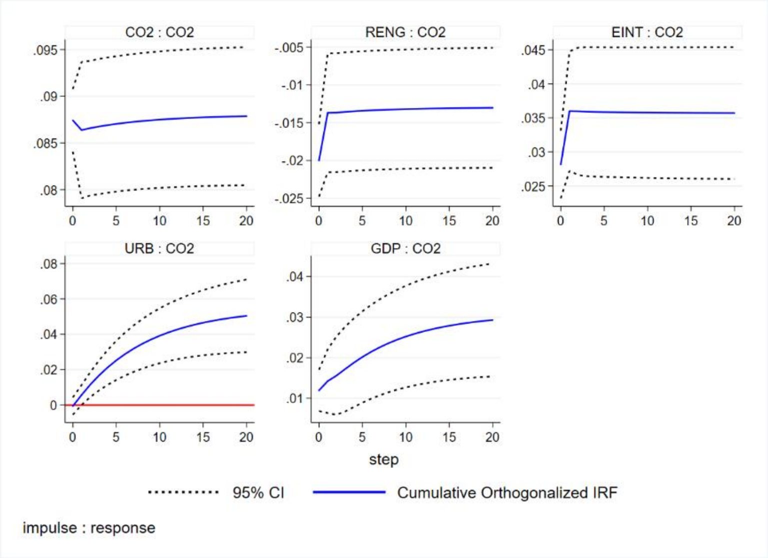
(f) forest rents

Observations: 1414 • Groups: 68



(g) remittances

Observations: 1155 • Groups: 68



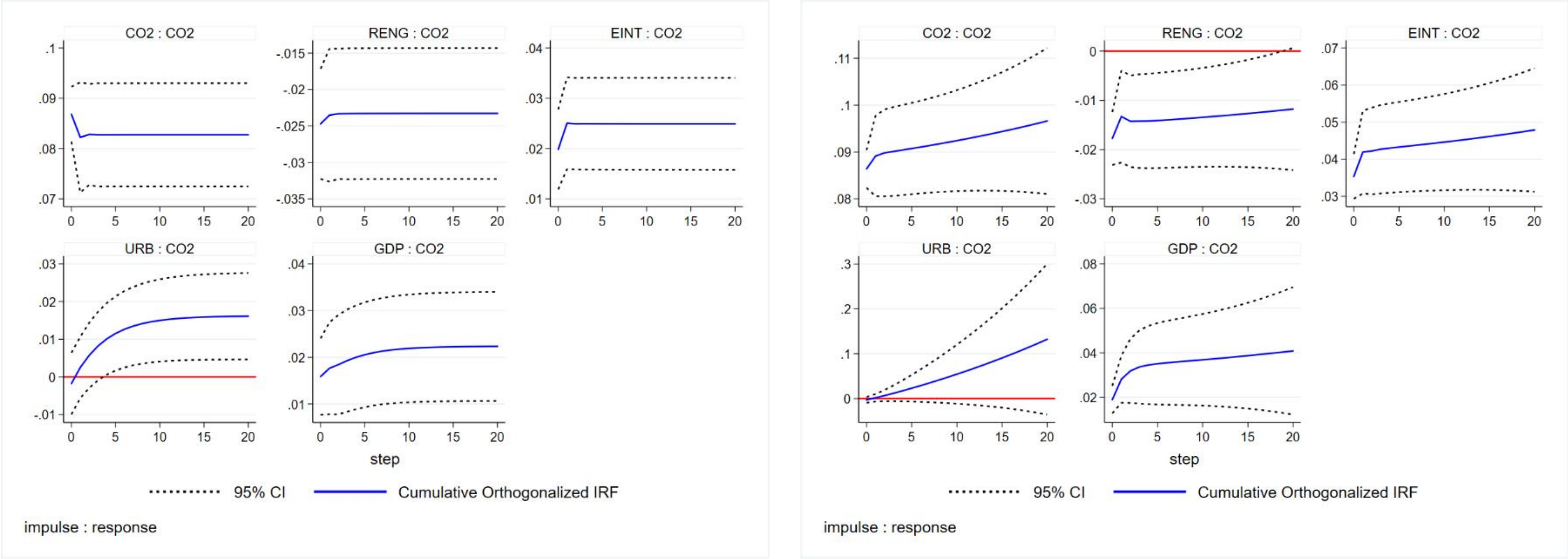
(h) domestic credit to private sector

Observations: 1326 • Groups: 68

Notes: Considering two generic variables A and B, “A: B” denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

Figure A - III.6: Cumulative orthogonalized IRFs: level of income and the Kyoto Protocol status

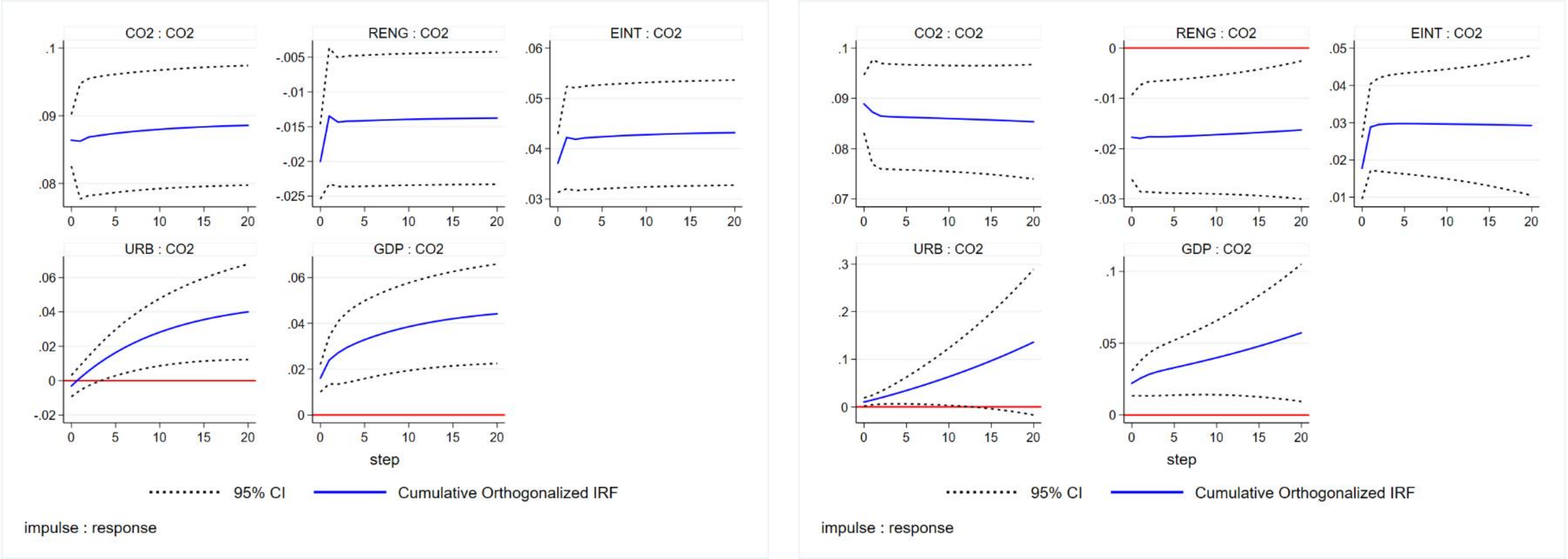
(a) low income economies **(b) lower-middle income economies**



Observations: 504 • Groups: 24

Observations: 924 • Groups: 44

(c) Kyoto Protocol group A (ratification or asscension date<2005) **(d) Kyoto Protocol group B (ratification or asscension date≥2005)**



Observations: 966 • Groups: 46

Observations: 462 • Groups: 22

Notes: Considering two generic variables A and B, "A: B" denotes the response of B following shocks to A. The continuous line denotes the impulse response functions. The dashed lines stand for the associated 95% confidence interval computed based on 1000 Monte Carlo simulations.

Table A - III.9: Cross-sectional dependence tests

Test/Variable	CO2_T	CO2_B	CO2_NC	CO2_OIC	CO2_PI
BC scaled LM	508.921*** (0.000)	172.403*** (0.000)	259.421*** (0.000)	188.111*** (0.000)	456.459*** (0.000)
Pesaran CD	168.292*** (0.000)	22.035*** (0.000)	77.171*** (0.000)	46.489*** (0.000)	93.698*** (0.000)
Pesaran scaled LM	510.399*** (0.000)	173.882*** (0.000)	260.899*** (0.000)	189.568*** (0.000)	457.938*** (0.000)
Breusch-Pagan LM	36729.01*** (0.000)	14014.72 *** (0.000)	19888.26*** (0.000)	14816.93*** (0.000)	33187.98*** (0.000)

Notes: The Breusch-Pagan (1980) LM, Pesaran (2004) scaled LM, Pesaran (2004) CD, and Baltagi et al. (2012) Bias-Corrected (BC) scaled LM test. H0 is "no cross-section dependence (correlation)". P-values in brackets. ***, **, *, denotes significance at the 1%, 5% and 10% level, respectively.

Table A - III.10: Stationarity analysis I

Test/ Variable	Harris-Tzavalis test			
	Level (cons & trend)		Δ (cons)	
	rho	*p_value*	*rho*	*p_value*
CO2_T	0.629	(0.001)***	-0.028	(0.000)***
CO2_B	0.667	(0.075)*	-0.150	(0.000)**
CO2_NC	0.643	(0.006)***	-0.083	(0.000)***
CO2_OIC	0.512	(0.000)***	-0.225	(0.000)***
CO2_PI	0.618	(0.000)***	-0.010	(0.000)***

Notes: We remove cross-sectional means and apply small-sample adjustment to T. H0 is "Panels contain unit roots". Tajikistan and Togo (for CO2_OIC), and Congo Rep. and Ghana (for CO2_PI) are excluded from the sample due to missing values. P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - III.11: Stationarity analysis II

Test/ Variable	Pesaran's CADF test							
	Level (cons & trend)		Δ (cons)		Level (cons & trend)		Δ (cons)	
	Augmented by one lag (average)				Augmented by two lags (average)			
	t-bar	*p-value*	*t-bar*	*p-value*	*t-bar*	*p-value*	*t-bar*	*p-value*
CO2_T	-2.533**	(0.024)	-3.359***	(0.000)	-2.697***	(0.000)	-2.803***	(0.000)
CO2_B	-2.105	(0.966)	-3.287***	(0.000)	-1.964	(0.999)	-2.486***	(0.000)
CO2_NC	-2.255	(0.686)	-3.433***	(0.000)	-2.123	(0.951)	-2.475***	(0.000)
CO2_OIC	-8.874***	(0.000)	-20.063***	(0.000)	2.369	(0.991)	-6.841***	(0.000)
CO2_PI	-4.375***	(0.000)	-14.658***	(0.000)	-1.947**	(0.026)	-10.466***	(0.000)

Notes: H0 is "all series are nonstationary". For the unbalanced panels, namely for CO2_OIC and CO2_PI, we report the standarized t-bar statistic. P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table A - III.12: Forecast-error variance decompositions: sectoral CO2 emissions

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2_T
GDP	99.55	0.00	0.24	0.13	0.06
URB	12.09	87.75	0.02	0.01	0.01
EINT	21.88	0.09	77.97	0.02	0.02
RENG	1.11	0.70	8.22	89.19	0.76
CO2_T	1.79	0.83	4.66	3.08	89.61

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2_B
GDP	99.68	0.00	0.16	0.13	0.00
URB	14.20	85.77	0.00	0.01	0.00
EINT	22.48	0.59	76.85	0.03	0.03
RENG	1.22	0.17	7.76	90.81	0.01
CO2_B	2.11	0.10	3.93	2.29	91.55

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2_OIC
GDP	99.42	0.15	0.20	0.20	0.01
URB	13.26	86.49	0.01	0.07	0.14
EINT	22.39	0.04	77.46	0.07	0.02
RENG	2.12	0.08	7.69	89.83	0.25
CO2_OIC	0.62	5.36	4.56	0.99	88.45

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2_NC
GDP	98.61	0.70	0.27	0.09	0.30
URB	13.39	86.55	0.01	0.01	0.02
EINT	21.01	0.94	77.93	0.00	0.09
RENG	0.92	0.16	7.80	91.01	0.08
CO2_NC	2.36	5.17	0.64	0.01	91.79

Response variables	**Impluse variables**				
	GDP	URB	EINT	RENG	CO2_PI
GDP	97.44	2.25	0.17	0.11	0.01
URB	9.80	90.12	0.04	0.01	0.01
EINT	22.03	0.31	77.37	0.11	0.16
RENG	0.88	1.26	8.04	89.73	0.07
CO2_PI	0.51	3.68	1.42	0.21	94.16

Notes: Considering a twenty-year horizon, the numbers (in percentages) show the variation in the row variable that is explained by the column variables.

Table A - III.13: List of Non-Annex I parties of the Kyoto Protocol to the UNFCCC based on UN Treaty Collection-Status of Treaties

Non-Annex I Party	Signature	Ratification	Accession
Angola			8 May 2007
Armenia			25 April 2003
Bangladesh			22 October 2001
Benin			25 February 2002
Bhutan			26 August 2002
Bolivia	09 July 1998	30 November 1999	
Burkina Faso			31 March 2005
Burundi			18 October 2001
Cabo Verde			10 February 2006
Cameroon			28 August 2002
Central African Republic			18 March 2008
Chad			18 August 2009
Comoros			10 April 2008
Congo, Dem. Rep			23 March 2005
Congo Rep.			12 February 2007
Côte d'Ivoire			23 April 2007
Egypt	15 March 1999	12 January 2005	
El Salvador	08 June 1998	30 November 1998	
Ethiopia			14 April 2005
Georgia			16 June 1999
Ghana			30 May 2003
Guatemala			5 October 1999
Guinea			07 September 2000
Guinea-Bissau			18 November 2005
Honduras	25 February 1999	19 July 2000	
India			26 August 2002
Indonesia	13 July 1998	03 December 2004	
Jordan			17 January 2003
Kenya			25 February 2005
Kiribati			7 September 2000
Kyrgyz Republic			13 May 2003
Lao			6 February 2003
Lesotho			6 September 2000
Liberia			5 November 2002
Madagascar			24 September 2003
Malawi			26 October 2001
Mali	27 January 1999	28 March 2002	
Mauritania			22 July 2005
Mongolia			15 December 1999
Morocco			25 January 2002
Mozambique			18 January 2005
Myanmar			13 August 2003
Nepal			16 September 2005
Nicaragua	07 July 1998	18 November 1999	
Nigeria			10 December 2004
Pakistan			11 January 2005
Papua New Guinea	02 March 1999	28 March 2002	
Philippines	15 April 1998	20 November 2003	

(**Table A - III.13:** continued)

Non-Annex I Party	Signature	Ratification	Accession
Rwanda			22 July 2004
Senegal			20 July 2001
Sierra Leone			10 November 2006
Solomon Islands		13 March 2003	
Sri Lanka			3 September 2002
Sudan			2 November 2004
Swaziland			13 January 2006
Tajikistan			29 December 2008
Tanzania			26 August 2002
Togo			2 July 2004
Tunisia			22 January 2003
Uganda			25 March 2002
Ukraine	15 March 1999	12 April 2004	
Uzbekistan		12 October 1999	
Vanuatu			17 July 2001
Vietnam	03 December1998	25 September 2002	
Yemen			15 September 2004
Zambia	05 August 1998	07 July 2006	
Zimbabwe			30 June 2009

Notes: The information corresponds to April 2020 status of Non-Annex I parties, retrieved from the following webpage: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en.

«CHAPTER IV»

Does Political Stability Hinder Pollution? Evidence from Developing States*

Abstract: We examine the nexus between CO2 emissions and political stability, using a sample of low and lower-middle income countries. Panel vector error correction model (PVECM) estimations unveil a nonlinear, bell-shaped pattern between variables at the aggregate level, robust to a broad set of alternative specifications. Moreover, we find important heterogeneities with respect to countries' distinct characteristics and for alternative measures of pollution. Besides, the country-specific estimates reveal contrasting patterns regarding the relationship between CO2 and political stability. Overall, the findings suggest that both the formal and informal sides of political stability play a vital role in mitigating CO2 pollution in developing countries, and may provide meaningful insights for policymakers.

Keywords: CO2 emissions; political stability; developing states.

JEL Codes: Q28, Q56, O13, P48

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IV.1. Introduction

Political stability has always been a central pillar in the well-being of society. Over the years, political crises have unrevealed some of the adverse effects they may have on an economy. Moreover, the factors behind the political distortions are among the most diverse and very often difficult to predict, ultimately causing a series of economic inefficiencies. Going back to the late '80s and early '90s, we find the idea that an unstable political environment leads to economic inefficiencies as the binder of the studies of Alesina & Tabellini (1989, 1990), Tabellini & Alesina (1990), Cukierman et al. (1992), Ozler & Tabellini (1992), Alesina et al. (1992), and the related works. Specifically, the authors argue that when a government becomes uncertain about its functioning, it will jeopardize the state's regime, its successor will inherit, by adopting sub-optimal policies. However, this is just a straightforward example of how political stability might reflect on a country's environmental well-being through the propensity of government failure, but the spectrum of channels is much larger.

In this regard, Margolis (2010) claims that state stability is just a fraction of political stability, which, overall, represents the concurrence of both formal and informal roles and structures within a political object. Accordingly, looking in retrospect, it is inevitable not to notice that political conflicts encompass besides government-related crises, also religious and ethnic tensions, institutional and business imbalances, external crises, among others. Based on the Global Peace Index report (GPI, 2017), the number of political conflicts almost doubled in 2016 compared to 2006, reaching a number of 402 from 268. During the ten years, violent crises (i.e. medium-intensity conflicts) registered the most significant increase, from 83 to 188, while 38 conflicts are classified as highly violent crises in 2016 (5 less compared to 2015). Furthermore, since 2006, Asia and Oceania, followed by Sub-Saharan Africa, have reported the highest increase in the number of conflicts, on average. Besides, the history has shown that such political distress episodes are more likely to be encountered in developing countries when compared to the developed nations—the Central African Republic Bush War (2004-07), the conflict in the Niger Delta (2004-present), the Houthi insurgency in Yemen (2004-15), the Chadian Civil War (2005-10), the Djiboutian-Eritrean border conflict (2008), the Ivorian crises (2010-11), the Arab Spring (2010-12), the Central African Republic conflict (2012-present), the Burkinabé coup d'état attempt (2016), to mention just a few of them.

Consequently, the effects of political conflicts may impinge on the government's position on environmental issues through the associated policies and regulations, and also could influence both the business organizations' and population's views concerning environmental quality. The environmental degradation-political stability nexus literature is relatively new and sparse, with most of the studies documenting the effect of corruption along with other institutional quality proxies on pollution. On the one hand, in the early literature, Desai's landmark study (1998) highlights the potential effects that corruption has on worsening environmental degradation, notably in developing economies. A few years later, based on theoretical work, the findings of López & Mitra (2000) suggest, among others, that under both cooperative (i.e. Nash) or non-cooperative (i.e. Stackelberg) assumptions, the potential effects of corruption do not interfere with the occurrence of environmental Kuznets curve.[1] Furthermore, Cole (2007), employing the instrumental variables technique on a sample of 94 countries over the period 1987-2000, shows that corruption impacts positively both sulfur (SO2) and carbon dioxide (CO2) emissions per capita. Likewise, using cross-country data for 99 developing states, Gani (2012) investigates the link between five governance dimensions and CO2 pollution. Overall, the results point out that good governance may reflect in lower CO2 emissions. More recently, Zhang et al. (2016) examine the impact of corruption on CO2 emissions in 19 Asia-Pacific Economic Cooperation (APEC) countries over 1992-2012. The panel quantile regression model is used to test if corruption exhibits a heterogeneous effect on different CO2 pollution levels. The empirical findings indicate that the impact is negative and statistically significant for lower emissions countries, while no statistical link is found between variables in higher emission states.

On the other hand, a growing strand of studies focuses on the relationship between growth and pollution, while controlling for the potential effects of corruption and other political institution variables. In this regard, Welsch (2004) shows in a cross-country study that corruption significantly impacts the relationship between per capita income and various pollution indicators. Ozturk & Al-Mulali (2015) for Cambodia and Sarkodie & Adams (2018) for South Africa, using time-series analysis, find that better governess/corruption control and political-institutional quality, respectively, could help

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[1] According to the traditional environmental Kuznets curve hypothesis, the relationship between environmental degradation and economic growth follows an inverted-U shaped pattern (Grossman & Krueger, 1991).

in mitigating the pollution. Also, in Romania's case, the results of Shahbaz et al. (2013) illustrate that democracy helps reduce energy emissions. Moreover, Abid (2017), using panel data analysis, shows that a higher institutional quality could reduce CO2 emissions in European Union (EU) countries, while for the Middle East and African (MEA) states, the institutional quality indicators are not statistically significant. In the same vein, the empirical findings of Apergis & Ozturk (2015) for 14 Asian countries suggest that government effectiveness, quality of regulation, and corruption control reflect lower CO2 emissions, while higher political stability and absence of violence reflects in more CO2 pollution.

Relatedly, other theoretical and empirical works show that corruption either reduces the stringency of environmental regulations (see e.g. Damania et al., 2003; Fredriksson et al., 2004, Pellegrini & Gerlagh, 2006), impacts the crucial income turning point[2] of the EKC[3] positively (Lopez & Mitra, 2000; Leitão, 2010), diminishes the effects of shadow[4] economy on pollution (Biswas et al., 2012), or exhibits a nonlinear relationship on pollution (Halkos & Tzeremes, 2013). Besides, Fredriksson & Svensson (2003) link both corruption and political instability with environmental regulation. In their seminal contribution, authors argue that for low levels of corruption, political instability exerts a negative impact on the environmental regulation stringency, while for high levels, the effect becomes positive. Nevertheless, a limitation of their study is that the political instability proxy capture only sovereign crises. It is worth mentioning that a series of the studies mentioned above, along with others such as Leitão (2010), assess the indirect effect of corruption on pollution, mainly through the economic growth[5], and occasionally via other macro indicators (e.g. financial development, foreign direct investments, and public expenditure). Additionally, some recent contributions such as Bernauer & Koubi (2009), Adams & Klobodu (2017, 2018), Bae et al. (2017), Lægreid & Povitkina (2018), and Arminen & Menegaki (2019) have documented, among others, the potential impact of various political framework factors on environmental degradation. On

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[2] Conversely, Galinato & Galinato (2012) show that the income turning point is not significantly impacted by political stability and corruption control.

[3] EKC=Environmental Kuznets Curve. The EKC states that the relationship between pollution and economic growth is bell-shaped, as Grossman & Krueger (1991) suggested.

[4] Goel et al. (2013) also explore the shadow economy's effect on environmental degradation. The empirical results indicate that as the shadow economy increases, the recorded CO2 emissions decrease.

[5] The corruption degree may hinder economic growth, thus, decreasing the pollution levels. As such, if the indirect effect of corruption is negative and larger in absolute value, it would surpass the positive direct effect, resulting in an overall negative impact (Cole, 2007).

this last point, we note that some studies address the issue of states' actual and reported emissions in relationship with corruption and effectiveness of environmental regulations (Ivanova, 2011; Goel et al., 2013), or provide evidence of institutional quality spillover effect on environmental quality (Hosseini & Kaneko, 2013). For a survey on the empirical literature of the institutions and governance impact on environmental policy, environmental performance, and green investment, see the recent work of Dasqupta & De Cian (2018), among others.

This paper aims to widen the extant literature on the relationship between environmental degradation and political stability (PS) in developing countries by accounting for the limitations of the previous related works. Indeed, in such countries, the politico-economic structure possesses different characteristics compared to developed nations, making it difficult for decision bodies to balance the political-economic system and environmental degradation. Furthermore, the more pronounced dynamicity of political framework requires a continuous adaptation and proper monitoring of environmental related policies and regulations. As such, given that environmental policies' outcomes are more visible in the long-run, sudden political changes could interfere with or even deter the associated goals' achievement. Besides, simple stylized facts show that over the 1990-2015 period, in our sample of 47 low and lower-middle income states, the evolution of political stability and CO2 emissions seems to be nonlinear, characterized by significant ups and downs (see the Figure IV.2 below). In this context, examining a potential (threshold) effect of political stability on CO2 pollution in a large sample of developing countries could be of interest to both academia and policymakers.

The contribution of our analysis is threefold. First, none of the related studies explore the potential common long-run pattern between variables to the best of our knowledge, while allowing country-specific short-run heterogeneities. Despite that the effects of political stability on environmental degradation seem to be more noticeable in the long-run, the vast majority of studies mentioned above do not explore a possible cointegration relationship between variables. Moreover, we examine a potential threshold effect of political stability on CO2 emissions by augmenting the initial model with the political stability variable's squared term. In doing so, we build upon the panel Autoregressive Distributed Lag (ARDL) approach under an error correction specification; namely, we employ a panel vector error correction model (PVECM) via the Pooled Mean

Group (PMG) estimator introduced by Pesaran et al. (1999). Second, in the spirit of Margolis (2010), we adopt a broader definition of political stability, captured by the political risk index of the International Country Risk Guide (ICRG) of Political Risk Services (PRS) Group. Third, we enrich the empirical literature dedicated to developing countries by focusing on a large sample of 47 low and lower-middle income states.

The results are as follows. We find evidence of a significant nonlinear, bell-shaped impact of political stability on CO2 emissions. As such, political stability may contribute to decreasing CO2 pollution in developing economies, but only after the 66.47 (in PS index points) threshold is reached. According to the political stability index[6], this value is approximately nearly half of the moderate political stability interval. In this regard, it is worth mentioning that country-specific political stability maximum index values in our sample signal that several countries did not yet achieve this universal turning point reveal by panel-based analysis. This result is robust to alternative estimation techniques, additional control factors, when altering the sample using distinct criteria, when delimiting between the PS index subcomponents, alternative methods in computing the PS composite index, and an alternative approach estimating the threshold effect.

However, the findings show a greater or lower sensitivity depending on the several distinct sample characteristics and alternative measures of pollution, thus, providing some meaningful insights. First, concerning the economies (i) with a low income level, (ii) which ratified/acceded the Kyoto Protocol before it entered into force, and (ii) those with a common-law origin, estimations unveil that further political stability is associated with a decrease in CO2. Conversely, a monotonically increasing link seems to emerge for countries with a lower-middle income, a civil law inheritance, and those which ratified or acceded to Kyoto Protocol after 2005. Bearing in mind the results associated with the latter subgroups, they may hint at least two scenarios. On the one hand, the positive relationship may suggest that these states still have to ameliorate political unrest to reach the optimal level of stability above which the CO2 emissions would fall. On the other hand,

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[6] According to ICRG methodology, a value of political risk rating between 0.0% to 49.9% indicates a very high risk; 50.0% to 59.9% high risk; 60.0% to 69.9% moderate risk; 70.0% to 79.9% low risk; and 80.0% or more very low risk. As we refer to the index in terms of political stability in order to reflect the increasing scale, we interpret the values as follows: 0.0% to 49.9% suggests a very low political stability, 50.0% to 59.9%, low political stability; 60.0% to 69.9%, moderate political stability; 70.0% to 79.9%, high political stability; and 80.0% or more, very high political stability.

greater political stability may lead to a more relaxed attitude of policymakers, inducing, among others, the adoption of less stringent environmental policies.

Second, the results are also heterogeneous when using different pollution indicators. Notably, the bell-shaped curve holds only in the case of one local pollutant (i.e. PM2.5bio), while for the remaining four considered a U-shaped (PM2.5fossil, PM2.5, and PM10) or an increasing (SO2) pattern is at work. Indeed, regarding local pollutants, the environmental policies targeting them are mostly adopted at the national level and largely reflect individual countries' domestic situation. Thus, an undisturbed political environment accompanied by lower international pressure may induce a more relaxed attitude from policymakers, and, ultimately, lax environmental regulations. Taken together, these may trigger an increase in associated pollution. Moreover, looking at countries' demand and supply of nature, the results suggest that political stability may reduce both the biocapacity and ecological footprint. However, given that the negative effect's magnitude is greater for biocapacity, these points need more attention in order to avoid countries plunging into a potential biocapacity debt.

The individual country analysis complements the overall panel one by looking at the CO2-political stability nexus across each group member. Focusing on the statistically significant results, we find that various patterns characterize the link between variables: U-shaped (Morocco, Mozambique, Papua New Guinea, Tunisia, Yemen), bell-shaped (Angola, Bangladesh, Bolivia, Guinea-Bissau, Honduras, Madagascar, Malawi, Mali, Myanmar, Niger, Sierra Leone, Sri Lanka, Togo, Uganda, Vietnam), monotonically increasing (Cameroon, El Salvador, Haiti, Mongolia, Nigeria, Zambia) or decreasing (Republic of the Congo). Although most states for which the relationship between indicators is statistically significant display an inverted-U shaped pattern, echoing the overall panel one, the presence of other patterns and the absence of a significant link for some countries highlight the political systems' peculiarities and, eventually, how they reflect on environmental quality. Indeed, it is a laborious task (which goes beyond the scope of this study) that requires a thorough analysis within each state political framework to discern how its key pillars interact and influence in a certain way the state of the environment. However, a basic descriptive inquiry—which must be seen as a first nondefinitive step in the search for related answers—may indicate that the industrialization process, high unemployment, and globalization degree, together with a limited share of forest rents and implication of military in politics, could contribute in triggering various political-related imbalances that would further harm the quality of the environment. Thus, judging from the policymakers' viewpoint, particular attention must be paid to these aspects when it comes to shaping environmental policies.

The rest of the paper is structured as follows. Section 2 describes the data and estimation technique, section 3 reports the results, section 4 assess their robustness, section 5 explores potential heterogeneities, section 6 provides the country-specific findings, and section 7 concludes and discusses some policy implications.

IV.2. Data and methodology

This section aims at describing and discussing the data used in empirical analysis and the estimation technique.

IV.2.1. Data

The analysis focuses on countries classified by World Bank (2018) as economies with low and lower-middle income. We select the states based exclusively on the availability of our primary variable of interest, i.e. political stability. Thus, our unbalanced panel contains 47 out of 81 low and lower-middle income economies (see Table A-IV.1 in the Appendix for the list of countries). The environmental pollution is proxied by *CO2* emissions per capita obtained from Maenhout et al. (2017), while the data for the *PS* (political stability) composite index come from the ICRG (2019) of the PRS Group. The PS is a broad index that comprises 12 weighted political and social components.[7] Besides, one of the main advantages is that it gives a comparable basis for countries covered by ICRG, based on associated political stability score.[8] The control variables, namely gross domestic product per capita (*GDP*), renewable energy (*RENG*), and energy intensity (*EINT*) that we included in the analysis and may equally affect CO2 emissions come from World Development Indicators (World Bank, 2019). The selection of these explanatory factors has its roots in

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[7] government stability, socioeconomic conditions, investment profile, internal conflict, external conflict, corruption, military in politics, religious tensions, law and order, ethnic tensions, democratic accountability, and bureaucracy quality.

[8] https://www.prsgroup.com/wp-content/uploads/2014/08/icrgmethodology.pdf.

the well-known STIRPAT[9] and EKC literature, whereas they are also in line with 2030 Sustainable Development Goals. All the variables included in regression models are expressed in natural logarithm, thereby, the coefficients can be interpreted as elasticity.

Figures IV.1-2 illustrate some stylized facts of the main variables for the whole sample (i.e. kernel density, histogram, evolution over time, and the scatter plot), whereas Tables A-IV.1-2 in the Appendix show the variables' definitions and summary statistics. First, we note that the average value of CO2 emissions (PS) over the period 1990-2015 is 0.861 (55.645), with a standard deviation of 1.431 (9.929). Also, the median of CO2 and PS index is 0.399 and 56.840, respectively. The larger difference between the mean and median value for CO2 emission—the median is approximately half of the mean value—may suggest the presence of extreme values (i.e. outliers) in the data. Second, the kernel density of CO2 emissions variable suggests the following: (1) the CO2 emissions distribution exhibits bimodality, while the most significant one is visible in the year 2000, following the year 2015; (2) the major peak of distribution increases in 2000 compared to 1990, and then decreases in 2015 compared to 2000; (3) overall, a divergence process is visible for CO2 emissions, with a mean annual rate of divergence[10] around -1.37%. Third, according to kernel density for PS index, we can state the following: (1) all the three distributions corresponding to each year are left-skewed; (2) the peak increases over time, indicating convergence across group members; (3) the average rate of convergence per year between 2015 and 1990 is roughly 2.25%. Fourth, completing the kernel density plots, the variables' histogram over the period analyzed indicate bimodality for CO2 emissions and left-skewnesses for PS index. Overall, these graphs indicate that our variables do not follow the normal Gaussian distribution, especially the PS composite index. Fifth, according to the variables' evolution over time, the CO2 has a monotonically increasing nonlinear evolution, while the PS seems to be characterized by much nonlinearity. Nonetheless, both series exhibit ups and downs with different amplitudes

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[9] STIRPAT=Stochastic Impacts by Regression on Population, Affluence, and Technology. The STIRPAT framework was developed by Dietz & Rosa (1994, 1997) as the stochastic counterpart of IPAT identity proposed by Ehrlich & Holdren (1971, 1972).

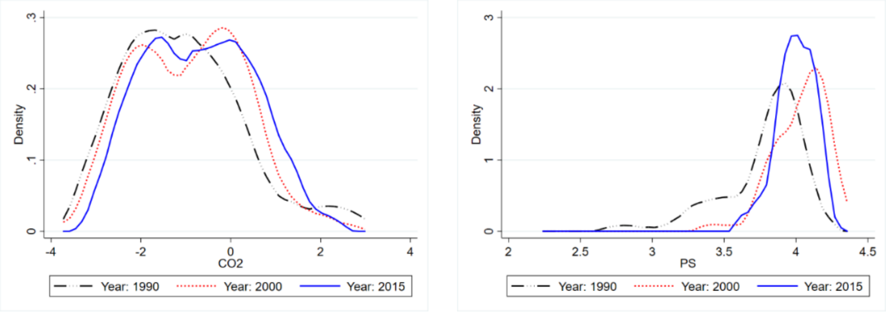
[10] In the spirit of Williamson & Fleming (1977), we compute the mean convergence per year as $MC/year = \left[\frac{(CV_{t_1}-CV_{t_2})}{CV_{t_1}} \times 100\right] \div (t_2 - t_1)$, where CV_{t_1} (CV_{t_2}) denotes the Pearson's coefficient of variation at the earlier (later) date, and $t_1(t_2)$ represents the earlier (later) date. The statistic implies the simplifying assumption that any period is equivalent to another (Williamson & Fleming, 1977). Also, we note that the CV of a variable is calculated by dividing its standard deviation to the mean and then multiplying the result by 100. A decrease (increase) during a specific period would suggest a convergence (divergence) process.

during their evolution over time. Finally, the scatter plot shows a positive relationship between variables at first sight, while the points distribution may suggest a possible nonlinear pattern.

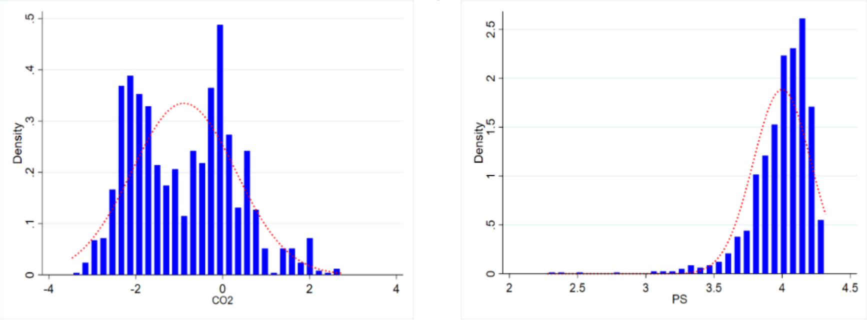
Figure IV.1: CO2 and PS kernel density plots and histogram [full sample]

(a) CO2 **(b) PS**

Kernel density



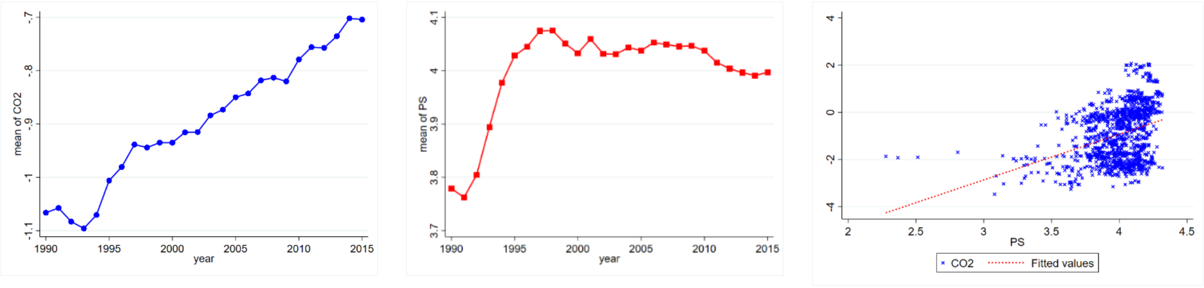
Histogram



Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

Figure IV.2: CO2 and PS evolution over time and scatterplot [full sample]

(c) CO2 **(d) PS** **(e) CO2 versus PS**



Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

IV.2.2. Panel Autoregressive Distributed Lag (ARDL) approach

We use the PVECM scenario of the panel ARDL approach to estimate the cointegration vector's long-run elasticities. This technique allows us to retrieve the important long-run coefficients computed based on the Ordinary Least Squares (OLS) estimates of short-run ones, while it also gives us the possibility to capture these short-run dynamics between variables explicitly.

Besides, the ARDL approach it is quite appealing, given that it provides consistent estimates even if the regressor are integrated of different orders, i.e. I(0) and I(1), and whether they are exogenous or endogenous (Pesaran & Smith, 1995; Pesaran & Shin, 1999). It is commonly acknowledged that a considerable number of macroeconomic time-series are difference stationary and, more than that, they are likely to be characterized by feedback effects. Thus, considering our variables' nature, namely that they are expressed in levels and not growth rates, we expect to exhibit unit root processes. Also, based on the previous related literature (see e.g. the Introduction section for details), political stability may impact pollution, but equally, the vice-versa is quite plausible. For example, high levels of CO2 emissions could trigger certain perturbations in socioeconomic and government structures, as well as tensions from various non-governmental organizations, which, in turn, may reflect lower political stability. Likewise, according to economic theory and several empirical shreds of evidence, the reverse causality could also arise between our control factors (i.e. GDP, RENG, and EINT) and CO2 emissions.

More specifically, in our empirical analysis, we rely mainly on the PMG estimator developed by Pesaran et al. (1999), given its features, which may easily corroborate our sample's characteristics. On the one hand, the main advantage of the PMG estimator is given by the flexibility in short-run coefficients and error variances, which are allowed to vary depending on the individual panel members (groups), while the long-run slopes are pooled across panel members. Thus, this technique allows for short-run country-specific heterogeneities, while assuming a common long-run trajectory between environmental pollution and political stability. In our specific case, the long-term pattern could be explained by the common global environmental instruments to fight climate change such as the Kyoto Protocol and the Paris agreement, along with the states' willingness to achieve political stability through mitigating corruption, reducing conflicts, and improving the overall socio-economic and -political conditions. However, it is reasonable to believe that the countries included in the analysis possess, at least, different short-run dynamics. First, the environmental regulations and macroeconomic policy are different across states; each country adopts the macroeconomic policy and environmental regulations that best fit its peculiar economic context. Second, we mix countries with low and lower-middle income levels from various regions around the globe. Consequently, we expect that the distinct cultural heritage might play an essential role in how population and policymakers relate to environmental and political aspects. Third, the countries' adhesion of regional intergovernmental organizations [see e.g. Common Market for Eastern and Southern Africa (COMESA), Union Economique et Monétaire Ouest Africaine (UEMOA), Economic Community of West African States (ECOWAS)—African states; Association of Caribbean States, Caribbean Community (CARICOM), Organization of American States (OAS)—American states; Asia-Pacific Economic Cooperation, Asian Development Bank, Association of Southeast Asian Nations (ASEAN)—Asian states; European Union (EU), Central European Free Trade Agreement (CEFTA), North Atlantic Treaty Organization (NATO)—European states; Pacific Islands Forum Secretariat, East-West Center, Secretariat of the Pacific Regional Environment Program (SPREP)—Pacific states] could impact both the economic and political system differently.

On the other hand, from the econometric perspective, in dealing with macro-panels (i.e. time-series panels with large or moderate *N* and *T* dimensions), the most suitable estimators are those that can also be used for exploring the slopes heterogeneity across groups, such as PMG and A(MG) techniques (Eberhardt, 2011). Moreover, when the variables' series exhibits unit root, and they are also cointegrated, the applicability of an error correction model is strongly recommended.

Following the work of Pesaran et al. (1999), the mathematical specification of the autoregressive distributed lag [$ARDL(p, q_1 \dots q_k)$] dynamic panel model can be written as

$$CO2_{it} = \sum_{j=1}^{p} \partial_{ij} CO2_{it-j} + \sum_{j=0}^{q} \gamma_{ij}' x_{it-j} + \mu_i + \varepsilon_{it}. \tag{1}$$

In the above equation the subscript $i = \overline{1, N}$ represents the panel members (countries) and $t = \overline{1, T}$ designates the periods (number of years); CO2 is our dependent variable, the log of CO2 emissions per capita, and $x_{it} = (PS_{it},\ GDP_{it},\ RENG_{it}, EINT_{it})'$ $(k \times 1)$ is the vector of explanatory variables, with $\gamma_{ij} (k \times 1)$ associated coefficients vector; μ_i denotes the country-specific fixed effects, while ε_{it} represents the error term. We also note that the lag order of the dependent variable, p, and independent factors, q, should be set such that the error term, ε_{it}, does not exhibit serial correlation across panel members, i.

Furthermore, the individual mean level coefficient estimates based on the ARDL approach are computed as

$$\hat{\beta}_{ARDL,i} = \frac{\sum_{j=0}^{q} \hat{\gamma}_{ij}}{1 - \sum_{j=1}^{p} \hat{\partial}_{ij}}. \tag{2}$$

Therefore, the mean long-term estimates are given by the following expression: $N^{-1} \sum_{i=1}^{N} \hat{\beta}_{ARDL}$. In addition, we note that $\hat{\partial}_{ij}$ and $\hat{\gamma}_{ij}$ represent the short-run estimates from equation (1).

Assuming that variables are nonstationary and cointegrated, the above equation [(1)] can be rewritten into a PVECM. Thus, the equation that incorporates along with long-term coefficients both the short-run elasticities and the error correction term (ECT) has the following form

$$\Delta CO2_{it} = \phi_i(CO2_{it-1} - \lambda_i' x_{it}) + \sum_{j=1}^{p-1} \partial_{ij}^* \Delta CO2_{it-j} + \sum_{j=0}^{q-1} \gamma_{ij}'^* \Delta x_{it-j} + \mu_i + \varepsilon_{it}, \tag{3}$$

where $\phi_i = -(1 - \sum_{j=1}^{p} \partial_{ij})$, $\lambda_i = \sum_{j=0}^{q} \gamma_{ij} / (1 - \sum_k \partial_{ik})$, $\partial_{ij}^* = -\sum_{m=j+1}^{p} \partial_{im}\ for\ j = 1, \dots, p-1$, $\gamma_{ij}^* = -\sum_{m=j+1}^{q} \gamma_{im}\ for\ j = 1, \dots, q-1$, and Δ denotes the difference operator. With respect to ϕ_i, the coefficient of ECT, we expect to be negative and statistically significant, to confirm the long-run relationship between variables and determine the speed of adjustment.

Regarding the explanatory factors, we are mainly interested in the coefficient associated with the PS composite index. However, given the drawbacks caused by omitted variable bias, we augment the initial model with other important factors that may influence the CO2 pollution. Such factors that account for the size of the economy (GDP per capita), technological progress and stringency of environmental regulations (RENG), and the energy efficiency and energy conservation potential of an economy (EINT)[11], may equally distort the CO2-PS nexus if omitted from the model. Moreover, these are one of the most used explanatory variables of environmental degradation according to EKC and

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[11] In the related literature, it is well recognized that one of the most important drivers of CO2 pollution is energy consumption. However, considering the particularities of our countries (i.e. the income group), the data for energy consumption is not available for many of them. As such, we proxy the county's energy structure by its energy intensity. The energy intensity is a more complex indicator, given that it comprises not only the economic system of a country such as economic structure, business cycles, the overall standard of living, but also the important climatic conditions.

STIRPAT literature (see e.g. Apergis et al., 2010; Narayan & Narayan, 2010; Shaifei & Salim, 2013; Al-mulali et al., 2015; Apergis, 2016; Jelbi et al., 2016; Awad & Warsame, 2017; Wang & Lin, 2017; Pablo-Romero & Sánchez-Braza, 2017; Joshi & Beck, 2018; Lazăr et al., 2019; among others).

Furthermore, it is worth noted that renewable energy and energy efficiency programs are two of the most well-known mechanisms use at the international and national levels by the competent bodies to reduce the adverse effects of global warming, especially those of greenhouse gas emissions (GHG). According to the United Nations (UN) Environment Programme 2016 report on "Renewable energy and energy efficiency in developing countries: contributions to reducing global emissions"[12], is it expected that the renewable energy and energy efficiency programs carried out over 2005-2015 in developing economies, to help in minimizing the GHG by 0.4 gigatonnes/year until 2020. Based on the same source, even a more substantial reduction could be achieved, namely, one gigatonne/year, if the global commitments of climate financing complement these projects. In this fashion, different mechanisms aiming to help both countries with and without biding commitments operate under the Kyoto protocol umbrella. An example of such a mechanism that directly targets poor countries is the well-known Clean Development Mechanism (CDM). This flexible, heavily regulated market-based mechanism has a double objective, namely to help both developing (i.e. non Annex parties) and developed nations (i.e. Annex I parties) to fight climate change trough achieving cost-effective reductions, based on a voluntary implication. Particularly, the industrialized countries can buy Certified Emission Reductions (CERs) units as an outcome of the green projects they carry out in developing economies to fulfill some of their emission caps (Carbon Trust, 2009).

IV.3. Results

Prior to modeling the link between variables, we examine their series properties, namely the cross-sectional dependence, the stationarity, and the cointegration relationship. Concerning political stability's impact on CO2 emissions, we first report the baseline

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[12] The full report can be accessed at the following link http://wedocs.unep.org/bitstream/handle/20.500.11822/10027/1_gigaton_coalition_report_2016.pdf?sequence=1&isAllowed=y.

results, and further, we account for a potential threshold effect. Both the preliminary analysis and regression models cover the period 1990-2015.

IV.3.1. Preliminary analysis

This subsection details the tests employ to investigate each of the variables' properties mentioned above.

IV.3.1.1. Cross-sectional dependence

To investigate the series cross-sectional dependence, we use a battery of four tests such as Baltagi et al. (2012) Bias-Corrected (BC) scaled LM, Pesaran (2004) CD, Pesaran (2004) LM scaled, and Breusch-Pagan LM (1980). The associated results are summarized in Table IV.1. We note that the null hypothesis of cross-sectional independence is strongly rejected in all cases in favor of the cross-sectional dependence, given that all test statistics are statistically significant at 1% level.

Table IV.1: Cross-sectional dependence analysis

Test/Variable	**CO2**	**PS**	**GDP**	**RENG**	**EINT**
BC scaled LM	232.61*** (0.00)	150.71*** (0.00)	282.43*** (0.00)	213.50*** (0.00)	196.8379*** (0.00)
Pesaran CD	52.10** (0.00)	60.72*** (0.00)	79.49*** (0.00)	54.72*** (0.00)	35.97099*** (0.00)
Pesaran scaled LM	233.55*** (0.00)	151.65*** (0.00)	283.37*** (0.00)	214.44*** (0.00)	197.7779*** (0.00)
Breusch-Pagan LM	11940.76*** (0.00)	8132.67*** (0.00)	14257.32*** (0.00)	11051.94*** (0.00)	10277.14*** (0.00)

Notes: H0 is "cross-sectional independence (i.e. no correlation)". P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.3.1.2. Stationarity

We test the stationarity property using two tests, namely the Fisher-type based augmented Dickey-Fuller (ADF) first-generation unit root test developed by Choi (2001), and the second-generation unit root test introduced by Pesaran (2003). The second generation of tests are robust to cross-sectional dependence, while for the Phillips-Perron test, we demean the data to alleviate its potential effects. Additionally, both tests work well with unbalanced panel datasets. Table IV.2 shows the results for three-lags regressions specifications. We include both constant and trend in the equation for the variables in levels, whereas for their first difference, only the constant term. Overall, the findings confirm that the variables' series are integrated of order one [I(1)].

Table IV.2: Stationarity analysis

Test/ Variable	**Pesaran**				**Fisher-type ADF**			
	Level (cons & trend)		**Δ (cons)**		**Level (cons & trend)**		**Δ (cons)**	
	t-bar	*p-value*	*t-bar*	*p-value*	*z stat*	*p-value*	*z stat*	*p-value*
CO2	-2.041	(0.976)	-2.214***	(0.001)	-3.863***	(0.000)	-30.312***	(0.000)
PS	0.244	(0.596)	-7.506***	(0.000)	-3.321***	(0.000)	-21.302***	(0.000)
GDP	0.212	(0.584)	-8.904***	(0.000)	-0.200	(0.420)	-20.900***	(0.000)
RENG	1.633	(0.949)	-2.966***	(0.002)	-1.277	(0.100)	-28.237***	(0.000)
EINT	-1.616	(1.000)	-1.739	(0.559)	-1.990**	(0.023)	-25.764***	(0.000)

Notes: Pesaran (2003) H0 is "all series are nonstationary", and Fisher-type (ADF) (Choi, 2001) H0 is "all panels contain a unit root". P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.3.1.3. Cointegration

To examine the potential cointegration relationship between variables, we employ the Engle-Granger based test of Kao (1999) and Pedroni (1999, 2004), and Westerlund's (2007) ECM panel cointegration test. The former imposes that the coefficients' slope are homogeneous, while the latter two allow for slopes heterogeneity. Likewise, under the null hypothesis, all tests assume that there is no cointegration relationship between variables. Moreover, the Westerlund's (2007) test allows mitigating the cross-sectional dependence trough the bootstrap procedure.

Table IV.3: Cointegration analysis

Pedroni test	**Individual Intercept**		**Individual Intercept & Trend**	
Within dimension	**Statistic**	**p-value**	**Statistic**	**p-value**
Panel PP-Statistic	-1.587*	(0.056)	-5.024***	(0.000)
Panel ADF-Statistic	-2.308***	(0.010)	-6.522***	(0.000)
Panel PP-Statistic (Weighted)	-3.513***	(0.000)	-5.565***	(0.000)
Panel ADF-Statistic (Weighted)	-4.181***	(0.000)	-6.868***	(0.000)
Between dimension	**Statistic**	**p-value**	**Statistic**	**p-value**
Group PP-Statistic	-3.444***	(0.000)	-5.563***	(0.000)
Group ADF-Statistic	-5.285***	(0.000)	-7.300***	(0.000)
Kao test	**t-Statistic**	**p-value**		
ADF	-3.053**	(0.001)		
Westerlund test	**Statistic**	**p-value**	**Statistic**	**p-value**
	Bootstrap replications (100)		*Bootstrap replications (800)*	
Gt	-2.431*	(0.090)	-2.431	(0.101)
Ga	-8.612**	(0.020)	-8.612**	(0.034)
Pt	-17.264***	(0.000)	-17.264**	(0.030)
Pa	-8.196**	(0.020)	-8.196**	(0.050)

Notes: Automatic lag length selection based on Schwartz Information Criterion (SIC) with a maximum lag of three. Newey-West automatic bandwidth selection and Bartlett kernel. The statistics' significance was determined by comparing calculated and tabulated values provided by Pedroni (1999). H0 is "no cointegration". ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively. For Westerlund's (2007) test we use three lags following the Akaike Information Criterion (AIC) test. P-values in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

The results of cointegration tests are illustrated in Table IV.3. For Pedroni (1999, 2004) test, the panel PP- and ADF-statistic, normal and weighted version, corresponds to the homogeneous alternative hypothesis (or within dimension), while group PP- and ADF-statistic refers to heterogeneous alternative (or between dimension) (Pedroni, 1999, 2004). We report the results both for individual intercept and individual intercept and trend specification. For Westerlund's (2007) test, we report the group mean (Gt) statistic designed to test the alternative hypothesis that at least one cross-sectional unit is cointegrated, and panel (Pt) statistic constructed to test the alternative that the whole panel is cointegrated, along with their asymptotic versions (Persyn & Westerlund, 2008). Unanimously, the findings indicate that our variables are cointegrated.

IV.3.2. Pollution and political stability: baseline estimates

According to our sample features, namely the moderate N and T dimensions and also as suggested by the Akaike Information Criterion (AIC), the estimates are based on an ARDL$\left(p = 1, q_{\overline{1,k}} = 1\right)$ model.[13] As well, it is worth mentioning that the ARDL approach is sensitive to the choice of lag orders, and the accuracy of the coefficients' estimates depends on its correct specification. Thus, the estimates may be inconsistent when the lag orders are underestimated, while overestimating the lag orders may induce both efficiency and power loss (Chudik et al., 2013).

Nonetheless, to check our reasoning for setting the appropriate number of lags, we increase the regressors' lag number and estimate the ARDL$\left(p = 1, q_{\overline{1,k}} = 2\right)$, the second-best specification, according to AIC. The results depicted by the column (1a) and (2a) of Table A-IV.4 in the Appendix show that all the coefficients of the second lag of first differenced variables do no exhibit statistical significance at any defined level. As such, these results further strengthen the rationale behind choosing the ARDL$\left(p = 1, q_{\overline{1,k}} = 1\right)$ as the most suitable specification.

Furthermore, to validate from the econometric perspective the suitability of the PMG technique, we also estimate the model using the Dynamic Fixed Effects (DFE) and Mean Group (MG) estimator proposed by Pesaran & Smith (1995). The DFE technique

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[13] We keep the number of lags at the minimum possible given that our model contains a relatively large number of covariates, which along with their associated lags may determine the Hessian matrix to become unstable or asymmetric during estimation.

assumes that both the long- and short-run coefficients together with the ECT are equal for all panel members, while only the intercept varies across panel members. Conversely, the MG estimator allows heterogeneous long- and short-run slopes, intercepts, and error variances. Also, to choose the appropriate modeling technique, and in our case, to validate or invalidate the preferred estimator, we apply the Hausman Chi-2 test. According to test results, the null hypothesis of a common long-run path is accepted (see the bottom of column 1 of Table IV.4), thus, confirming that the PMG estimator is the most appropriate to model our data.

Table IV.4: CO2 emissions and political stability: baseline estimates

Dependent variable: ΔCO2						
	PMG		**MG**		**DFE**	
	(1a)	**(1b)**	**(2a)**	**(2b)**	**(3a)**	**(3b)**
			Long-run estimates			
PS	0.205***	0.274***	-4.192	0.222*	1.013***	0.454***
	(0.031)	(0.027)	(5.241)	(0.137)	(0.209)	(0.125)
GDP		0.804***		-0.030		0.896***
		(0.050)		(0.412)		(0.121)
RENG		-0.054		-0.783		-0.254**
		(0.044)		(0.970)		(0.114)
EINT		0.536***		-0.418		0.653***
		(0.039)		(0.557)		(0.120)
			Short-run estimates			
ECT	**-0.187*** **	**-0.228*** **	**-0.208*** **	**-0.560*** **	**-0.099*** **	**-0.171*** **
	(0.029)	**(0.033)**	**(0.030)**	**(0.051)**	**(0.012)**	**(0.016)**
ΔPS	0.063	0.008	0.023	-0.033	0.075**	0.042
	(0.063)	(0.057)	(0.065)	(0.058)	(0.037)	(0.037)
ΔGDP		0.960**		0.858*		0.462***
		(0.446)		(0.500)		(0.069)
ΔRENG		-1.405***		-0.891***		-0.258***
		(0.295)		(0.378)		(0.045)
ΔEINT		0.730*		0.547		0.264***
		(0.443)		(0.498)		(0.044)
C	-0.416***	-2.140***	-0.904***	0.705	-0.481***	-1.718***
	(0.082)	(0.325)	(0.181)	(3.208)	(0.079)	(0.290)
Log Likelihood	1547.248	2029.572	1547.248	2029.572	1547.248	2029.572
Groups	47	47	47	47	47	47
Observations	1158	1138	1158	1138	1158	1138
Hausman Chi-2 test p-value	0.4580	0.8340				

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The Hausman's test H0 is that "countries share a common long-run trend". According to test results (p-value=0.4580/0.8340), the H0 is accepted, confirming that the PMG estimator is preferred. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table IV.4 provides the estimated long-run elasticities and short-run dynamics, both for the core model (i.e. when capturing the pure effect of PS on CO2 emissions) and the extended model (i.e. when we introduce the explanatory factors to mitigate a potential omitted variable bias). First, regardless of the estimation technique, the findings show that the ECT is negative and strongly statistically significant, consolidating the existence of long-run relationships between variables. Likewise, it validates our modeling strategy and, more importantly, it suggests that our model is correctly specified. As such, if an exogenous shock alters the system's equilibrium, the CO2 emissions help the system to readjust to the long-run equilibrium, with the associated speed of adjustment.

Second, the PMG results (see column 1 of Table IV.4), illustrate that political stability exhibits a significant long-term positive impact on CO2 pollution. On the one hand, this finding may indicate that in times of peace, namely when the components of our PS index incline towards a certain balance regarding the political framework, the environmental issues do not represent a primary concern either for governmental and non-governmental organizations as well as for population in general. Indeed, this result seems somehow counterintuitive, as we would think that a higher politically stable society could, for instance, provide the proper framework to better design, implement, and monitor the environmental policy, causing, ultimately, a decrease in pollution levels. Nonetheless, it is well recognized that in less developed countries, compared to the advanced ones, the environmental policies and regulations are fewer and less stringent. Besides, concerning the global pollutants (e.g. CO2 emissions), the international instruments that have been adopted over the years, such as the Kyoto Protocol, has focused extensively on the active role of advanced economies in fighting climate change, while the developing states are more passive players in the process.[14]

On the other hand, it would be possible that the relationship between CO2 emissions and PS to be nonlinear, and the political stability to help in mitigating pollution only above a certain threshold is achieved. Since developing countries are more prone to political instability episodes (see the Introduction section for more details) and taking into account that the maximum (mean) value of PS composite index in our sample over the period analyzed is roughly 75 (55.65) out of 100 points, it is likely that the negative effect on CO2 to be visible for values of PS index that exceed at least its mean. Moreover, the straightforward graphs of the main variables (see Figure IV.2 in the Data and methodology section) seem to fuel a potential nonlinear relationship between variables.

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[14] For example, when considering the local pollutants, namely the sulfur dioxide emissions, nitrous oxide emissions, and particulate matter concentrations, among others, the policies and regulations are more prevalent and stringent even in developing economies, given that they are adopted more intensively at the national level based on particular necessities.

As such, the baseline results call for a reassessment of the model in terms of its specification. In this fashion, the next section is devoted to investigating a potential nonlinear effect of PS on CO2 pollution.

IV.3.3. Pollution and political stability: threshold effect estimates

The previous baseline results have raised some question marks regarding a potential threshold effect of political stability on CO2 pollution. Thus, our novel hypothesis is that the negative effect of political stability on environmental pollution could arise only beyond a specific threshold is reached. Next, we rely on the most appropriate estimation technique (i.e. the PMG estimator) and include in the model also the quadratic term of political stability (PS2). Supposing that our hypothesis holds, we expect a positive significant coefficient for PS and a negative one for its squared term. We note that we keep the number of lags the same as in the baseline model, while also estimating the ARDL$\left(p = 1, q_{\overline{1,k}} = 2\right)$ specification to validate the chosen model's lags order. Likewise, the estimates summarized in column (1b) and (2b) of Table A-IV.5 in the Appendix validate our initial specification, since all the coefficients of the second lag of the short-run dynamics lack statistical significance. Subsequently, we drop them and estimate the corresponding model, namely the ARDL$\left(p = 1, q_{\overline{1,k}} = 1\right)$.

The full sample results are displayed in columns (1a) and (1b) of Table IV.5. Let us discuss the important long-term findings. First, we find evidence in favor of a long-run, bell-shaped relationship between CO2 emissions and political stability, given that the coefficient of political stability (political stability squared) is positive (negative). As such, our novel hypothesis holds and suggests that above the threshold value, which equals 66.47[15] (measured in PS index points), a more politically stable environment is associated with a decrease in CO2 emissions, on average [see column (1b) in Table IV.5]. Also, we note that the findings remain robust when we estimate the model without the control variables (i.e. the core specification), and the turning point occurs for a lower value of political stability, namely 52.50 [see column (1a) in Table IV.5]. For better visualization, the estimated relationship between PS and CO2 is depicted in Figures IV.3-4 below.

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[15] We compute the threshold value based on the first derivative of CO2 with respect to PS. Let us assume that the relationship between CO2 emissions (y) and PS (x) is estimated via the generic quadratic equation $y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 x_{it}^2 + \varepsilon_{it},\ i = \overline{1,N}\ and\ t = \overline{1,T}$. The turning point of the equation is computed as $\ddot{\Upsilon} = \beta_1/(-2\beta_2)$.

On the one hand, these findings complement the ones of Zhang et al. (2016), who show a heterogeneous impact of corruption on CO2 emissions among APEC states. However, our model specification, empirical strategy, and sample differ considerably from Zhang et al. (2016). Besides, we use a broader political stability index, which comprises, along with the corruption, other important political system subcomponents. On the other hand, distinct from the findings of Apergis & Ozturk (2015)[16], our estimates suggest that a threshold effect is at work when modeling the link between CO2 emissions and political stability in developing states. Thus, after the optimum level is reached, along with corruption control (see e.g. Desai, 1998; Cole, 2007; Gani, 2012; Apergis & Ozturk, 2015), all the subcomponents of the political stability index contribute to some extent in reducing CO2 pollution.

Figure IV.3: The estimated relationship between PS and CO2 [augmented model]

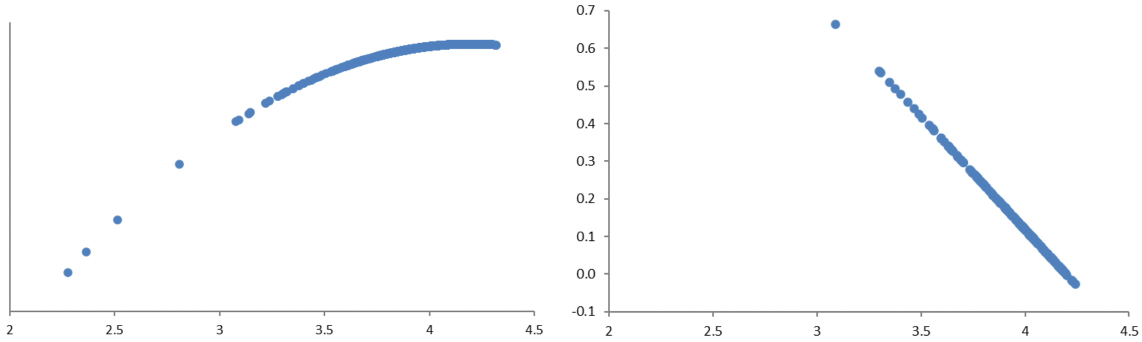
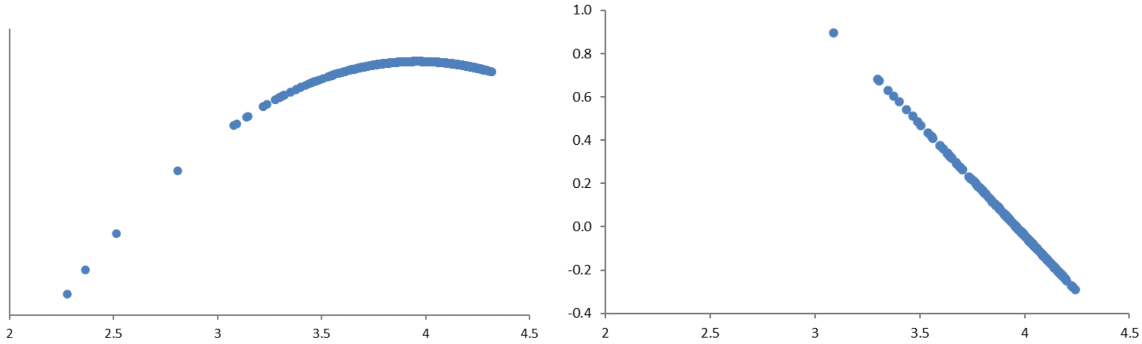

(1a) the estimated relationship CO2/PS (1b) the derivative $dCO2/dPS$

Figure IV.4: The estimated relationship between PS and CO2 [core model]


(2a) the estimated relationship CO2/PS (2b) the derivative $dCO2/dPS$

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[16] In particular, the authors find that in terms of the probability of a government to be destabilized/abolished by unconstitutional or forceful means, higher political stability and absence of violence increase CO2 emissions in Asian countries.

Second, the estimates point out that economic growth contributes to increasing CO2 emission levels (see e.g. He & Richard, 2010; Wang, 2012; Joshi & Beck, 2018; Lazăr et al., 2019). The result is expected, given that developing countries exhibit faster growth rates than the vast majority of developed nations. Indeed, the intensive industrialization process requires a substantial amount of energy use, but it is all at the cost of damaging the environment. However, it is encouraging to see that the renewable energy technologies (see e.g. Ben Jelbi et al., 2016; Dogan & Seker, 2016) inclines the balance in favor of the environment and helps in reducing the CO2 emissions. This may imply that the positive outcomes of renewable energy projects implemented since 2005 in developing countries are becoming more visible and represents crucial tools in mitigating the pollution—all the more that according to the UN Environment Programme (2015), these projects, together with the energy efficiency ones implemented over 2005-2015 period, are expected to decrease by 2020 the GHG by 0.4 gigatons of CO2 per year. However, the energy intensity increases the CO2 emissions, since its coefficient exhibits a positive sign. As such, this may indicate either that the number of associated projects was not very large to produce noticeable effects and/or the outcomes are delayed due to possible distortions in the implementation process.

Third, the strongly significant ECT coefficient confirms, yet again, the accuracy of our results, while it indicates an average speed of adjustment towards the long-run equilibrium. Finally, we note that only the first difference in GDP (RENG) significantly increases (decrease) CO2 emissions in the short-run.

Table IV.5: CO2 emissions and political stability: threshold estimates

Dependent variable: ΔCO2						
	PMG		**MG**		**DFE**	
	(1a)	**(1b)**	**(2a)**	**(2b)**	**(3a)**	**(3b)**
			Long-run estimates			
PS	4.087***	2.523***	98.748*	-1.564	2.908	9.759***
	(0.758)	(0.702)	(59.793)	(11.747)	(2.110)	(2.581)
PS^2	-0.516***	-0.300***	-12.093*	0.148	-0.257	-1.204***
	(0.100)	(0.092)	(7.301)	(1.438)	(0.283)	(0.333)
GDP		0.791***		-0.104		0.864***
		(0.051)		(0.548)		(0.122)
RENG		-0.069***		-0.537		-0.238**
		(0.024)		(1.177)		(0.115)
EINT		0.543***		-0.379		0.612***
		(0.046)		(0.646)		(0.121)
			Short-run estimates			
ECT	**-0.192*** **	**-0.229*** **	**-0.248*** **	**-0.649*** **	**-0.099*** **	**-0.169*** **
	(0.031)	**(0.031)**	**(0.038)**	**(0.061)**	**(0.012)**	**(0.016)**
ΔPS	0.719	2.726	-1.323	-5.141	0.178	0.360
	(4.063)	(3.456)	(5.002)	(4.335)	(0.315)	(0.536)
ΔPS^2	-0.092	-0.342	0.153	0.644	-0.014	-0.042
	(0.504)	(0.427)_	(0.617)	(0.541)	(0.042)	(0.070)
ΔGDP		0.919**		0.502		0.432***
		(0.449)		(0.361)		(0.069)
ΔRENG		-1.376***		-0.809**		-0.265***
		(0.291)		(0.362)		(0.045)
ΔEINT		0.698		0.292		0.275***
		(0.445)		(0.353)		(0.043)
C	-1.814***	-3.068***	-16.120**	-11.588	-0.822**	-4.689***
	(0.304)	(0.431)	(7.947)	(12.784)	(0.377)	(0.817)
Log likelihood	1603.802	2078.713	1603.802	2078.713	1603.802	2078.713
Groups	47	47	47	47	47	47
Observations	1158	1158	1158	1158	1158	1158
Hausman Chi-2 test p-value	0.4072	0.8520				
Pattern	bell-shaped	bell-shaped				
PS turning point (Ÿ)	3.96085 (52.501 pts.)	4.19675 (66.469 pts.)				

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The value of turning point is expressed in log. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4. Robustness checks

We draw upon several methods to check the robustness of our benchmark threshold estimates. In addition, we note that being interested mainly in the long-term impact of political stability on environmental degradation, we focus on interpreting the associated results.

IV.4.1. Alternative estimation technique

So far, our estimates based on the ARDL approach do not consider the potential influence of unobserved common factors. Moreover, the analysis conducted in subsection 3.1.1 indicates that our variables are marked by cross-sectional dependence. Thus, we are prone to believe that the regression model estimates that capture the link between indicators may also be altered by cross-sectional dependence.

Recently, researchers such as Pesaran (2006), Chudik et al. (2013), Chudik & Pesaran (2015a), Bond & Eberhardt (2009), and Eberhardt & Teal (2010), among others, develop a series of panel estimators which are designed to deal with the potential presence of cross-sectional dependence both in unobservables (errors) and observables (regressors). In particular, the issue of unobserved common factors that may drive the error' cross-sectional dependence is addressed by assuming a multifactor error structure. Besides, given the possible correlation between the regressors and these unobserved common factors, it becomes even more essential to appropriately address this potential issue to guarantee the estimates' unbiasedness (Chudik et al., 2013).

Therefore, considering the simple static traditional fixed-effects panel model[17] below

$$CO2_{it} = \mu_i + \beta_i x_{it} + u_{it}, \tag{4}$$

the unobserved common factors are capture by the structure of error term, u_{it}, and regressors, x_{it}, as follows

$$u_{it} = \sigma_i' f_t + \epsilon_{it}, \tag{5}$$

$$x_{it} = \ddot{\mu}_i + \Gamma_i' f_t + \nu_{it}. \tag{6}$$

---

[17] Theoretically, we assume a fixed-effects panel data model, whereas, in the empirical analysis, we consider both the homogeneous and heterogeneous scenarios.

In equation (5), the error term comprises the $(k \times 1)$ vector of unobserved common factors, f_t, and the associated country-specific factor loadings, σ_i, along with the idiosyncratic errors, ϵ_{it}. Moreover, in equation (6), $\ddot{\mu}_i$ and Γ stands for the country-specific fixed-effects and the $(m \times k)$ matrix of factor loadings, respectively. Likewise, ν_{it} represents the idiosyncratic components of x_{it}, which are assumed to be distributed independently of the idiosyncratic errors (innovations), ϵ_{it}.

According to Chudik & Pesaran (2015b), the unobserved common factors, f_t, capture both the common global shocks, which affect all the countries simultaneously, namely the strong factors, and the regional spillovers which impact specific subgroups of states, namely the weak factors. As such, mathematically, this translates into the following straightforward expression: $f_t = f_t^s + f_t^w$, where f_t^s stands for the $(k \times 1)$ vector of finite number of strong factors, and f_t^w represents the $(k \times 1)$ vector of the infinite number of weak factors. Given the period and the sample under investigation, the unobserved common factors could be induced by the 2008-09 global recession, different supply side, pollution, and political related shocks, and several technological, growth, financial, trade, energy, and political spillovers.

Subsequently, to assess our findings' robustness concerning the potential presence of cross-sectional dependence, we employ four approaches, which are specially designed to cope with this specific issue, among others. In particular, depending on the estimator, we consider either the benchmark ECM specification or the classical one, both in its static and dynamic scenarios.

IV.4.1.1. The Cross-Section Augmented ARDL (CS-ARDL) approach

Having in mind that our main estimates rely on the ARDL approach, first, we consider its cross-sectional augmented version, namely the CS-ARDL. Therefore, in line with the work of Chudik et al. (2013), we write the equation of CS-ARDL as follows

$$CO2_{it} = \sum_{j=1}^{p} \partial_{ij} CO2_{it-j} + \sum_{j=0}^{q} \gamma'_{ij} x_{it-j} + \sum_{j=0}^{\pi} \omega'_{ij} \bar{z}_{t-j} + \mu_i + u_{it}, \tag{7}$$

where the new terms $\bar{z}_{t-j} = \left(\overline{CO2}_{t-j}, \bar{x}'_{t-j}\right)'$, $\bar{z}_t = N^{-1} \sum_{i=1}^{N} z_t$, while π stands for the number of cross-sectional averages' lags.

In addition, taking into account the nonstationary and cointegration features of the variables, we can rewrite the above equation into the following ECM

$$\Delta CO2_{it} = \phi_i(CO2_{it-1} - \theta_i' x_{it}) + \sum_{j=1}^{p-1} \delta_{ij}\, \Delta CO2_{it-j} + \sum_{j=0}^{q-1} \varphi_{ij}'\, \Delta x_{it-j} + \\ + \sum_{j=0}^{\pi} \omega_{ij}' \bar{z}_{t-j} + \mu_i + u_{it}, \quad (8)$$

The ECM findings based on equation (8) are displayed in the first half of Table IV.6. We provide the estimates for the PMG estimator, given that it is the one preferred by the data. Also, according to the N and T dimensions and in line with the main analysis, we assume an $ARDL(p = 1, q = 1)$ model, while we include only the contemporaneous cross-sectional averages of the variables, namely, we set $\pi = 0$. As mentioned in subsection 2.2, the PMG estimator assumes homogeneity for the long-run coefficients and heterogeneity for the short-run ones. However, the CS-ARDL estimation command is designed in such a way that all the coefficients are assumed to be heterogeneous. Thus, when the long-term coefficients are pooled, it uses the mean group estimate of the ECT (speed of adjustment) (Ditzen, 2019).

Table IV.6: Threshold estimates: robustness [CS-ARDL and CS-DL estimator]

	ECM specification		**Classic specification**		
	Dependent variable: ΔCO2		**Dependent variable: CO2**		
	CS-ARDL-PMG		**CS-DL-PMG**	**CS-DL-MG**	**AMG-DL**
	(1a)	**(1b)**	**(2)**	**(3)**	**(4)**
Long-run estimates					
PS	4.796***	4.493*	1.941	-0.420	3.813
	(1.774)	(2.525)	(1.885)	(5.001)	(3.879)
PS^2	-0.602***	-0.561*	-0.240	0.030	-0.482
	(0.221)	(0.320)	(0.236)	(0.627)	(0.490)
GDP	0.815***	0.823***	0.832***	1.362***	0.678***
	(0.267)	(0.221)	(0.291)	(0.451)	(0.161)
RENG	-0.213	-0.183	-0.291	-1.009***	-0.657***
	(0.423)	(0.293)	(0.433)	(0.325)	(0.200)
EINT	0.461**	0.471***	0.523**	1.135**	0.676***
	(0.235)	(0.183)	(0.263)	(0.467)	(0.146)
Short-run estimates					
ECT	**-0.542*** **	**-0.545*** **			
	(0.096)	**(0.129)**			
$\Delta CO2_{(t-1)}$	0.457***	0.454***			
	(0.096)	(0.129)			
ΔPS	2.377	2.222	-0.689	-1.067	3.062
	(3.121)	(12.718)	(0.883)	(3.665)	(2.486)
ΔPS^2	-0.300	-0.280	0.076	0.147	-0.375
	(0.391)	(1.594)	(0.115)	(0.457)	(0.311)
ΔGDP	0.564*	0.593*	-0.220	-0.116	0.420***
	(0.334)	(0.314)	(0.150)	(0.260)	(0.156)
ΔRENG	-0.390	-0.326	-0.074	-0.126	-0.598***
	(0.599)	(0.415)	(0.220)	(0.255)	(0.163)
ΔEINT	0.277	0.300	-0.198**	-0.337	0.287***
	(0.274)	(0.214)	(0.088)	(0.236)	(0.100)
CDP					0.545***
					(0.194)
C	-9.161	-8.322	-7.280	-2.303	-7.372
	(6.792)	(8.497)	(6.783)	(12.562)	(7.593)
R_squared	0.57	0.58	0.72	0.11	
RMSE	0.07	0.07	0.08	0.05	0.03
CD statistic	-0.39	-0.06	-2.36**	-1.61	
Groups	43	47	44	44	47
Observations	1075	1138	1092	1092	1138
Pattern	bell-shaped	bell-shaped			
PS turning point (Ÿ)	3.98411	3.9988			

Notes: For the ARDL approach we use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. CDP stands for the common dynamic process. CD and RMSE denote the Cross-Sectional Dependence and the Root Mean Square Error, respectively. CD H0 is "errors are weakly cross sectional dependent". The value of turning point is expressed in log. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

In the first column of Table IV.6, we report the estimates when we allow checking if, within each panel, the time dimension is sufficiently large to compute the individual mean group regression. As such, we note that four countries (i.e. Liberia, Moldova, Niger, Ukraine) are dropped due to insufficient observations. In the second column of ECM specification, we run the model, including all the panel members. Despite controlling for cross-sectional dependence and time dimension, overall, the results are in line with those revealed by the classical ARDL approach. First, the PS terms display the expected signs and are statistically significant, all the more that the computed turning point value (see the bottom of Table A-IV.6 and the Figure A-IV.1 in the Appendix for the estimated relationship between variables) is fairly comparable to the one unveils by the benchmark threshold analysis. Second, the long-term coefficients of explanatory factors are statistically significant and have the expected signs, except for the RENG variable, which does not significantly negatively impact CO2. In addition, their coefficient magnitude it is very close to the one of the main ARDL analysis. Third, the error correction term is negative and strongly significant, whereas the speed of adjustment to the long-run equilibrium is almost double, compared to benchmark threshold estimates. Fourth, a slight difference compared to the classical ARDL approach is the lag of the first difference of CO2 emissions variable coefficient, explicitly reported by the model. In this regard, subtracting the value of one from it, we obtain the important error correction term coefficient. Finally, for both the ECM models, the CD statistic value strongly rejects the null hypothesis of weakly cross-sectional dependence in errors. Correspondingly, the results suggest that the inclusion of only contemporaneous cross-sectional averages fully mitigate the potential adverse effects of unobserved common factors.

IV.4.1.2. The Cross-Section Augmented Distributed Lag (CS-DL) approach

As a complementary approach to CS-ARDL estimation of the long-run relationship between variables, Chudik et al. (2013) proposed the CS-DL method. Opposite to the ARDL approach, which computes the estimates of long-run coefficients indirectly based on the short-run ones, the CS-DL method estimates the long-run coefficients directly. Additionally, this technique allows (i) the nonstationary in regressors and/or factors), (ii) homogeneity and heterogeneity in short- and/or long-run coefficients, provides (iii) good performance when the time dimension is moderate, whereas it is robust to both potential (iv) serial correlation in unobserved common factors and idiosyncratic errors, and (v) weakly cross-sectional dependence in idiosyncratic errors (Chudik et al., 2013). Indeed, it is worth noted that the above mentioned applied, especially when the model includes the appropriate cross-sectional averages. However, the CS-DL technique provides inconsistent estimates when the variables are subject to reverse causality, namely when the endogenous variable's lagged values are correlated to the independent factors

(Chudik et al., 2013). Therefore, this could be an important disadvantage regarding our study, given that CO2 emissions are usually persistent.

In the spirit of Chudik et al. (2013) and Chudik et al. (2016), we can write the equation of CS-DL in the below form

$$CO2_{it} = \tau_i' x_{it} + \sum_{j=0}^{q-1} \sigma_{ij}' \Delta x_{it-j} + \psi_{ico2}\overline{CO2}_t + \sum_{j=0}^{\pi} \psi_{ixj}' \bar{x}_{t-j} + \eta_i + e_{it}, \qquad (9)$$

where $\bar{x}_t = N^{-1}\sum_{i=1}^{N} x_{it}$, $\overline{CO2}_t = N^{-1}\sum_{i=1}^{N} CO2_{it}$, $e_{it} = A_i(L)^{-1}u_{it}$, $\eta_i = A_i(L)^{-1}u_{it}$, $\tau_i = A_i(L)^{-1}\sum_{j=0}^{q}\gamma_{ij}$, $\sigma_i = A_i(L)^{-1}\nu_{ij}$, $\nu_{ij} = -\sum_{k=j+1}^{q}\gamma_{ik}\ for\ j = 1, \dots, p-1$. ψ_{ico2} and ψ_{ixj} are the factor loadings which also comprise $A_i(L)^{-1}$, compared to ω_{ij} from equation (7), while L denotes the lag operator.

We run the regression models considering $q = 1$, both for the pooled version (CS-DL-PMG), and when we relax the long-run slopes homogeneity assumption (CS-DL-MG). As well, for regressors, we include only their contemporaneous cross-sectional averages, namely, we set $\pi = 0$.[18] Besides, we augment the AMG technique (see subsection 4.1.4 for more details) and estimate its DL version by adding additional factors, both the first differences of the regressors and the cross-sectional averages of the dependent variable and regressors. The results summarized in the last three columns of Table IV.6 show that the PS does not significantly impact the CO2, even if the coefficients of PS terms display the expected signs for both the CS-DL-PMG and AMG-DL estimator. Likewise, for the other explanatory factors, the signs of the associated coefficients are in line with those of ARDL benchmark estimation, and all exhibit a statistically significant impact on CO2 pollution (with the notable exception of the RENG variable for CS-DL-PMG technique). Overall, the findings may suggest that omitting the important feedback effects between variables, especially between PS and CO2, leads to bias estimates of the long-run effects. Thus, when the errors are correlated to the independent factors, the DL approach may lose its consistency.

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[18] Chudik et al. (2013) argue for setting the lag orders of regressors' cross-sectional averages equal to the value of the integer part of $T^{1/3}$, namely $[T^{1/3}]$. However, we keep the number of lags to the minimum, and we note that running the regression with $\pi = 1$ and $\pi = 2$ do not mitigate the cross-sectional dependence—the CD statistic significance remains at approximatevely the same level ($for\ \pi = 1$) or tends to slightly improve with the number of lags ($for\ \pi = 2$).

IV.4.1.3. The Common Correlated Effects (CCE) approach

To mitigate the potential issue of unobserved common factors, Pesaran (2006) developed the CCE estimator by augmenting the explanatory factors both with their, and the dependent variable cross-sectional averages. Nonetheless, the associated estimates of cross-sectional averaged variables are included only to control the potential bias induced by unobserved common factors and do not have a meaningful interpretation. Moreover, using Monte Carlo experiments, Pesaran (2006) shows that the estimator performs well for small N and T dimensions and also in the presence of a large degree of heterogeneity and dynamics. Also, the CCE approach provides robust estimates in the presence of both finite strong and infinite weak unobserved common factors in the errors (Pesaran & Tosetti, 2011), and when they are nonstationary (Kapetanios et al., 2011).

In the context of our analysis, adding as additional regressors the cross-sectional averages of both dependent and independent variables would yield to the mathematical expression of static CCE estimator as follows

$$CO2_{it} = \gamma_i' x_{it} + \omega_i' \bar{z}_t + \mu_i + u_{it}, \tag{10}$$

where $\bar{z}_t = (\overline{CO2}_t, \bar{x}_t')'$ and $\bar{z}_t = N^{-1}\sum_{i=1}^{N} z_t$. We estimate the relationship between the variables considering the pooled scenario of CCE estimator (CCE-P), and when we relax the long-run slopes homogeneity assumption, using its MG version (CCE-MG). Indeed, the estimator is robust to cross-sectional dependence in errors, factors nonstationary, and slopes heterogeneity, but does no allows for the lagged values of the dependent variable and/or weakly exogenous regressors (Chudik & Pesaran, 2015a).

Consequently, following Chudik & Pesaran's (2015a) work, to control for the potential persistence in the dependent variable, we employ the estimator in its dynamic form (i.e. DCCE). However, it is worth mentioning that the authors developed the DCCE estimator in the context of slopes heterogeneity assumption and for stationary panels where both N and T dimensions are sufficiently large (Chudik & Pesaran, 2015a). The mathematical expression of the dynamic model is written as

$$CO2_{it} = \partial_i CO2_{it-1} + \gamma_i' x_{it} + \sum_{j=0}^{\pi} \omega_{ij}' \bar{z}_{t-j} + \mu_i + u_{it}, \tag{11}$$

where $CO2_{it-1}$ is the lagged value of $CO2_{it}$, π denotes the number cross-sectional averages' lags of dependent and independent factors, and the remaining terms are defined as in the previous equations.

We report the associated results in Table IV.7, both for $\pi = 0$ and $\pi = 1$. First, in almost all cases, the coefficients of PS terms suggest a bell-shaped pattern between variables, but they lack statistical significance. Second, the coefficients of the additional explanatory factors display the expected signs and have a significant impact on CO2 emissions with predilection in static models. Third, the dependent variable's lag value is positive and strongly significant (except for the DCCE-MG scenario), suggesting high persistence in CO2 pollution. Indeed, as expected, and strengthening our previous assumption, the past levels of CO2 emissions contribute substantially to increasing the current ones in our group of developing economies.

In line with the DL approach, the CEE static estimates could be polluted when the dependent variable's lag is omitted from the model. Indeed, its novel dynamic version is designed to mitigate this issue, among others. However, the dynamic estimator is designed only for stationary panels, while taking into account the nonstationary and cointegration of our variables, its performance is questionable. Moreover, Chudik & Pesaran (2015a) argue that the estimator provides conclusive results when an adequate number of cross-sectional lags are added to regression and when the number of cross-sectional averages is equal or greater than the number of unobserved common factors. Since we include a maximum of one lag due to our panel dimension characteristics, this may also be problematic and affects its overall performance.

Table IV.7: Long-run threshold estimates: robustness [CCE estimator]

Dependent variable: CO2								
	Static models				**Dynamic models**			
	CCE-P		**CCE-MG**		**DCCE-P**		**DCCE-MG**	
	(1a)	**(1b)**	**(2a)**	**(2b)**	**(3a)**	**(3b)**	**(4a)**	**(4b)**
	$\pi = 0$	$\pi = 1$	$\pi = 0$	$\pi = 1$	$\pi = 0$	$\pi = 1$	$\pi = 0$	$\pi = 1$
PS	1.040	1.356	6.367	15.472	1.537	1.438	10.122	-1.486
	(1.793)	(1.671)	(5.617)	(10.984)	(3.350)	(2.776)	(7.747)	(6.876)
PS^2	-0.129	-0.161	-0.818	-1.946	-0.184	-0.165	-1.268	0.127
	(0.228)	(0.209)	(0.706)	(1.375)	(0.420)	(0.349)	(0.970)	(0.838)
GDP	0.740***	0.693**	0.841***	1.126**	0.518	0.534**	0.852***	1.035**
	(0.273)	(0.310)	(0.147)	(0.474)	(0.345)	(0.264)	(0.153)	(0.422)
RENG	-0.293	-0.263	-1.302***	-1.321***	-0.188	-0.240	-1.442***	-1.185***
	(0.464)	(0.488)	(0.332)	(0.390)	(0.556)	(0.487)	(0.324)	(0.390)
EINT	0.420*	0.410	0.570***	0.820*	0.320	0.356	0.644***	0.706*
	(0.252)	(0.281)	(0.119)	(0.498)	(0.326)	(0.231)	(0.148)	(0.393)
CO2$_{(t-1)}$					0.393***	0.283***	0.138***	-0.031
					(0.098)	(0.100)	(0.044)	(0.053)
C	-4.189	-7.280	-11.360	-35.110	-4.685	-5.463	-17.659	1.774
	(6.028)	(9.783)	(10.554)	(22.588)	(7.828)	(9.930)	(15.540)	(15.636)
CD statistic	-1.74*	-1.96**	3.39***	1.01	-1.34	-2.27**	0.22	-1.20
RMSE	0.08	0.08	0.05	0.05	0.07	0.07	0.05	0.05
Groups	47	45	47	47	47	43	47	43
Observations	1185	1108	1185	1142	1142	1032	1142	1032

Notes: CD and RMSE denote the Cross-Sectional Dependence and the Root Mean Square Error, respectively. CD H0 is "errors are weakly cross sectional dependent". Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.1.4. The Augumented Mean Group (AMG) approach

We also employ the novel Augmented Mean Group (AMG) estimator robust in the presence of cross-sectional dependence introduced in Bond & Eberhardt (2009) and Eberhardt and Teal (2010). More specifically, the AMG estimator allows country-specific long-run slopes coefficient and mitigates the potential presence of cross-sectional dependence in observables and unobservables directly through a "common dynamic process" variable, opposite to the CEE estimator that treats the unobservable common factors as a nuisance.

In this manner, the AMG estimates are obtained following a two-step regression procedure. The coefficients of time dummies ϕ_t (i.e. common dynamic process) are obtained in the first stage, employing the first difference OLS estimator on a pooled model augmented with the year dummies D_t

$$\Delta CO2_{it} = \beta \Delta x_{it} + \sum_{t=2}^{T} \phi_t \Delta D_t + e_{it}. \tag{12}$$

In the second stage, the newly created common dynamic process variable, ϕ_t, is added into the model as an explanatory factor. The estimator also allows for the introduction of a linear trend, namely in the below equation the term $\eta_i t$.

$$CO2_{it} = \alpha_i + \beta_i x_{it} + \eta_i t + d_i \phi_t + e_{it}. \tag{13}$$

The first column results under static specification in Table IV.8 indicate that our hypothesis holds, and the PS terms have a significant effect on CO2 emissions. Moreover, we estimate the model's dynamic counterpart by incorporating the first lag of the dependent variable. As shown in column (4) of Table IV.8, yet again, the findings support our assumption that the relationship between CO2 and political stability is bell-shaped. For better visualization, Figures A-IV.2-3 in the Appendix depict the estimated relationship for AMG and DAMG estimator, respectively.

To further check AMG estimates' stability, we run our model by imposing the common dynamic process on each panel member with a unit coefficient, namely, we subtract it from the dependent variable. Also, to control the omitted idiosyncratic processes that have a linear trajectory over time, we add a linear trend to the equation. The associated estimates are illustrated by the last two columns under both static and dynamic specification of Table IV.8. On the one hand, we note that the inverted-U shaped pattern between PS and CO2 is at work across all scenarios, given that the coefficient of PS and PS2 variables are strongly statistically significant. As well, the coefficients of explanatory factors (i.e. GDP, RENG, and EINT) have the expected sign and significantly impact the CO2 emissions (at 1% level of significance).

On the other hand, the coefficient of the lagged value of the dependent variable in dynamic scenarios suggests high persistence in CO2 emissions—these findings being also in line with those provided by the DCCE estimator. As well, the CDP coefficient is positive and highly significant, while the number of significant linear trends (see the bottom of Table IV.8) in static (i.e. AMG$^{IMP\_T}$) and dynamic (i.e. DAMG$^{IMP\_T}$) models are 16 and 15, respectively. Furthermore, the concave curve's estimated local maxima are comparable in all AMG specifications, whereas they match those of our benchmark ARDL approach and the robustness CS-ARDL one.

Table IV.8: Long-run threshold estimates: robustness [AMG estimator]

Dependent variable: CO2						
	Static models			**Dynamic models**		
	AMG	**AMG^{IMP}**	**AMG$^{IMP\_T}$**	**DAMG**	**DAMG^{IMP}**	**DAMG$^{IMP\_T}$**
	(1a)	**(1b)**	**(1c)**	**(1a)**	**(1b)**	**(1c)**
PS	5.645***	5.447***	4.864***	6.841***	6.707***	6.643***
	(2.019)	(1.968)	(1.714)	(1.834)	(2.034)	(1.268)
PS^2	-0.706***	-0.676***	-0.608***	-0.846***	-0.826***	-0.821***
	(0.254)	(0.246)	(0.218)	(0.234)	(0.250)	(0.156)
GDP	0.560***	0.482***	0.836***	0.408***	0.321***	0.613***
	(0.119)	(0.107)	(0.151)	(0.101)	(0.103)	(0.131)
RENG	-0.723***	-0.804***	-0.619***	-0.527***	-0.513***	-0.543***
	(0.179)	(0.232)	(0.141)	(0.121)	(0.152)	(0.146)
EINT	0.467***	0.479***	0.549***	0.470***	0.442***	0.530***
	(0.099)	(0.082)	(0.108)	(0.093)	(0.089)	(0.118)
CO2$_{(t-1)}$				0.221***	0.248***	0.248***
				(0.037)	(0.043)	(0.036)
CDP	0.645***			0.507***		
	(0.198)			(0.152)		
TREND			-0.005*			-0.009***
			(0.003)			(0.002
C	-13.589***	-12.780***	-15.293***	-14.227***	-13.617***	-13.672***
	(4.415)	(4.046)	(4.615)	(4.606)	(4.840)	(3.591)
RMSE	0.0516	0.0590	0.0525	0.0456	0.0501	0.0459
Groups	47	47	47	47	47	47
Observations	1185	1185	1185	1142	1142	1142
#GroupS_trends			16			15
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	3.99333	4.02641	3.99735	4.04182	4.05796	4.0411

Notes: CDP stands for common dynamic process. RMSE denotes the Root Mean Square Error. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.2. Additional controls

In addition to our main explanatory variables introduced into the model to overcome a potential omitted variable bias, we consider several other factors that might impact the CO2 pollution-political stability nexus. These factors capture the GDP composition (agriculture, industry, trade, and foreign direct investments), the environmental conditions (forest and total natural resources rents), the ongoing urbanization process (the share of the urban population in total), the progressive globalization process (KOF globalization index), the private sector financial status (domestic credit to the private sector), the labor force prospects (total unemployment), and the countries' broader development (human development index). According to the findings presented in Table IV.9, the inverted-U shape pattern between indicators remains qualitatively unchanged when controlling for this extensive set of factors. As well, the estimated turning point value across all models is comparable to the one of the benchmark model and lies well within the PS index range. In addition, the ECT is still negative and highly significant in all models, whereas its magnitude remains similar to the main threshold results.

Table IV.9: Threshold estimates: robustness [additional control factors]

Dependent variable: ΔCO2						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Long-run estimates						
PS	9.411*** (1.173)	2.213*** (0.515)	2.947*** (0.684)	2.557*** (0.785)	1.783*** (0.497)	4.093*** (0.711)
PS^2	-1.158*** (0.148)	-0.275*** (0.068)	-0.358*** (0.089)	-0.299*** (0.102)	-0.217*** (0.064)	-0.516*** (0.090)
GDP	0.715*** (0.050)	0.715*** (0.053)	0.794*** (0.041)	0.829*** (0.041)	0.610*** (0.042)	0.400*** (0.051)
RENG	-0.306*** (0.052)	-0.063* (0.033)	-0.040** (0.020)	-0.042*** (0.014)	0.043 (0.035)	-0.098** (0.047)
EINT	0.438*** (0.037)	0.457*** (0.046)	0.591*** (0.038)	0.665*** (0.043)	0.700*** (0.037)	0.502*** (0.045)
AGRI	0.155*** (0.026)					
IND		-0.065*** (0.017)				
TRADE			0.063*** (0.017)			
FDI				0.032*** (0.007)		
HDI					0.552*** (0.053)	
GLOB						0.344*** (0.025)
Short-run estimates						
ECT	**-0.207*** (0.037)**	**-0.229*** (0.033)**	**-0.256*** (0.036)**	**-0.247*** (0.034)**	**-0.278*** (0.040)**	**-0.240*** (0.047)**
ΔPS	0.708 (4.121)	1.059 (3.925)	3.851 (3.836)	2.669 (3.170)	4.582 (3.646)	1.721 (3.474)
ΔPS^2	-0.099 (0.511)	-0.132 (0.484)	-0.490 (0.477)	-0.335 (0.391)	-0.579 (0.452)	-0.219 (0.431)
ΔGDP	1.064** (0.494)	1.039** (0.408)	0.911** (0.418)	0.706** (0.353)	0.796*** (0.226)	0.971** (0.442)
ΔRENG	-1.391*** (0.322)	-1.481*** (0.318)	-1.361*** (0.282)	-1.485*** (0.308)	-1.409*** (0.305)	-1.439*** (0.318)
ΔEINT	0.800* (0.495)	0.721* (0.399)	0.660* (0.412)	0.531 (0.346)	0.405* (0.230)	0.679 (0.441)
ΔAGRI	-0.008 (0.022)					
ΔIND		0.016 (0.025)				
ΔTRADE			0.006 (0.014)			
ΔFDI				0.006 (0.012)		
ΔHDI					-0.658 (0.417)	
GLOB						-0.019 (0.061)
C	-5.406*** (0.985)	-2.669*** (0.397)	-3.746*** (0.546)	-3.51*** (0.494)	-2.970*** (0.445)	-3.488*** (0.701)
Log Likelihood	2087.731	2069.703	2119.441	2116.715	2079.872	2107.791
Groups	47	47	47	47	47	47
Observations	1110	1103	1128	1136	1069	1130
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	4.0608	4.01591	4.10834	4.27185	4.09519	3.96067

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The value of turning point is expressed in log. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectivel

(**Table IV.9:** continued)

Dependent variable: ΔCO2					
	(7)	(8)	(9)	(10)	(11)
	Long-run estimates				
PS	4.880***	2.886***	2.653***	3.225***	21.057***
	(0.907)	(0.684)	(0.707)	(0.627)	(1.944)
PS^2	-0.599***	-0.348***	-0.318***	-0.400***	-2.665***
	(0.115)	(0.090)	(0.089)	(0.083)	(0.248)
GDP	0.894***	0.756***	0.654***	0.690***	0.011
	(0.027)	(0.048)	(0.051)	(0.044)	(0.050)
RENG	0.013**	-0.053**	-0.036	-0.029*	-0.442***
	(0.006)	(0.021)	(0.033)	(0.017)	(0.069)
EINT	0.815***	0.525***	0.661***	0.572***	0.235***
	(0.033)	(0.045)	(0.045)	(0.041)	(0.038)
FORESTR	-0.039***				
	(0.006)				
NATR		-0.038***			
		(0.012)			
URB			0.363***		
			(0.069)		
CREDIT				0.055***	
				(0.012)	
UNEM					0.005
					(0.006)
	Short-run estimates				
ECT	**-0.236*** **	**-0.230*** **	**-0.329*** **	**-0.243*** **	**-0.189*** **
	(0.038)	**(0.030)**	**(0.041)**	**(0.036)**	**(0.045)**
ΔPS	3.390	2.960	1.083	2.071	-0.923
	(3.324)	(3.304)	(3.264)	(3.544)	(3.347)
ΔPS^2	-0.433	-0.375	-0.137	-0.255	0.115
	(0.410)	(0.407)	(0.404)	(0.438)	(0.412)
ΔGDP	0.977**	1.072**	1.027**	0.800**	0.928***
	(0.500)	(0.493)	(0.504)	(0.368)	(0.255)
ΔRENG	-1.331***	-1.321***	-1.349***	-1.642***	-1.507***
	(0.292)	(0.287)	(0.307)	(0.377)	(0.365)
ΔEINT	0.681	0.744	0.667	0.589*	0.596**
	(0.502)	(0.491)	(0.504)	(0.362)	(0.246)
ΔFORESTR	0.006			-0.006	
	(0.011)			(0.016)	
ΔNATR		0.018**			
		(0.008)			
ΔURB			22.954*		
			(14.160)		
ΔCREDIT				-3.432***	
				(0.525)	
ΔUNEM					-0.074**
					(0.034)
C	-4.614***	-3.162***	-4.879***	-3.432***	-7.921***
	(0.738)	(0.424)	(0.636)	(0.525)	(1.902)
Log Likelihood	2119.65	2115.065	2157.081	2096.291	2073.49
Groups	47	47	47	47	47
Observations	1128	1128	1138	1096	1095
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	4.06943	4.13828	4.1650	4.02641	3.94963

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The value of turning point is expressed in log. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.3. Altering the sample

To check the stability of the results, we alter the sample in several ways. On the one hand, to eliminate the 2008-09 great recession's potential effects, we first restrict the period to

1990-2007. Second, we prolong the restriction to the 1990-2010 period to account for a potential delayed global recession impact in developing states. Moreover, given that the Cold War effects may equally distort our main findings, we restrict the sample's time dimension to 1996-2015. Indeed, the years following major political unrest episodes that affected several states worldwide, such as the Cold War, could be challenging in reestablishing economic stability. Overall, as illustrated in columns (1)-(3) in Table IV.10, the findings are robust even after applying these restrictions on the sample's T dimension.[19]

On the other hand, our sample period covers the 2010-12 Arab Spring, which could also influence the CO2 emissions-political stability nexus. As such, we drop from the sample the countries that belong to the Middle East and North Africa (MENA) region where it took place, namely Egypt, Morocco, Tunisia, and Yemen. Furthermore, according to Central Intelligence Agency (CIA)[20] crude oil exports classification, we exclude the states that occupy positions among the top thirty, namely Angola, Nigeria, Vietnam, Indonesia, Congo Rep, and Egypt. Thus, we can assess whether the "big players" of the petroleum industry influence the relationship between environmental quality and political stability. Results reported in columns (4)-(5) indicate that excluding these states do not alter the long-term, bell-shaped pattern between CO2 emissions and political stability. Besides, the coefficient of ECT is similar both in magnitude and sign with the main threshold findings.

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[19] For the models in columns (1)-(2), we report the results only for the reduced model (i.e. without the inclusion of the control variables), given that the initial values are not feasible when we attempt to estimate a model with a shorter time dimension and too many explanatory factors.

[20] For more details see https://www.cia.gov/library/publications/the-world-factbook/fields/262rank.html.

Table IV.10: Threshold estimates: robustness [altering the sample]

Dependent variable: ΔCO2				
	2008-09 restriction	**2010-12 restriction**	**1990-96 (Cold War) restriction**	
	(1)	**(2)**	**(3a)**	**(3b)**
		Long-run estimates		
PS	10.994***	11.285***	5.835**	12.109***
	(1.713)	(1.660)	(2.530)	(2.158)
PS^2	-1.392***	-1.432***	-0.774**	-1.520***
	(0.221)	(0.214)	(0.315)	(0.273)
GDP				0.162***
				(0.040)
RENG				-0.639***
				(0.062)
EINT				0.238***
				(0.027)
		Short-run estimates		
ECT	**-0.231*** **	**-0.219*** **	**-0.244*** **	**-0.250*** **
	(0.034)	**(0.034)**	**(0.039)**	**(0.044)**
ΔPS	2.342	-0.682	1.645	4.041
	(4.597)	(3.986)	(8.573)	(8.091)
ΔPS^2	-0.280	0.082	-0.187	-0.475
	(0.565)	(0.494)	(1.050)	(0.979)
ΔGDP				1.106***
				(0.405)
ΔRENG				-1.154***
				(0.306)
ΔEINT				0.754*
				(0.402)
C	-5.322***	-5.149***	-2.985***	-6.155***
	(0.807)	(0.818)	(0.511)	(1.097)
Log Likelihood	1154.027	1278.595	1381.961	1769.72
Groups	47	47	47	47
Observations	829	923	888	880
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	3.94638	3.94003	3.76683	3.98166

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

(**Table IV.10:** continued)

Dependent variable: ΔCO2				
	Arab Spring restriction		**Oil exporters restriction**	
	(4a)	**(4b)**	**(5a)**	**(5b)**
	Long-run estimates			
PS	14.696***	2.294***	14.729***	5.770***
	(1.798)	(0.738)	(1.799)	(1.255)
PS^2	-1.874***	-0.269***	-1.880***	-0.721***
	(0.231)	(0.097)	(0.231)	(0.162)
GDP		0.820***		0.684***
		(0.065)		(0.061)
RENG		-0.069***		-0.106**
		(0.025)		(0.049)
EINT		0.561***		0.731***
		(0.055)		(0.059)
	Short-run estimates			
ECT	**-0.197*** **	**-0.234*** **	**-0.190*** **	**-0.205*** **
	(0.032)	**(0.034)**	**(0.033)**	**(0.035)**
ΔPS	-0.523	4.085	-0.412	2.583
	(4.340)	(3.682)	(4.543)	(3.849)
ΔPS^2	0.062	-0.510	0.050	-0.329
	(0.538)	(0.455)	(0.563)	(0.476)
ΔGDP		0.929*		1.096**
		(0.490)		(0.503)
ΔRENG		-1.495***		-1.399***
		(0.312)		(0.331)
ΔEINT		0.721		0.770
		(0.486)		(0.505)
C	-5.959***	-3.113***	-5.769***	-3.928***
	(0.993)	(0.467)	(1.028)	(0.698)
Log Likelihood	1425.861	1844.564	1381.542	1789.269
Groups	43	43	41	41
Observations	1058	1038	1008	988
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ϋ)	3.91911	4.25299	3.91673	3.99793

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.4. Political stability subcomponents

To assess whether the impact of PS elements on CO2 follows a similar pattern to the main threshold model, we proceed as follows. First, in line with Bekaert et al. (2006), we build two subcomponents, namely the PS_SC1 and PS_SC2, which measure the quality of institutions and security status.[21] Second, we construct two subcomponents describing government quality (PS_SC3) and politico-economic equilibrium (PS_SC4). Table A-IV.2 in

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[21] In contrast to Bekaert et al. (2006), we name the variable ''security status'' instead of ''conflict'', as the higher the values, the lower the conflict, i.e. higher the security.

the Appendix illustrates the way we define the subcomponents[22], while Table A-IV.3 presents some related descriptive statistics.

According to the estimates provided by Table IV.11, all models show a long-run, bell-shaped pattern between the PS subindexes and CO2. Thus, CO2 pollution may increase at first for low institutional quality levels, security status, government quality, and politico-economic equilibrium, but the trend reverses in favor of the environment after the threshold in these indicators is reached. More specifically, CO2 emissions may peak at around a computed value (in associated points) of 7.09 for PS_SC1, 31.45 for PS_SC2, 8.28 for PS_SC3, and 12.73 for PS_SC4. Additionally, we note that all estimated thresholds lie within the related PS subcomponent range, while only for PS_SC3 and PS_SC4, the average value of the sample is above the threshold, suggesting that all countries attained the CO2 peak. Overall, these findings are in line with the main ones, indicating that the political stability's aggregate effect on CO2 mirrors its subcomponents' impact and is not the result of a mix between different patterns between variables.

Regarding the explanatory factors, their significant impact on CO2 remains the same as in the benchmark model. Besides, the ECT term is negative and strongly statistically significant across all models, showing an average speed of adjustment to the long-run equilibrium, ranging from -0.185 [see column (4) in Table IV.11) to -0.215 [see column (2) in Table IV.11].

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[22] We mention that all four subcomponents could be interpreted in the same manner: the higher the values, the higher the institution's quality, security status, government quality, and politico-economic equilibrium.

Table IV.11: Threshold estimates: robustness [political stability subcomponents]

Dependent variable: ΔCO2				
	PS_SC1	**PS_SC2**	**PS_SC3**	**PS_SC4**
	(1)	**(2)**	**(5)**	**(6)**
Long-run estimates				
PS_SC[*]	1.155***	1.932***	0.876***	1.875***
	(0.225)	(0.478)	(0.103)	(0.524)
PS^2_SC[*]	-0.294***	-0.280***	-0.207***	-0.368***
	(0.062)	(0.079)	(0.027)	(0.103)
GDP	0.536***	0.595***	0.172***	0.724***
	(0.054)	(0.052)	(0.065)	(0.067)
RENG	-0.107**	-0.010	0.093	-0.080*
	(0.052)	(0.045)	(0.082)	(0.043)
EINT	0.381***	0.372***	-0.043	0.421***
	(0.046)	(0.043)	(0.046)	(0.054)
Short-run estimates				
ECT	**-0.202*** **	**-0.215*** **	**-0.188*** **	**-0.185*** **
	(0.028)	**(0.032)**	**(0.039)**	**(0.027)**
ΔPS_SC[*]	0.076	-1.099	0.101	0.457
	(0.514)	(1.715)	(0.316)	(0.801)
ΔPS^2_SC[*]	-0.051	0.172	-0.020	-0.088
	(0.146)	(0.266)	(0.067)	(0.154)
ΔGDP	1.003**	0.900***	1.014***	0.805***
	(0.407)	(0.324)	(0.357)	(0.252)
ΔRENG	-1.407***	-1.510***	-1.400***	-1.582***
	(0.302)	(0.321)	(0.310)	(0.354)
ΔEINT	0.665*	0.615*	0.709**	0.571**
	(0.401)	(0.319)	(0.354)	(0.248)
C	-1.383***	-2.122***	-0.762***	-1.795***
	(0.209)	(0.328)	(0.174)	(0.286)
Log Likelihood	2068.354	2083.53	2056.315	2056.099
Groups	47	47	47	47
Observations	1138	1138	1138	1138
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	1.95959	3.44868	2.1144	2.54452

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. Each column from (1) to (4) corresponds to the associated PS subcomponent model. For instance, in column (1) the PS_SC[*] variables takes value 1 and describe the model of PS_SC[1]; the principle is preserved for all subcomponent's models. The value of turning point is expressed in log. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.5. Alternative methods in computing the PS composite index

Our primary exogenous variable, namely the political stability, is a composite index that comprises twelve ICRG indicators, which in turn, each captures several dimensions of the social, political, and economic context. Depending on the indicator and the weight assigned, the maximum points awarded are four (bureaucracy quality), six (corruption, military in politics, religious tensions, law and order, ethnic tensions, and democratic accountability) or twelve (socioeconomic conditions, investment profile, internal conflict, and external conflict), while their summation for a specific country and year gives the associated political risk rating. As stated before, the maximum value of 100 points suggests a very low political risk (i.e. high political stability), and, opposite, a value close to 0 indicates a high political risk (i.e. low political stability).

In the following, to assess the consistency of the main findings, we compute the composite index considering four alternatives.[23] On the one hand, we construct the index based on the components' mean, namely, arithmetic, geometric, and harmonic. We use all three types of mean's calculations, as each is suitable in specific cases and may add different information. For example, the simple average is meaningful when data follows a normal distribution, while the outliers' presence can easily bias its computation. The geometric and harmonic mean is recommended when dealing with distinct measurement units of the variables and working with ratios between variables. On the other hand, to mitigate the possible effect of outliers, we construct the index according to its components' median values instead of the mean ones.

The results are summarized in Table IV.12 First, we can observe that the coefficients' sign and their magnitude in all models correspond to those of the threshold benchmark estimates. Also, as expected, the magnitude of coefficients in the simple average model almost perfectly matches one of the main findings. Moreover, all variables significantly impact the CO2 emissions, except RENG in the harmonic mean model [see column (3) of Table IV.12]. Second, we note that in the last column of Table IV.12, the coefficients' magnitude is slightly lower compared to the other models. As such, it seems that some outliers are at work in our data, and the median version of the PS composite index reduces their effects. Third, the estimated PS threshold lies within the sample range across all models (see Figures A-IV.4-7 in the Appendix for the estimated relationship), while the error correction term has similar significant negative coefficients. Overall, we can argue that the results remain highly robust when using alternative index computations.

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[23] We refrain using other computation techniques such as the Principal Component Analysis (PCA), among others, following two reasons: (1) the index components are constructed based on other subcomponents; thus, further constructing an index based on other indexes will add much more complexity. Thus, it would make it quite challenging to have a meaningful interpretation; (2) usually, the PCA analysis is employed when there is a high correlation between variables, given that it would provide a proper interpretation of the newly constructed index. In this regard, we mention that the highest correlation between components in our dataset is roughly 0.55, while in the vast majority of cases, this is spread around the values of 0.1 and 0.2.

Table IV.12: Threshold estimates: robustness [alternative computation of PS index]

Dependent variable: ΔCO2				
	Mean	**GeomMean**	**HarmMean**	**Median**
	(1)	**(2)**	**(3)**	**(4)**
Long-run estimates				
PS	1.030***	0.326***	0.445***	1.053***
	(0.243)	(0.084)	(0.095)	(0.198)
PS^2	-0.301***	-0.125**	-0.252***	-0.355***
	(0.092)	(0.049)	(0.059)	(0.081)
GDP	0.791***	0.726***	0.619***	0.593***
	(0.051)	(0.047)	(0.044)	(0.053)
RENG	-0.069***	-0.065**	-0.055	-0.107**
	(0.024)	(0.030)	(0.037)	(0.052)
EINT	0.543***	0.510***	0.466***	0.364***
	(0.046)	(0.042)	(0.040)	(0.042)
Short-run estimates				
ECT	**-0.229*****	**-0.209*****	**-0.205*****	**-0.205*****
	(0.031)	**(0.031)**	**(0.032)**	**(0.029)**
ΔPS	1.025	1.102	-0.097	0.588
	(1.335)	(0.872)	(0.473)	(0.568)
ΔPS^2	-0.343	-0.411	0.060	-0.222
	(0.427)	(0.311)	(0.182)	(0.208)
ΔGDP	0.920**	1.061**	1.094**	1.044**
	(0.449)	(0.495)	(0.500)	(0.447)
ΔRENG	-1.376***	-1.413***	-1.409***	-1.309***
	(0.291)	(0.288)	(0.295)	(0.279)
ΔEINT	0.698	0.798*	0.817*	0.445*
	(0.445)	(0.492)	(0.496)	(0.445)
C	-2.054***	-1.628***	-1.421***	-1.417***
	(0.293)	(0.258)	(0.240)	(0.213)
Log Likelihood	2078.698	2063.988	2062.917	2062.653
Groups	47	47	47	47
Observations	1138	1138	1138	1138
Pattern	bell-shaped	bell-shaped	bell-shaped	bell-shaped
PS turning point (Ÿ)	1.71141	1.30067	0.8811	1.48083

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.4.6. Alternative approach in estimating the threshold effect

Motivated by the presence of the PS threshold effect on CO2 emissions documented previously, this subsection aims to further check the results' stability by considering an alternative approach. So far, using the polynomial equation method, we find that the PS exhibits a threshold effect on CO2. As well, based on the augmented (core) benchmark model, the estimated peak value is roughly 66.47 (52.50). Moreover, bearing in mind that our analysis relies on the PMG estimator, the one preferred by the data, we estimated a common threshold value for our sample of developing countries. Indeed, the robustness analysis shows that the PS threshold gravitates around the same value, both when we consider the potential cross-sectional dependence (see the CS-ARDL subsection), and when we relax the long-run slopes homogeneity assumption (see the AMG subsection). However, it would be interesting to see how the PS affects the CO2 emissions when different levels of PS index are assumed. On the one hand, complementary to the polynomial approach, the method we use allows us to check for nonlinearities in PS-CO2 emissions nexus. On the other hand, it gives us the possibility to examine how PS impacts CO2 emissions at specific PS index values and see if the findings match, to a certain extent, the polynomial approach.

According to Chudik et al. (2013) and Chudik et al. (2016), first, we estimate a classic homogeneous panel equation as follows

$$CO2_{it} = \mu_{\ddot{Y}} + \xi_{\ddot{Y}} I_{it}(\ddot{Y}) + e_{it}, \tag{14}$$

where the threshold dummy, $I_{it}(\ddot{Y})$, is constructed based on the indicator variable $I(PS_{it} \geq log\ddot{Y})$. Particularly, this indicator variable has the value 1 if the PS exceeds the specific value of the threshold, $\ddot{Y}$, and 0 otherwise. Also, $\mu_{\ddot{Y}}$ stands for the average CO2 emissions of economies with a PS index below the threshold value, $\ddot{Y}$. Besides, the above model is defined in such a way that (i) implies a universal threshold, $\ddot{Y}$, and (ii) assumes that for all states which have the PS exceeding the same threshold, the coefficients of the threshold dummy, $\xi_{\ddot{Y}}$, are identical.

Given that the mean (median) of PS composite index in our sample is roughly 55.64 (56.84), the minimum (maximum) is 9.75 (75), and the standard deviation is around 10, we consider a gap of 10 index points between the two consecutive values of $\ddot{Y}$. As such, we set the minimum equal to $\ddot{Y} = 25$ and the maximum equal to $\ddot{Y} = 65$, and estimate the equation (14) for every five thresholds assumed.

The results based on the pooled OLS (POLS) estimator are displayed in Table IV.13. On the one hand, we note that the magnitude of the estimated coefficient of $\mu_{\ddot{Y}}$ increases along with the values of $\ddot{Y}$ (see the second row of the Table IV.13). Thus, this result suggests the presence of important differences among the average CO2 emissions for countries that exceed the specific PS index threshold and those below the respective value. On the other hand, while the PS exhibits a positive impact on CO2 emissions, its magnitude declines along with the increase in the defined threshold value. Moreover, we note that the most substantial decrease in the coefficient magnitude corresponds to $\ddot{Y} \geq 55$, whereas a descending-plateau phase is visible between the PS values of about 45 and

55. As such, the POLS estimates indicate that a common global threshold occurs for the PS index value above 55, although some local thresholds are also at work. Overall, the findings highlight a turning point value quite comparable to the one revealed by the benchmark approach's core model, thus strengthening the initial findings.

Second, we relax the homogeneity assumption and allow the threshold dummy to impact the CO2 emissions differently, depending on the panel members (countries). Nonetheless, it is worth noting that the threshold keeps its universality condition, even if we assume slopes heterogeneity. The equation is written as follows

$$CO2_{it} = \mu_{i\ddot{Y}} + \xi_{i\ddot{Y}} I_{it}(\ddot{Y}) + e_{it}. \tag{15}$$

Table IV.14 illustrates the average estimates of $\mu_{i\ddot{Y}}$ and $\xi_{i\ddot{Y}}$, namely $\mu_{\ddot{Y}}$ and $\xi_{\ddot{Y}}$, following the MG approach. In terms of the signs associated with the variables' coefficients, the findings are similar to those of the POLS approach. Also, we can observe that the positive effect of PS on CO2 emissions is lower at both sides of the PS threshold value equal to 45. Indeed, this result is partially in line with the POLS approach estimates, which shows a decline in the magnitude of the threshold dummy coefficient around $\ddot{Y} \geq 55$. However, opposite to the case when we assume slopes homogeneity, both coefficients' magnitude is quite different. Besides, the threshold dummy coefficient is not statistically significant neither for the minimum nor maximum defined threshold value. Taken collectively, these findings may highlight, yet again, that the long-run slopes homogeneity assumption better fits the characteristics of our sample.

Third, we include along with the threshold dummy the other explanatory factors into the model, while we allow for potential dynamics and cross-sectional dependence in the data. Thus, we estimate the following modify version of equation (7)

$$CO2_{it} = \sum_{j=1}^{p} \partial_{ij} CO2_{it-j} + \sum_{j=0}^{q} \gamma'_{ij} x_{it-j} + \sum_{j=0}^{\pi} \omega'_{ij} \bar{z}_{t-j} + \xi_{i\ddot{Y}} I_{it}(\ddot{Y}) + \mu_{i\ddot{Y}} + u_{it}, \tag{16}$$

where all the terms are defined as in the previous equations.

Next, the ECM of the above specification is written as below

$$\Delta CO2_{it} = \phi_i(CO2_{it-1} - \theta_i' x_{it}) + \sum_{j=1}^{p-1} \delta_{ij}\, \Delta CO2_{it-j} + \sum_{j=0}^{q-1} \varphi_{ij}'\, \Delta x_{it-j}$$

$$+ \sum_{j=0}^{\pi} \omega_{ij}' \bar{z}_{t-j} + \xi_{i\ddot{Y}} I_{it}(\ddot{Y}) + \mu_{i\ddot{Y}} + u_{it}. \qquad (17)$$

In line with the preceding, we estimate the PMG scenario of the CS-ARDL approach, described in equation (17).[24] As such, this specification allows us to juxtapose the threshold findings following both methods and confront them. Likewise, we run the $ARDL(p = 1, q = 1)$ regression models, including only the contemporaneous cross-sectional averages of the variables.

Table IV.15 depicts the threshold CS-ARDL-PMG estimates. We notice that the threshold dummy coefficient decreases for larger values of $\ddot{Y}$, except for the last model (i.e. for a PS index equal or above the 65). Nonetheless, the associated threshold dummy coefficient has a statistically significant effect on CO2 emissions only for $\ddot{Y} \geq 35$ and $\ddot{Y} \geq 55$. Furthermore, and most importantly, its minimum value (i.e. -0.029) is attained for a threshold value above 55. Also, the PS variable positively impacts the CO2 emissions for all defined thresholds, except for $\ddot{Y} \geq 65$, where the effect seems to be negative. Therefore, the findings strongly indicate a global common threshold (which seems to lie somewhere above the 55 and below the 65 value of the PS index) beyond that political stability starts to reduce CO2 emissions. Indeed, these results support to a certain extent the previous ones, especially those unveil by the similar (CS)-ARDL approach that points out a turning point very close or above the PS index value of 55.

Table IV.13: Average long-run threshold effects estimates on CO2 [POLS estimator]

$\ddot{Y}$	**25**	**35**	**45**	**55**	**65**
$d_{\ddot{Y}}$	1.376***	1.171***	0.757***	0.709***	0.849***
	(0.223)	(0.118)	(0.082)	(0.061)	(0.090)
$\mu_{\ddot{Y}}$	-2.299***	-2.064***	-1.584***	-1.345***	-1.076***
	(0.221)	(0.113)	(0.074)	(0.041)	(0.034)
Groups	47	47	47	47	47
Observations	1025	1025	1025	1025	1025

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

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[24] Since we are mainly interested in the long-run coefficients, and also for brevity, we report their associated estimates and the ECT.

Table IV.14: Average long-run threshold effects estimates on CO2 [MG estimator]

$\ddot{\Upsilon}$	**25**	**35**	**45**	**55**	**65**
$d_{\ddot{\Upsilon}}$	0.013	0.081***	0.167***	0.121***	-0.019
	(0.011)	(0.031)	(0.034)	(0.044)	(0.035)
$\mu_{\ddot{\Upsilon}}$	-0.914***	-0.976***	-1.004***	-0.962***	-0.566**
	(0.172)	(0.175)	(0.175)	(0.173)	(0.228)
Groups	47	47	46	44	29
Observations	1025	1025	1179	1127	737

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table IV.15: Average long-run threshold effects estimates on CO2 [CS-ARDL-PMG estimator]

$\ddot{\Upsilon}$	**25**	**35**	**45**	**55**	**65**
$d_{\ddot{\Upsilon}}$	3.456	0.129***	0.005	-0.029***	0.010
	(4.258)	(0.033)	(0.010)	(0.006)	(0.008)
PS	0.167***	0.026	0.159***	0.182***	-0.089*
	(0.024)	(0.034)	(0.027)	(0.026)	(0.052)
GDP	0.310***	0.451***	0.308***	0.227***	0.782***
	(0.056)	(0.062)	(0.057)	(0.054)	(0.062)
RENG	0.039	-0.004	0.042	0.227***	0.017
	(0.040)	(0.032)	(0.041)	(0.067)	(0.037)
EINT	0.395***	0.462***	0.395***	0.311***	0.475***
	(0.041)	(0.041)	(0.041)	(0.039)	(0.053)
ECT	**-0.467*** **	**-0.475*** **	**-0.477*** **	**-0.457*** **	**-0.490*** **
	(0.057)	**(0.053)**	**(0.057)**	**(0.062)**	**(0.059)**
Groups	47	47	46	44	29
Observations	1138	1138	1113	1063	708

Notes: Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.5. Heterogeneity

So far, we unveiled that political stability exhibits a significant long-term nonlinear effect on CO2 emissions in our group of developing countries. Next, we investigate the presence of potential heterogeneities concerning the country's income level, Kyoto Protocol status, legal inheritance, and also with respect to alternative measures of pollution. Moreover, in line with the robustness section, given that we argue that the implications of political stability on environmental degradation are rather long-run phenomena, we focus on highlighting the associated findings.

IV.5.1. Level of economic development

Based on World Bank's (2018) classification, we split our sample into two subsamples, namely low income countries (LICs) and lower-middle income countries (LMICs). Table A-IV.1 in the Appendix gives information about the composition of each subgroup. Also, Table A-IV.4, along with Figure A-IV.8 and Figure A-IV.9, from the same Appendix, depicts the summary statistics and some stylized visual facts, respectively.

As shown in column (2) and (3) of Table IV.16, our hypothesis stands only for LICs, indicating that the relationship between PS and CO2 emissions is bell-shaped. As such, the CO2 emissions for LICs peak for a political stability index value at about 58.20 (in index points), which lies within the subsample PS index value range. However, the subgroup mean (i.e. 52.41) is below the threshold value, indicating that some states still need to improve their political stability in order to trigger a downward trajectory in CO2 emissions. For LMICs, we found no statistically significant link between variables in the quadratic specification. Next, to check the possibility of a linear relationship, we estimate the model by dropping the squared term of political stability. The results in column (4) of Table IV.16 indicate that political stability has a significant positive impact on CO2.

Concerning the long-term impact of the remaining variables, we note that EINT exerts the same positive effect on CO2 in both subsamples, while GDP and RENG have opposite signs depending on the income level subgroup. More specifically, in LICs, the economic growth (renewables) increases (decreases) CO2 emissions levels, while according to the linear specification, the vice-versa is at work for LMICs. Besides, the speed of adjustment to the long-run equilibrium seems to be about three times higher in the LICs subgroup, compared to LIMCs one.

First, the overall findings suggest positive environmental prospects for LICs countries, given that their future political stability is associated with a decrease in CO2, and the renewables also reduce the emissions levels. Second, for LMICs, the situation seems less optimistic, regarding both the effect of political stability and renewable energy on CO2. In this regard, the positive impact of PS on CO2 could indicate that eighter political stability needs to be enhanced in order to reach the associated threshold and/or its further levels may trigger a more relaxed attitude from decision-bodies in terms of environmental policy. Besides, the positive effect of renewable energy could be corroborated with the latter intuition, given that less pressure from decision-makers may suggest good environmental conditions and, thus, somewhat discourage the sustained implementation of green projects. In sum, particular attention should be given to political stability and renewables implications on environmental prospects in LMICs.

IV.5.2. Kyoto Protocol

We construct two subgroups according to the ratification or accession date of each country to the Kyoto Protocol. The first subgroup (KP1) corresponds to the states which ratified or acceded before the Protocol entered into force (i.e. year 2005), and the second subgroup (KP2) comprises the countries which ratified/acceded from 2005 onwards (see Table A-IV.18 in the Appendix). Some descriptive statistics related to each subsample are displayed in Table A-IV.4 in the Appendix, while Figures A-IV.8-9 provide some visual representations for the main variables.

Columns (3), (4a), and (4b) in Table IV.16 illustrate the related findings. First, we note that KP1 countries exhibit an inverted-U shaped pattern between CO2 emissions and political stability, consistent with the full sample results. Also, based on the estimated PS threshold, the CO2 emissions seem to start decreasing beyond the value of 52.67 (in index points). Compared to the main augmented model, the peak of CO2 pollution arises for a PS index value of about ten points lower. On the one hand, this may imply that the states that ratified or acceded before the Protocol entered into force have been involved earlier and more actively to combat global warming than their counterparts. On the other hand, the increasingly visible side effects of pollution could have made these countries much more willing to engage in mitigation and prevention activities.

Second, the estimates for KP2 economies reveal that the link between CO2 and political stability might be linear, considering that the PS index terms are not statistically significant in the quadratic specification. As such, further, we estimate the model by dropping the squared term of PS. Indeed, the estimates in column (4b) of Table IV.16 unveil a significant positive impact of political stability on CO2 emissions. Thus, in line with our previous reasoning for the KP1 countries' subgroup, these findings are somehow expected, as we would think the opposite for states which ratified or acceded to Protocol from 2005 onwards. However, similar to LMICs, these states need to pay more attention to the implications of political stability for the environment.

Regarding the control factors, the negative (positive) impact of renewable energy share for KP1 (KP2) may also support our previous intuition, indicating that the related projects are much more numerous and have produced the wanted outcomes, especially among the KP1 subsample countries. Moreover, GDP and energy intensity significantly and positively impact the CO2 emissions in both subgroups. Likewise, the error correction terms' coefficient shows a comparable speed of adjustment to the long-run equilibrium in both cases.

IV.5.3. Legal origin

The legal inheritance, such as common law (associated with former British colonies) and civil law (associated with former French colonies), strongly influences countries' political framework and plays an influential role in shaping the policies, including environmental related ones. On the one hand, as La Porta et al. (2008) emphasize, a strand of studies point out that concerning several domains (e.g. government ownership of banks, La Porta et al., 2002; the burden of entry regulations, Djankov et al., 2002; regulation of labor markets, Botero et al., 2004; the incidence of military conscription, Mulligan & Shleifer, 2005a, 2005b; and government ownership of the media, Djankov et al., 2003), the government and regulation prevail in civil law countries compared to common law ones. In other words, the civil law is more oriented towards policy implementation, while common law puts more emphasis on the market (La Porta et al., 2008). On the other hand, some authors (see e.g. Landes, 1998 and North et al., 2000) suggest that a higher quality of economic and political institutions is associated with the former British colonies than the French ones.

Consequently, based on LaPorta et al. (2008) database, we differentiate between countries with British and French legal origin system and run the regression models accordingly (the related summary statistics and stylized visual facts are illustrated in the Appendix by Table A-IV.4 and Figures A-IV.8-9, respectively). The results are displayed by the column (5), (6a), and (6b) in Table IV.16. First, according to the significance and signs of PS terms, for English legal origin countries, the relationship between CO2 emissions and PS seems to be bell-shaped [see the column (5) of Table IV.16]. Also, the PS threshold value beyond that the CO2 pollution may start to decrease is estimated at around 51.93 in index points (see the bottom of Table IV.16). Based on the PS index values for common law states, the estimated threshold is well within the sample range. However, the turning point's value remains below the subsample mean (i.e. 54.72), signaling that some common law economies do not achieve yet the PS value that would ensure a reduction in CO2 emissions.

Second, the column (6a) indicates that for civil law states, the squared term of PS variable does not exhibit statistical significance, suggesting a potential linear relationship between variables. In this regard, according to estimates of the linear model [see column (6b)], we find that the PS significantly increases the CO2 emissions in French legal origin economies. As such, even if we would intuitively think that in civil law states the environmental policies are more abundant than in common law ones, given their predisposition to policy implementation, the situation seems a bit different. Indeed, related to environmental policies, rather than their number, the associated stringency may have a much greater implication on the evolution of environmental conditions. Overall, this subgroup of countries (similar to LMICs and KP2 states), depending on the specific situation, could either put efforts to increase political stability or facilitate the adoption of more stringent policies in order to combat environmental degradation.

Table IV.16: Threshold estimates: heterogeneity [level of economic development, Kyoto Protocol, and legal origin]

Dependent variable: ΔCO2	**LICs**	**LMICs**		**KP1**	**KP2**		**British lo.**	**French lo.**	
	(1)	**(2a)**	**(2b)**	**(3)**	**(4a)**	**(4b)**	**(5)**	**(6a)**	**(6b)**
				Long-run estimates					
PS	3.368***	1.145	0.375*	6.069***	-5.980	0.381***	18.244***	0.014	0.301***
	(0.978)	(1.473)	(0.212)	(1.576)	(6.321)	(0.049)	(2.989)	(1.652)	(0.064)
PS^2	-0.414***	-0.106		-0.765***	0.708		-2.309***	0.028	
	(0.128)	(0.185)		(0.202)	(0.788)		(0.383)	(0.208)	
GDP	0.827***	0.807***	-0.551***	0.757***	1.157***	1.043***	-0.915***	0.910***	0.829***
	(0.100)	(0.053)	(0.151)	(0.069)	(0.152)	(0.141)	(0.181)	(0.049)	(0.059)
RENG	-0.218*	-0.000	0.778**	-0.123**	1.840***	1.206***	-1.935***	-0.056***	-0.076
	(0.120)	(0.032)	(0.364)	(0.052)	(0.492)	(0.310)	(0.232)	(0.020)	(0.048)
EINT	0.564***	0.932***	0.219*	0.826***	0.096	0.463***	-0.507***	0.693***	0.576***
	(0.071)	(0.068)	(0.119)	(0.067)	(0.133)	(0.096)	(0.136)	(0.062)	(0.063)
				Short-run estimates					
ECT	**-0.334*** **	**-0.171*** **	**-0.079** **	**-0.218*** **	**-0.112** **	**-0.181*** **	**-0.206** **	**-0.233*** **	**-0.218*** **
	(0.055)	**(0.038)**	**(0.032)**	**(0.044)**	**(0.047)**	**(0.057)**	**(0.088)**	**(0.034)**	**(0.030)**
ΔPS	-0.097	4.060	0.049	2.202	2.293	-0.024	-2.270	6.301	-0.014
	(4.445)	(4.994)	(0.067)	(4.866)	(2.545)	(0.042)	(5.708)	(5.150)	(0.082)
ΔPS^2	-0.015	-0.496		-0.277	-0.280		0.274	-0.792	
	(0.565)	(0.612)		(0.601)	(0.324)		(0.701)	(0.636)	
ΔGDP	1.261	0.660***	0.943***	0.472***	1.424***	1.748*	0.664***	1.204	1.263*
	(1.001)	(0.165)	(0.150)	(0.138)	(0.555)	(0.947)	(0.234)	(0.754)	(0.711)
ΔRENG	-1.648***	-1.179***	-1.237***	-1.021***	-3.034***	-2.540***	-1.672**	-1.003***	-1.041***
	(0.589)	(0.265)	(0.276)	(0.313)	(1.032)	(0.724)	(0.679)	(0.308)	(0.316)
ΔEINT	0.941	0.419***	0.554***	0.137	1.002*	1.496	0.507**	0.916	0.951
	(1.012)	(0.117)	(0.102)	(0.109)	(0.571)	(0.954)	(0.208)	(0.751)	(0.714)
C	-5.033***	-1.937***	-0.101**	-4.419***	-0.649**	-3.107***	-4.369**	-2.242***	-2.065***
	(0.839)	(0.430)	(0.047)	(0.927)	(0.278)	(0.979)	(1.884)	(0.330)	(0.298)
Log Likelihood	785.1082	1308.808	1274.593	1474.793	603.919	606.3391	738.6285	1254.098	1212.757
Groups	20	27	27	32	15	15	16	29	29
Observations	480	658	658	763	375	375	390	698	698
Pattern	bell-shaped		increasing	bell-shaped		increasing	bell-shaped		increasing
PS turning point (Ÿ)	4.06398			3.96415			3.94992		

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The value of turning point is expressed in log. ”lo.” stands for legal origin. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Finally, for both samples, ECT's coefficient is negative and strongly significant, indicating that the empirical technique fits the data characteristics, and the estimates present a high accuracy. Also, the coefficient's absolute value is around 0.2 in both cases, but slightly higher for the French legal origin sample. Thus, if a potential exogenous shock will alter the system, the CO2 variable will help adjust the system to the long-term equilibrium with a roughly similar adjustment speed for both subsamples. Moreover, the GDP and EINT have a positive long-run impact on CO2 emissions for civil law countries, while the opposite holds for common law ones. Likewise, the RENG seems to contribute to reducing the CO2 pollution in the long-run for both subgroups of states, but the magnitude of the impact is much higher in common law one.

IV.5.4. Alternative measures of pollution

To evaluate how other types of environmental degradation indicators respond to political stability impact in our sample of developing countries, we focus on a set of local and global pollutants (see Tables A-IV.2-3 in the Appendix for their definitions and some summary statistics). On the one hand, we consider five well-known local pollutants, namely the PM2.5 under three variations (bio, fossil, and their summation), PM10, and SO2 emissions per capita. Since the local pollutants are more extensively regulated on a national level, the regulatory measures might have a more extended history compared to global pollutants. Thus, we expect the threshold to be reached for a lower level of PS composite index or to observe distinct patterns between indicators.

On the other hand, we also focus on two neoteric and comprehensively global pollution measures, namely the per capita ecological footprint and biocapacity (see Table A-IV.2 in Appendix for variable details). With respect to a specific country, the former indicator captures the demand side of nature, namely the amount of nature required to support the economy. Conversely, the latter refers to the supply side of nature, namely, the economy's capacity to generate mainly natural resources and absorb the waste. Therefore, an ecological deficit is at work when a country's ecological footprint surpasses its biocapacity, putting in other words, the respective country is biocapacity debtor.

The estimations in Table IV.17 illustrate the following. First, the bell-shaped model emerges only for PM2.5bio, indicating a similar result to that revealed for CO2. However, the peak in PM2.5io arises for a political stability index value estimated at 53.18, which is more than ten points lower than its counterpart in the CO2 model. According to this finding, almost all the countries (with the notable exception of Democratic Republic of

Congo and Haiti) included in our analysis surpass the threshold, given that the individual PS maximum value is higher than the threshold one. Moreover, the situation seems to be a bit different for the other local pollutants, and the future political stability may be associated with higher CO2, given that the relationship is eighter U-shaped (PM2.5fossil, PM2.5, and PM10) or monotonically increasing (SO2). In this regard, the computed trough for the U-shaped curve occurs for a PS index value at about 43.75 for PM2.5 fossil, 25.87 for PM2.5, and 50.97 for PM10. Overall, our expectations are somehow confirmed, given that the results may indicate that the policies and regulations aimed at mitigating local pollutants have been presumably implemented more frequently even in developing states and, thus, proved to be effective much faster. Nonetheless, they must be continuously adapted to cope with the changing needs, and careful attention should be paid to local pollutants for which an increase in political stability is associated with an intensification of their future emissions. Indeed, in this regard, it may be the case that their reinforcement is trigger by a more lax regulatory setting, among others.

Second, political stability exerts a significant negative impact both on ecological footprint and biocapacity. Taken together, these two results seem to oppose each other, implying that a stable political system may contribute in reducing the quantity of nature (e.g. land and water) needed to produce the goods and assimilate the waste, but that it also may hinder the increase of natural resources' share and waste absorption. Likewise, based on our estimates, the magnitude of political stability's negative effect seems slightly higher for biocapacity than the ecological footprint. Thus, increased attention should be paid at the implications of political stability on countries' ecological reserve, considering that a sharp decline in countries' biocapacity can cause an unwanted ecological deficit.

Table IV.17: Threshold estimates: heterogeneity [alternative measures of pollution]

Dependent variable:	**ΔPM2.5bio**	**ΔPM2.5fossil**	**ΔPM2.5**	**ΔPM10**	**ΔSO2**	
	(1)	**(2)**	**(3)**	**(4)**	**(5a)**	**(5b)**
			Long-run estimates			
PS	0.876***	-3.097***	-0.677**	-1.316***	0.896	0.094***
	(0.308)	(0.915)	(0.324)	(0.349)	(0.919)	(0.035)
PS^2	-0.110***	0.409***	0.104**	0.167***	-0.095	
	(0.040)	(0.117)	(0.043)	(0.045)	(0.119)	
GDP	0.573***	1.108***	0.755***	0.936***	1.233***	0.721***
	(0.027)	(0.056)	(0.025)	(0.026)	(0.039)	(0.074)
RENG	0.701***	0.088***	0.671***	0.767***	0.187***	0.213***
	(0.028)	(0.029)	(0.032)	(0.025)	(0.037)	(0.043)
EINT	0.430***	0.830***	0.611***	0.859***	0.867***	0.565***
	(0.028)	(0.069)	(0.026)	(0.027	(0.051)	(0.063)
			Short-run estimates			
ECT	**-0.248*** **	**-0.192*** **	**-0.203*** **	**-0.165*** **	**-0.264*** **	**-0.287*** **
	(0.043)	**(0.032)**	**(0.040)**	**(0.037)**	**(0.038)**	**(0.038)**
ΔPS	7.266	0.113	11.041	10.268	-2.211	-0.033
	(14.090)	(2.749)	(14.162)	(11.612)	(5.590)	(0.074)
ΔPS^2	-0.970	-0.022	-1.431	-1.319	0.256	
	(1.784)	(0.339)	(1.801)	(1.479)	(0.696)	
ΔGDP	0.461***	0.186	0.459***	0.501***	1.030**	1.333**
	(0.133)	(0.290)	(0.113)	(0.179)	(0.499)	(0.535)
ΔRENG	0.085	-1.899***	0.022	0.212	-0.537	-0.420
	(0.121)	(0.683)	(0.117)	(0.173)	(0.377)	(0.366)
ΔEINT	0.056	-0.162	0.144*	0.282*	1.204**	1.273**
	(0.105)	(0.271)	(0.087)	(0.157)	(0.515)	(0.552)
C	-5.554***	-3.894***	-4.303***	-3.522***	-7.151***	-6.050***
	(0.965)	(0.659)	(0.843)	(0.803)	(1.031)	(0.795)
Log Likelihood	2397.206	1572.364	2396.599	2500.685	1406.373	1352.78
Groups	47	47	47	47	47	47
Observations	997	997	997	997	997	997
Pattern	bell-shaped	U-shaped	U-shaped	U-shaped		increasing
PS turning point (Ÿ)	3.97379	3.78601	3.25344	3.93129	3.07779	

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The analyzed period is 1990-2012 for all the local pollutants (i.e. PM2.5bio, PM2.5fossil, PM2.5, PM10, and SO2). Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

(**Table IV.17:** continued)

Dependent variable:	**ΔECOFT**		**ΔBIOCAP**	
	(6a)	**(6b)**	**(7a)**	**(7b)**
		Long-run estimates		
PS	0.359	-0.070***	-1.142*	-0.084***
	(0.471)	(0.023)	(0.645)	(0.026)
PS^2	-0.056		0.130	
	(0.061)		(0.082)	
GDP	0.437***	0.457***	-0.058	-0.085*
	(0.017)	(0.019)	(0.042)	(0.047)
RENG	-0.152***	-0.140***	0.134***	0.107***
	(0.017)	(0.017)	(0.028)	(0.030)
EINT	0.116***	0.143***	0.058*	0.059
	(0.017)	(0.021)	(0.033)	(0.037)
		Short-run estimates		
ECT	**-0.354*****	**-0.354*****	**-0.204*****	**-0.191*****
	(0.047)	**(0.046)**	**(0.045)**	**(0.043)**
ΔPS	2.273	0.000	-1.313	-0.041
	(1.944)	(0.060)	(2.632)	(0.072)
ΔPS^2	-0.281		0.153	
	(0.241)		(0.322)	
ΔGDP	0.512***	0.479***	0.486***	0.494***
	(0.124)	(0.117)	(0.130)	(0.123)
ΔRENG	-0.129	-0.135	0.056	0.067
	(0.164)	(0.162)	(0.103)	(0.097)
ΔEINT	0.107	0.086	-0.130	-0.141
	(0.107)	(0.104)	(0.104)	(0.097)
C	-1.215***	-1.021***	0.420***	0.041*
	(0.162)	(0.135)	(0.103)	(0.023)
Log Likelihood	2143.038	2123.225	2811.869	2773.23
Groups	47	47	47	47
Observations	1135	1135	1135	1135
Pattern		deceasing		decreasing
PS turning point ($\ddot{Y}$)				

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. The analyzed period is 1990-2012 for all the local pollutants (i.e. PM2.5bio, PM2.5fossil, PM2.5, PM10, and SO2). Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

IV.6. Country-specific analysis

According to the aggregate findings, the relationship between CO2 emissions and political stability follows a bell-shaped pattern. To identify potential heterogeneities among the states in our sample, we explore the CO2-PS nexus at the country-specific level. In this fashion, we rely on the novel AMG estimator in its dynamic version, the best option considering our sample's characteristics. As such, the approach allows us to capture the long-term relationship between variables for each country while mitigating the potential effects of cross-sectional dependence and persistence in CO2 emission, through the inclusion of the common dynamic process and the lag value of the dependent variable, respectively.

IV.6.1. Estimates, turning points, and patterns

First, Table IV.18 displays the estimations that assume a quadratic relationship between CO2 emissions and political stability. Based on the findings, the coefficients associated with PS terms exhibit statistical significance for more than half of the states, for which the quadratic function holds. In particular, our estimates unveil a bell-shaped pattern in Angola, Bangladesh, Bolivia, Guinea-Bissau, Honduras, Madagascar, Malawi, Mali, Myanmar, Niger, Sierra Leone, Sri Lanka, Togo, Uganda, and Vietnam, suggesting that these countries achieved the turning point of political stability that would ensure a decline in CO2 pollution. Conversely, for Morocco, Mozambique, Papua New Guinea, Tunisia, and Yemen, further political stability levels may be associated with an increase in CO2 emissions, given that the relationship between CO2 and PS seems to be U-shaped.

To have a clearer picture of the relationship between the variables and better comprehend the potential differences in its magnitude across the states, we compute both the associated threshold (see the last column of Table IV.18) and represent the estimated relationship graphically (see Figure IV.3). One the one hand, for the economies that display a bell-shaped pattern, we observe that the peak in CO2 emissions occurs for an estimated value of PS index between roughly 44 and 65 (in index points). In particular, the lowest PS threshold for which the CO2 pollution may switch its trend is found in Myanmar and has a value of around 44, while the highest is around 65 and is encountered in Malawi. Moreover, for half of the countries which exhibit the bell-shaped pattern, the CO2 peak emerges for a computed PS threshold value between roughly 44 and 49. These states, according to their estimated PS turning point, in the ascending order are Myanmar (44), Togo (45), Uganda (45), Bangladesh (47), Sierra Leone (47), Sri Lanka (48), and Angola (49). Also, for five of the remaining states, the CO2 peak for a PS value computed at around 55 for Bolivia, 52 for Guinea-Bissau, 55 for Madagascar, 54 for Mali, and 54 for Niger. At the same time, three states achieve the CO2 peak for a PS index value at around 62 (Honduras and Vietnam) or 65 (Malawi). Regarding the U-shaped patterns, only for Tunisia, the U-shaped curve's trough arises at a PS value that exceeds 60 points. The other states that exhibit a convex shape between variables passed the threshold for a PS index value estimated at around 59 (Morocco), 52 (Mozambique), 58 (Papua New Guinea), and 59 (Yemen).

Second, for the countries where the coefficients of political stability terms are not statistically significant, we assume a linear relationship. As such, the results in Table IV.19 point out a monotonically increasing link between PS and CO2 for ten countries (namely: Cameroon, El Salvador, Haiti, Mongolia, Nigeria, and Zambia), and a negative one for the Republic of the Congo. The remaining countries included in the sample show no statistically significant relationship between CO2 emissions and political stability (see Table IV.19 for more details).

Overall, we observe that the differences in countries with a significant quadratic link between CO2 and PS are not too pronounced since, considering the PS intervals, most countries' estimated threshold gravitate, more or less, within the same interval. This could also be seen more easily from the country-specific charts in Figure IV.3. However, bearing in mind the much wider range of individual patterns unveiled (i.e. bell-shaped, U-shaped, decreasing, increasing, and no statistically significant link), it seems that the aggregate bell-shaped pattern does not prevail at the disaggregated level. Although the countries belong to the same low and lower-middle income and Kyoto Protocol broad group, and have the same general long-term goals, such as fostering political stability and economic development, while maintaining environmental sustainability, the findings indicate that significant individual heterogeneities are present among them.

For example, regarding the Kyoto Protocol, a source of these heterogeneities may be given by the uneven coverage and the diversity of projects that have been implemented among the developing countries via the Clean Development Mechanism (CDM) by the

Annex I parties.[25] On the one hand, it is worth remembering that many developing countries were quite skeptical about the CDM and even opposed its introduction (Carbon Trust, 2009).[26] As such, this probably had more repercussions concerning the desired uniform implementation. On the other hand, the reverse may also be possible, as the developed nations may focus more extensively on the developing countries where political stability is higher to avoid any inconvenience that may arise during the process. In addition, the flexibility of the mechanism allows industrialized economies to implement projects to reduce emissions where the costs are the lowest (Carbon Trust, 2009). Nonetheless, beyond any global mechanism, it is up to each country to establish the timing, means of action, and intensity of the fight against climate change.

Table IV.18: Country-specific estimates [quadratic specification]

Dependent variable: CO2

	PS		**PS²**		**PS turning point** (Ÿ)
	Coef.	**Std. err**	**Coef.**	**Std. err**	
Angola	*13.275**	*(6.946)*	*-1.699**	*(0.906)*	*3.9053 (49.664 pts.)*
Bangladesh	*7.964****	*(2.785)*	*-1.030****	*(0.363)*	*3.86561 (47.732 pts.)*
Bolivia	*29.956***	*(15.349)*	*-3.683***	*(1.867)*	*4.06643 (58.348 pts.)*
Burkina Faso	6.132	(8.416)	-0.765	(1.059)	
Cameroon	-4.544	(34.249)	0.687	(4.210)	
Congo, Dem. Rep.	6.363	(7.211)	-0.900	(1.059)	
Congo, Rep.	11.086	(31.169)	-1.516	(4.007)	
Cote d'Ivoire	-5.065	(4.599)	0.665	(0.581)	
Egypt, Arab Rep.	8.696	(5.923)	-1.064	(0.735)	
El Salvador	-0.005	(3.724)	0.028	(0.467)	
Ethiopia	2.927	(2.206)	-0.392	(0.309)	
Gambia	10.167	(8.578)	-1.246	(1.039)	
Ghana	30.502	(35.068)	-3.656	(4.264)	
Guinea	-15.794	(14.195)	2.031	(1.819)	
Guinea-Bissau	*45.246****	*(17.248)*	*-5.700****	*(2.182)*	*3.96863 (52.911 pts.)*
Haiti	-2.550	(3.497)	0.360	(0.477)	
Honduras	*21.232**	*(11.620)*	*-2.569**	*(1.429)*	*4.1314 (62.265 pts.)*
India	-0.133	(0.658)	0.021	(0.084)	
Indonesia	-0.153	(3.043)	0.020	(0.380)	
Kenya	11.942	(11.710)	-1.490	(1.441)	
Liberia	3.435	(3.803)	-0.436	(0.494)	
Madagascar	*18.228***	*(8.326)*	*-2.274***	*(1.030)*	*4.00794 (55.033 pts.)*
Malawi	*16.008****	*(6.160)*	*-1.915****	*(0.747)*	*4.17902 (65.301 pts.)*
Mali	*12.425***	*(5.016)*	*-1.551***	*(0.640)*	*4.00542 (54.894 pts.)*

Notes: Local extrema are computed using the first derivative of CO2 with respect to PS. All reported estimated PS threshold values are in the range of observed PS index for each country. "pts." stands for points, the measure unit of PS composite index. RMSE denotes the Root Mean Square Error. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

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[25] The Annex I countries represent the developed nations which signed the Protocol and have binding commitments to reduce or limit their greenhouse gas emissions.

[26] Accessed at https://prod-drupal-files.storage.googleapis.com/documents/resource/public/Global%20Carbon%20Mechanisms%20-%20Emerging%20Lessons%20And%20Implications%20-%20REPORT.pdf.

(**Table IV.18:** continued)

Dependent variable: CO2					
	PS		**PS^2**		**PS turning point** (Ÿ)
	Coef.	**Std. err**	**Coef.**	**Std. err**	
Moldova	15.221	(19.869)	-1.857	(2.392)	
Mongolia	3.865	(27.625)	-0.341	(3.274)	
Morocco	*-11.969***	*(6.051)*	*1.464***	*(0.735)*	*4.08757 (59.594 pts.)*
Mozambique	*-29.283****	*(10.244)*	*3.690****	*(1.275)*	*3.96796 (52.876 pts.)*
Myanmar	*7.241****	*(2.828)*	*-0.952***	*(0.382)*	*3.80109 (44.749 pts)*
Nicaragua	1.753	(4.531)	-0.215	(0.567)	
Niger	*33.464**	*(20.446)*	*-4.193**	*(2.537)*	*3.99015 (54.062 pts.)*
Nigeria	6.696	(10.274)	-0.811	(1.339)	
Pakistan	-0.546	(0.946)	0.073	(0.123)	
Papua New Guinea	*-84.118***	*(37.753)*	*10.328***	*(4.632)*	*4.07201 (58.674 pts.)*
Philippines	-3.295	(3.189)	0.426	(0.398)	
Senegal	15.589	(44.529)	-1.934	(5.512)	
Sierra Leone	*5.179****	*(1.223)*	*-0.671****	*(0.163)*	*3.85801 (47.370 pts.)*
Sri Lanka	*11.038****	*(4.997)*	*-1.419****	*(0.645)*	*3.88893 (48.858 pts.)*
Tanzania	10.370	(66.525)	-1.215	(8.065)	
Togo	*49.028****	*(16.887)*	*-6.347****	*(2.189)*	*3.8261 (45.883 pts.)*
Tunisia	*-13.806****	*(7.727)*	*1.670****	*(0.925)*	*4.1319 (62.296 pts.)*
Uganda	*13.315****	*(7.008)*	*-1.741****	*(0.912)*	*3.82383 (45.779 pts.)*
Ukraine	9.249	(27.394)	-1.135	(3.309)	
Vietnam	*16.808***	*(6.701)*	*-2.029***	*(0.820)*	*4.1407 (62.846 pts.)*
Yemen, Rep.	*-35.784****	*(6.007)*	*4.377****	*(0.744)*	*4.0876 (59.596 pts.)*
Zambia	-0.871	(6.344)	0.149	(0.781)	
Zimbabwe	1.532	(3.551)	-0.206	(0.455)	
Control			Yes		
CDP			Yes		
Lag(CO2)			Yes		
RMSE	0.0456				
Groups	47				
Observations	1142				

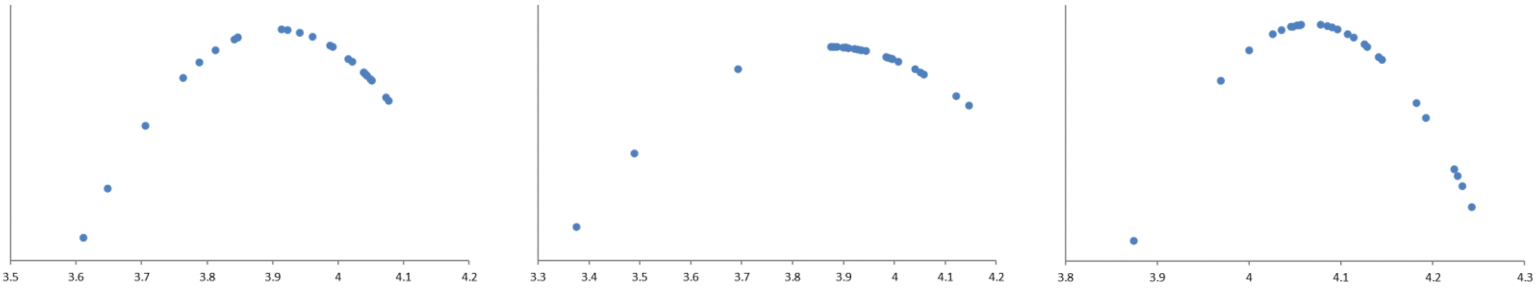
Notes: Local extrema are computed using the first derivative of CO2 with respect to PS. All reported estimated PS threshold values are in the range of observed PS index for each country. ”pts.” stands for points, the measure unit of PS composite index. RMSE denotes the Root Mean Square Error. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Table IV.19: Country-specific estimates [linear specification]

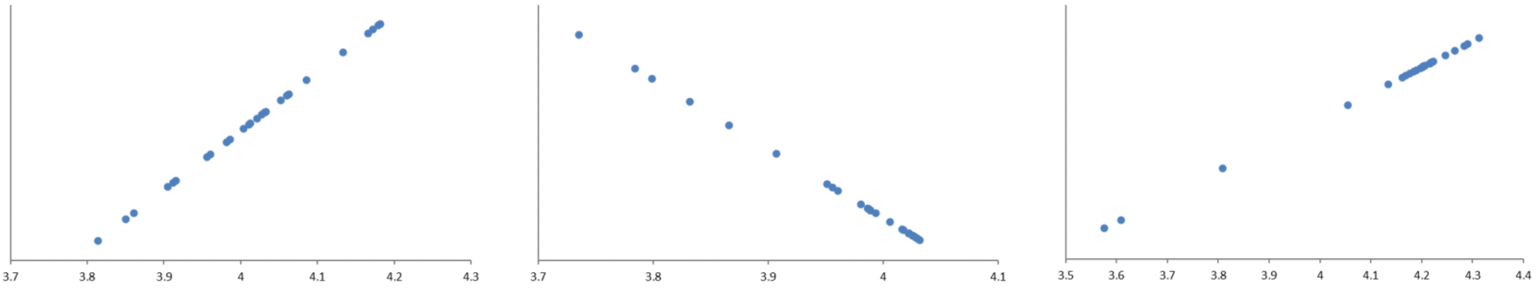
Dependent variable: CO2		
	PS	
	Coef.	**Std. err**
Burkina Faso	0.147	(0.236)
Cameroon	_1.150**_	_(0.455)_
Congo, Dem. Rep.	0.117	0.251
Congo, Rep.	_-0.595*_	_(0.320)_
Cote d'Ivoire	0.120	(0.154)
Egypt, Arab Rep.	0.083	(0.073)
El Salvador	_0.202*_	_(0.117)_
Ethiopia	0.116	(0.091)
Gambia	-0.144	(0.140)
Ghana	0.432	0.306
Guinea	-0.026	(0.223)
Haiti	_0.221*_	_(0.126)_
India	0.034	(0.017)
Indonesia	-0.007	(0.049)
Kenya	-0.192	(0.144)
Liberia	0.108	(0.110)
Moldova	-0.188	(0.106)
Mongolia	_0.925**_	_(0.374)_
Nicaragua	0.081	(0.092)
Nigeria	_0.563***_	_(0.192)_
Pakistan	0.007	(0.025)
Philippines	0.229	(0.163)
Senegal	0.027	(0.395)
Tanzania	0.318	(0.450)
Ukraine	-0.126	(0.224)
Zambia	_0.357***_	_(0.115)_
Zimbabwe	-0.012	(0.125)
Controls	Yes	
CDP	Yes	
Lag(CO2)	Yes	
RMSE	0.0496	
Groups	27	
Observations	651	

Notes: RMSE denotes the Root Mean Square Error Standard errors in brackets.
***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

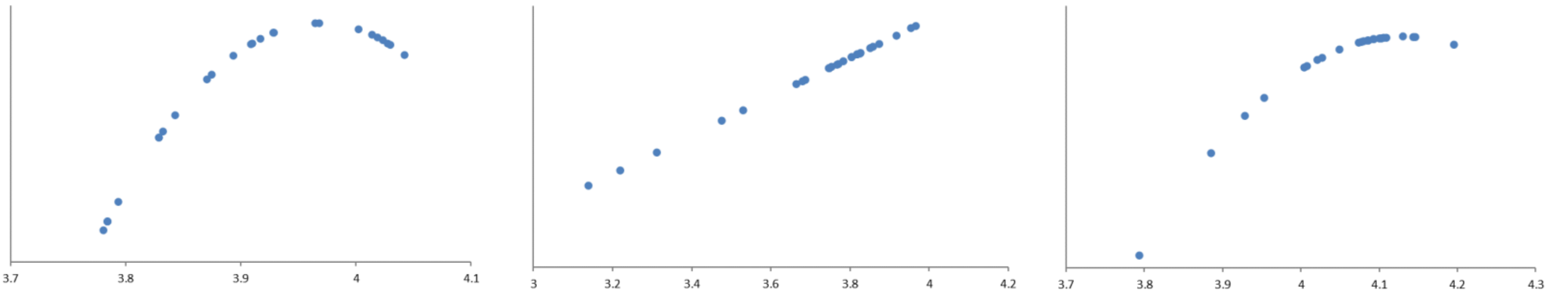
Figure IV.5: The estimated relationship between PS and CO2 [country analysis]



Angola Bangladesh Bolivia

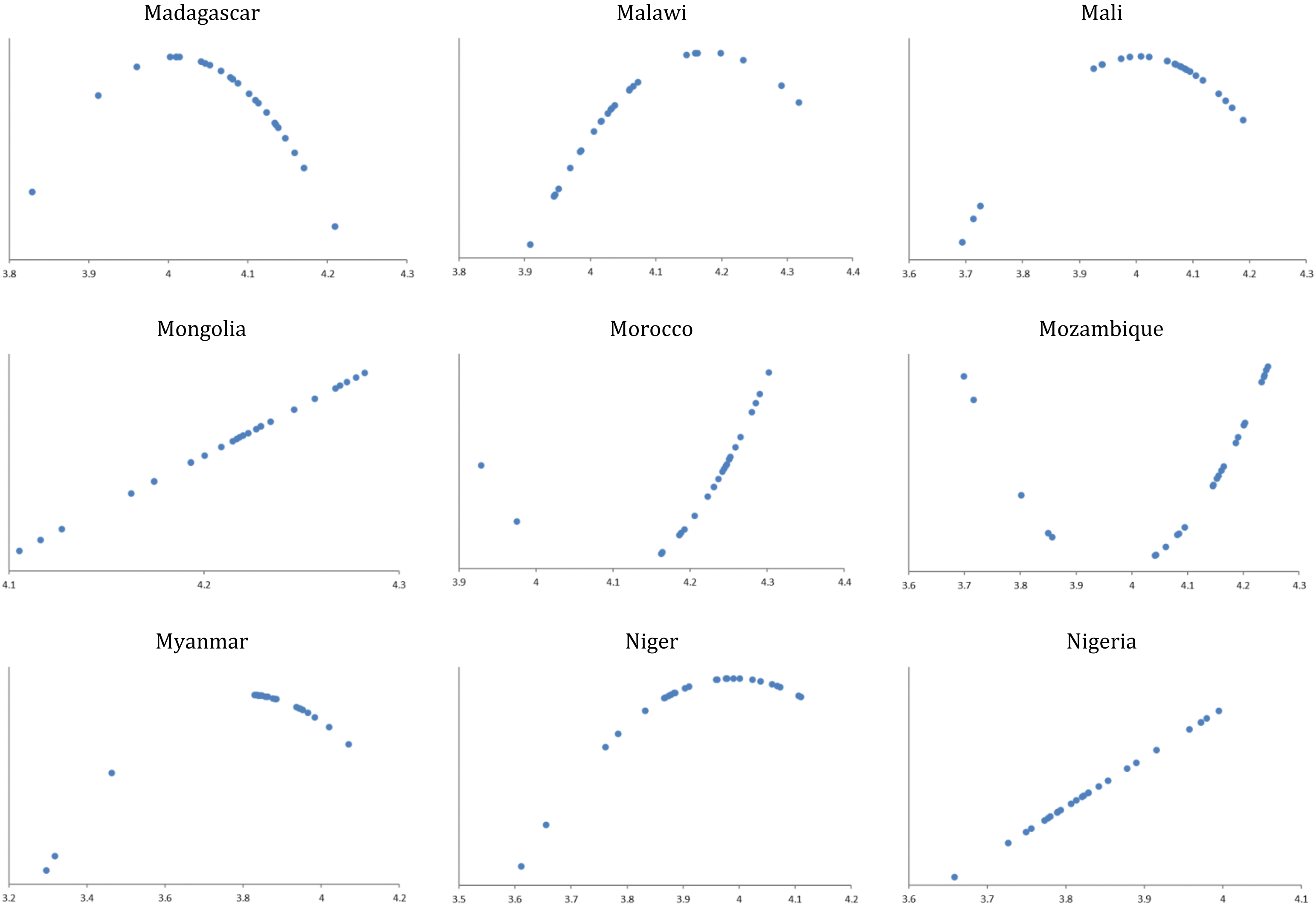


Cameroon Congo, Rep. El Salvador

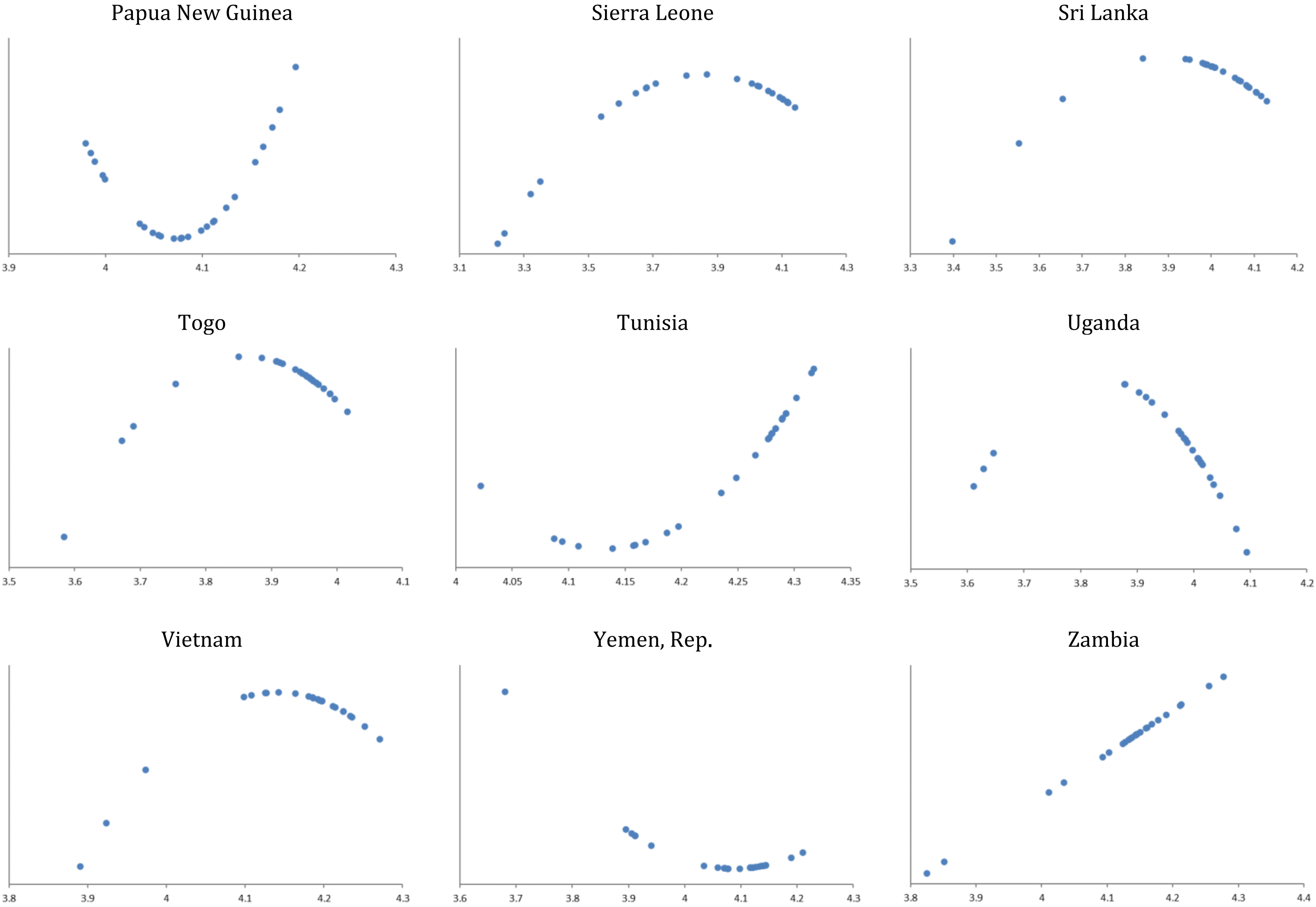


Guinea-Bissau Haiti Honduras

(**Figure IV.5:** continued)



(**Figure IV.5:** continued)


Papua New Guinea

Sierra Leone

Sri Lanka

Togo

Tunisia

Uganda

Vietnam

Yemen, Rep.

Zambia

IV.6.2. Discussion

The country-specific analysis unveils a broad diversity of patterns (see Figure IV.3) in the relationship between CO2 and political stability at the disaggregated level. Thus, it would be interesting to look more in-depth at the states associated with a similar increasing or decreasing behavior for large PS values, to see if specific patterns emerge. In the following, for the newly created subgroups (i.e. the first one which comprises all the states that exhibits a bell-shaped or monotonically decreasing pattern, and the second one in which we include the states associated to a U-shaped or monotonically increasing relationship between the CO2 and PS) we expose the conclusions we have drawn based on a descriptive examination[27] of the structural characteristics with respect to different groups' composition criteria and some macro indicators used previously in the analysis.

The findings related to subgroups' composition criteria, namely the income level, legal inheritance, and Kyoto Protocol signature status, are as follows. First, among the countries that display a bell-shaped or monotonically decreasing pattern, about half of them belong to the low income subsample, have a French legal origin, and/or ratified or acceded to the Kyoto Protocol from 2005 onwards, while for the other half the vice-versa holds—they are lower-middle income economies with a common law legal inheritance which ratified or acceded to the Kyoto Protocol before it entered into force. Therefore, according to the smaple's structural criteria mentioned above, it seems very unlikely to draw some appropriate conclusions. Second, concerning the second subgroup of economies where the CO2-PS nexus pattern is eighter U-shaped or monotonically increasing, we note that almost all states belong to lower-middle income subsample, except Haiti and Mozambique. However, Haiti and Mozambique have in common the civil law legal inheritance, and they are also low income economies that adhered to or acceded to the Kyoto Protocol after it entered into force. Overall, based on the subgroups' structural analysis, we did not obtain sufficient information, which motivates us to

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[27] We note that the conclusions drawn following the descriptive examination should be treated with much caution, given that they provide only elementary information regarding potential common features that certain countries share. Besides, having in mind the large group of states under examination and their different geographical regions, becomes quite challenging to distinguish large clusters. However, this simple analysis may give us a first intuition of the CO2-PS nexus diversity sources. Indeed, a more in-depth analysis of each country's economic structure and its domestic policies, among others, may provide further insights, but we let this for future research as it goes beyond the present study scope.

proceed further and look at some macro indicators' descriptive statistics over the period 1990-2015.

Consequently, we consider the mean and median value of the variables added as further controls in subsection 4.2, along with the PS composite index elements, and compare their relative ranking of the individual country results across the newly created subgroups. We use both central tendency measures to mitigate the outliers' potential impact, all the more that the states included in the two subgroups cover five distinct geographical regions. Besides, we report the results only for variables for which we observe specific patterns, namely the share of agriculture in GDP, the share of industry in GDP, the unemployment rate, the globalization index, the share of forest rents in GDP, and the military in politics component of the PS index (see Tables A-IV.6-17 in the Appendix).

On the one hand, the nine economies of the first subgroup occupy the first places regarding the highest average share of agriculture in GDP, while according to the average share of industry, ten states of the same first subgroup have the first lowest values.[28] Besides, what is quite interesting is the opposite position of Angola and the Republic of Congo against the other subgroup members, with respect to both agriculture and industry indicators. More specifically, these two states are ranked last (first) regarding the average agriculture (industry) share in GDP. Furthermore, completing the above findings, for the average unemployment rate, we observe the same behavior. Twelve members of the first subgroup are classified among the states with the lowest average unemployment rate over the period 1990-2015 (with the average rate ranging between roughly 1.03—Myanmar and 4.41—Guinea-Bissau), while Angola and Republic of the Congo exhibit the largest rate (i.e. around 17) followed by five countries belonging to the second subgroup. These differences displayed by Angola and the Republic of Congo compared to members of the same subsample could be related to their oil sector, which drives not only the exports and government revenues but also the overall economy [Central Intelligence Agency (CIA), The World Factbook, 2020].[29] Besides, Angola is a member of the Organization of the Petroleum Exporting Countries (OPEC) and also a diamond exporter, while both states are located in Africa and share a common border.

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[28] Except Mozambique, which is also included among these ten countries.

[29] Accessed at https://www.cia.gov/library/publications/resources/the-world-factbook/.

On the other hand, regarding the globalization index, the first six countries with the lowest mean value belong to the first subgroups, while the first three with the highest average belong to the second one. It is also worth noting that thirteen states of the first group are ranked among those with the lowest average of globalization—this value ranging from 29.13 to 45.70. Concerning the largest average share of forest rents in GDP, the first positions are taken by nine economies of the first subsample[30], while the first three countries with the lowest average share belong to the second subsample. From the PS index elements only for one, namely military in politics, there seems to be a certain cluster. In particular, for fifteen countries out of nineteen classifieds with the lowest average value belong to the first subgroup, while the first eight (excluding Malawi) have the highest average and belong to the second subgroup. Putting differently, across the members of the first subgroup, the military's participation in politics seems to be greater; thus, the political risk may be higher compared to the economies of the second group.

Overall, these simple descriptive findings may suggest that the decreasing trend in CO2 pollution for further increase in political stability may be associated especially to more agrarian economies with a large share of forest rents, where the industry sector is not yet much developed. Indeed, it is generally acknowledged that a considerable amount of CO2 emissions result from the industry sector, especially when it is at the height of development since the economic processes are becoming more and more intense. This may corroborate with a lower degree of political stability, assuming that during industrialization, the ongoing privatization process may induce distortions in the government's proper functioning and increase the business risks. Thus, in economies where the agricultural sector exceeds the industrial one, political stability may be higher, triggering a decrease in pollution. With regard to forest rents, a high share may favor allocating more resources for various beneficial purposes, including environmental sustainability. Also, the rents are usually divided between the private and public sectors, thus, a satisfactory amount can minimize the risk of conflicts that may arise between them.

Besides, most of these states seem to have both a relatively low unemployment rate and globalization degree, while the military's implication in politics is high. On the

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[30] Likewise, Mozambique is the one exception ranked among them, based on the average share of forest rents.

one hand, low unemployment could be explained in relation to agriculture-oriented economies, where most people work on their land. On the other hand, in poor economies, people are more willing to work under any conditions to secure an income and support their lives. As such, the population is unlikely to easily engage in strikes, among other forms of demonstrations, against the government. Likewise, globalization implies that countries are more open up to trade and foreign investments. Thus, a greater globalization degree may trigger foreign pressures such as diplomatic conflicts, trade barriers, economic pressure from the investors, various other sanctions and restrictions, and in the worst cases, may also induce territorial conflicts. In terms of military forces, their intervention in politics is often meant to secure overall stability. However, a systematic military intervention is likely to raise corruption levels across the governance framework. In the first scenario, the political stability may act against pollution, thus, lowering its levels. In the second one, when the corruption degree becomes very high, the reported emissions levels may be underestimated; therefore, we would only notice an apparent decrease in environmental pollution.

IV.7. Conclusion, and policy implications

Environmental degradation and political stability are two of the most well-debated topics in the sphere of macroeconomics, which potentially have significant consequences on society's welfare. The events of the last ten-twenty years have shown that poorer countries are more prone to political conflicts, while, quite often, they are more violent than those in developed nations. Political stability is at the core of many economic implications, including the environmental sustainability ones. According to empirical research in the field, the findings are still inconclusive concerning the pollution-political stability nexus. Also, the vast majority of studies focused on the impact of corruption and other institutional quality proxies on environmental degradation, predominantly in developed nations, whereas the evidence for developing states remains incomplete.

This paper shed light on the impact of political stability on CO2 pollution in a sample of 47 developing countries spanned over 1990-2015. More specifically, we examined a potential political stability threshold effect on CO2 emissions by controlling simultaneously for the size of the economy, the technological progress, the stringency of environmental regulations, and the states' energy efficiency and energy conservation status. In doing so, we relied on the PVECM technique, which allowed us to control for the presence of short-run heterogeneities across panel members while considering a common long-term path.

Aggregated results supported our hypothesis and revealed a long-term, bell-shaped pattern between political stability and CO2 emissions, robust to several alternative specifications. Thus, political stability starts to reduce CO2 pollution beyond a certain political stability threshold is reached. In this regard, judging based on the range of political stability index values, some countries in our sample still have to improve their political stability condition to be environmentally effective. Moreover, we unveiled significant heterogeneities in CO2 emissions-political stability nexus in terms of countries' income level, Kyoto Protocol status, legal inheritance, and for alternative measures of pollution. First, the political stability is found to increase CO2 pollution in (i) lower-middle income states, (ii) for states which ratified or acceded to the Kyoto Protocol from 2005 onwards, and (iii) for the civil law economies. Second, an inverted-U pattern is at work for their counterparts subsamples, namely for low income countries, those who ratified or acceded to the Kyoto Protocol before it entered into force, and British legal origin economies. Finally, the estimates emphasized a series of patterns such as a bell-shape, inverted-U, or a monotonically decreasing link, when considering an extensive set of local and global environmental degradation measures.

Besides, the complementary, disaggregated (country-specific) findings revealed the complexity of CO2 emissions-political stability nexus by pointed out distinct patterns between variables. Indeed, these various relationship's shapes were somehow expected, given that the estimated threshold following aggregated investigation suggested that some economies did not surpass it yet.

According to the overall results, some relevant policy implications could be drawn. On the one hand, the proper functioning and stability of the political system as a whole play a vital role in shaping the economies' environmental status. Consequently, in line with our empirical findings, both formal (i.e. governmental roles and structures) and informal sides (i.e. social roles and structures) of the political framework contribute substantially to reducing environmental degradation. Likewise, close cooperation between governmental and non-governmental structures could foster political stability, reflecting more efficient and effective policies and regulations. Furthermore, developing countries often face a trade-off between growth and environmental degradation, demanding more attention from policymakers. Thus, to avoid a possible 'pollution-trap' and reduce environmental degradation, the adoption of more environmentally friendly policies and low-carbon growth strategies that would closely track the environmental issues and ensure long-term sustainability is required.

On the other hand, to eliminate possible deviations from the desired environmental path, more attention should be directed towards the countries (or specific subgroups of countries) and pollutants for which political stability is associated with an increase in associated emissions. In these cases, to catalyze political stability optimum achievement, much careful monitoring should be enacted regarding the political stability evolution and its potential effects on related emissions. Also, given that a more stable policy framework could give a deceptive impression of environmental policies' effectiveness, decision-makers should not adopt a more relaxed attitude in this regard but instead, continuously assess their potential impact on the environment and even increase their stringency if the situation requires. Moreover, the maximization of energy efficiency and energy conservation and the replacement of old fossil fuel-based energy with the new generation of renewable and nuclear technologies may lower CO2 pollution. Future perspectives could be a regional or sectorial analysis to capture potential disparities in the environmental degradation-political stability nexus within countries and/or economic sectors.

Appendix

Table A - IV.1: List of countries

Geographic region					
East Asia and Pacific (6)	**Europe and Central Asia (2)**	**Latin America and Caribbean (5)**	**Middle East and North Africa (4)**	**South Asia (4)**	**Sub-Saharan Africa (26)**
Indonesiaǂ	Moldovaǂ	Boliviaǂ	Egypt, Arab Rep.#ǂ	Bangladesh	Angola#ǂ
Mongolia	Ukraineǂ	El Salvadorǂ	Moroccoǂ	India	Burkina Faso*#ǂ
Myanmar		Haiti*#ǂ	Tunisiaǂ	Pakistan#	Cameroonǂ
Papua New Guinea		Hondurasǂ	Yemen, Rep.*ǂ	Sri Lanka	Congo, Dem. Rep.*#ǂ
Philippinesǂ		Nicaraguaǂ			Congo, Rep.#ǂ
Vietnamǂ					Côte d'Ivoire#ǂ
					Ethiopia*#ǂ
					Gambia*
					Ghana
					Guinea*ǂ
					Guinea-Bissau*#ǂ
					Kenya#
					Liberia*
					Madagascar*ǂ
					Malawi*
					Mali*ǂ
					Mozambique*#ǂ
					Niger*ǂ
					Nigeria
					Senegal*ǂ
					Sierra Leone*#
					Tanzania*
					Togo*ǂ
					Uganda*
					Zambia#
					Zimbabwe*#

Notes: (*), (#), and (ǂ) indicate that the respective country belongs to low income group, ratified, adhered or acceded to Kyoto Protocol from 2005 onwards, and has a french legal origin.

Table A - IV.2: Variables' definition

Variable	Defintion	Source
CO2	CO2 per capita emissions totals of fossil fuel use and industrial processes (tonnes)	The European Commission, Joint Research Centre (EC-JRC)/Netherlands Environmental Assessment Agency (PBL). Emissions Database for Global Atmospheric Research (EDGAR), release EDGARv4.3.2_FT2016 (1970-2016). Janssens-Maenhout, G., Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Olivier, J.G.J., Peters, J.A.H.W., Schure, K.M., Fossil CO2 and GHG emissions of all world countries, EUR 28766 EN,Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-73207-2, doi:10.2760/709792, JRC107877 (http://edgar.jrc.ec.europa.eu/overview.php?v=booklet2017&dst=CO2pc)
PS	Political stability composite index defined as the sum of the government stability, socioeconomic conditions, investment profile, internal conflict, external conflict, corruption, military in politics, religious tensions, law and order, ethnic tensions, democratic accountability, and bureaucracy quality component. [scale from 0-100, 0 designating the highest risk – low political stability, and 100 the lowest risk–high political stability]	International Country Risk Guide (ICRG), Political Risk Services (PRS) Group (https://www.prsgroup.com/explore-our-products/international-country-risk-guide/)
PS_Mean	Political stability composite index defined as the simple average of its components.	
PS_GeomMean	Political stability composite index defined as the geometric mean of its components.	
PS_HarmMean	Political stability composite index defined as the harmonic mean of its components.	
PS_Median	Political stability composite index defined as the median of its components.	
PS_SC1	The sum of corruption, law and order, and bureaucracy quality.	
PS_SC2	The sum of internal conflict, external conflict, religious tensions, and ethnic tensions.	
PS_SC3	The sum of government stability and military in politics.	
PS_SC4	The sum of socioeconomic conditions, investment profile and democratic accountability.	
GDP	GDP per capita based on purchasing power parity (PPP) (constant 2011 international $)	The World Bank, World Bank Indicators (http://data.worldbank.org/indicator)
RENG	Renewable energy consumption (% of total final energy consumption)	
EINT	Energy intensity level of primary energy computed as total primary energy supply over GDP measured in constant 2011 US dollars at PPP (MJ/$2011 PPP GDP)	
URB	Urban population (% of total population)	
AGRI	Agriculture, forestry, and fishing, value added (% of GDP)	
IND	Industry (including construction), value added (% of GDP)	
TRADE	Merchandise trade (% of GDP)	
FORESTR	Forest rents (% of GDP)	
NATR	Total natural resources rents (% of GDP)	
UNEM	Unemployment, total (% of total labor force)	

(**Table A - IV.2:** continued)

Variable	**Defintion**	**Source**
FDI	Foreign direct investments (% of GDP)	The United Nations Conference on Trade and Development (https://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx?sCS_ChosenLang=en)
HDI	The Human Development Index (scale between 0 and 1, 0 designating the absence of human development, and 1 the maximum degree of human development)	The United Nations Development Programme (http://hdr.undp.org/en/content/human-development-index-hdi)
GLOB	The Globalization Index (scale between 0 and 100, 0 designating the lack of globalization, and 100 the maximum degree of globalization)	The KOF Swiss Economic Institute. Dreher (2006) and Gygli, Haelg, Potrafke and Sturm (2019) (https://www.kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html)
PM2.5bio	Particulate matter per capita emissions totals with aerodynamic diameters 2.5 from bio components (gigagrams)	Authors' computation based on the European Commission, Joint Research Centre (EC-JRC)/Netherlands Environmental Assessment Agency (PBL). Emissions Database for Global Atmospheric Research (EDGAR), release EDGAR v4.3.2 (1970-2012) of March 2016. Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., van Aardenne, J. A., Monni, S., Doering, U., Olivier, J. G. J., Pagliari, V., and Janssens-Maenhout, G.: Gridded Emissions of Air Pollutants for the period 1970-2012 within EDGAR v4.3.2, Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-31 in review, 2018. (http://edgar.jrc.ec.europa.eu/overview.php?v=432), DOI (https://data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR) and World Bank Indicators data (population: https://databank.worldbank.org/data/home.aspx
PM2.5fossil	Particulate matter per capita emissions totals with aerodynamic diameters 2.5 from fossil components (gigagrams)	
PM2.5	Particulate matter per capita emissions totals with aerodynamic diameters 2.5 from bio and fossil components (gigagrams)	
PM10	Particulate matter per capita emissions totals with aerodynamic diameters 10 (gigagrams)	
SO2	SO2 per capita emissions national totals for the entire territory based on fuel sold (gigagrams)	
ECOFT	Ecological footprint per capita captures the biologically productive land and water area an individual, population, or activity requires for producing produce all the resources it consumes, to accommodate its occupied urban infrastructure, and to absorb the waste it generates, using prevailing technology and resource management practices (global hectares)	The Global Footprint Network. National Footprint Accounts, 2019 Edition (http://data.footprintnetwork.org)
BIOCAP	Biocapacity per capita captures the capacity of the biosphere to regenerate and provide natural resources and services for life (global hectares)	

Table A - IV.3: Summary statistics [full sample]

Variable	Mean	Std. dev	Median	Min	Max	Observations
Main model						
CO2	0.861	1.431	0.399	0.031	15.298	1222
PS	55.645	9.929	56.840	9.750	75.000	1205
GDP	3156.883	2211.214	2657.992	354.284	11411.940	1207
RENG	61.488	28.848	70.569	0.600	98.342	1212
EINT	9.101	7.300	6.434	1.910	57.988	1222
Additional controls						
AGRI	23.757	12.421	21.657	3.383	79.042	1180
IND	26.103	11.014	25.145	3.243	77.413	1174
TRADE	53.322	24.870	46.670	4.909	169.568	1195
FDI	36.178	99.048	16.499	0.008	1315.545	1217
HDI	0.489	0.118	0.477	0.208	0.766	1145
GLOB	46.856	9.976	46.236	22.645	70.601	1213
FORESTR	4.927	5.976	2.839	0.000	36.068	1197
NATR	10.786	10.706	7.393	0.107	59.619	1197
URB	37.845	14.942	36.556	11.076	69.700	1222
CREDIT	21.427	18.296	15.544	0.402	114.723	1167
UNEM	6.050	4.434	4.45	0.299	23.925	1175
Alternative approach in computing the PS composite index						
PS_Mean	4.637	0.827	4.736	0.812	6.250	1205
PS_GeomMean	3.196	1.750	3.847	0.000	5.475	1205
PS_HarmMean	2.621	1.482	3.136	0.000	4.965	1205
PS_Median	3.837	0.949	4.000	0.333	6.000	1205
Political stability subcomponents						
PS_SC1	6.642	1.962	7.000	0.750	11.000	1205
PS_SC2	25.153	4.708	25.500	5.090	34.170	1205
PS_SC3	10.264	2.613	10.500	1.000	16.130	1205
PS_SC4	13.585	3.462	14.080	1.000	20.670	1205
Alternative measures of pollution						
PM2.5.bio	4.22e-06	2.26e-06	4.35e-06	1.58e-07	9.51e-06	1081
PM2.5fossil	4.64e-07	9.14e-07	1.71e-07	1.72e-08	0.0000102	1081
PM2.5	4.68e-06	2.23e-06	4.63e-06	2.94e-07	0.0000121	1081
PM10	8.96e-06	4.37e-06	8.64e-06	6.10e-07	0.00002	1081
SO2	4.51e-06	7.60e-06	1.57e-06	3.12e-07	0.000084	1081
ECOFT	1.357	0.849	1.202	0.012	7.465	1215
BIOCAP	2.594	4.287	1.272	0.243	27.685	1215

Table A - IV.4: Summary statistics [subsamples]

Variable	Mean	Std. dev	Median	Min	Max	Observations
LICs						
CO2	0.228	0.282	0.130	0.031	1.814	520
PS	52.412	10.435	53.775	9.750	75.000	520
GDP	1478.721	762.610	1370.612	354.284	4478.744	510
RENG	78.064	21.747	84.612	0.862	98.342	510
EINT	12.389	9.234	10.210	1.910	57.988	520
LMICs						
CO2	1.329	1.730	0.857	0.105	15.298	702
PS	58.100	8.771	59.460	27.000	75.000	685
GDP	4384.807	2115.035	3971.183	728.031	11411.940	697
RENG	49.445	27.370	52.844	0.600	92.961	702
EINT	6.665	3.966	5.503	1.992	26.699	702
Kyoto < 2005						
CO2	1.031	1.666	0.528	0.061	15.298	832
PS	57.577	9.126	58.750	9.750	75.000	815
GDP	3415.468	2251.240	2922.776	711.192	11411.940	817
RENG	55.043	29.343	59.261	0.600	96.842	822
EINT	7.927	6.081	5.944	1.910	57.988	832
Kyoto >= 2005						
CO2	0.496	0.550	0.232	0.031	2.591	390
PS	51.608	10.330	52.525	21.740	72.080	390
GDP	2615.182	2023.049	2099.822	354.284	10096.660	390
RENG	75.072	22.378	80.249	5.554	98.342	390
EINT	11.605	8.889	8.539	2.056	50.134	390
French legal origin						
CO2	0.997	1.616	0.576	0.031	15.298	754
PS	56.053	9.619	57.370	21.740	75.000	737
GDP	3418.341	2370.691	2938.268	354.284	10767.030	749
RENG	56.228	31.141	64.532	0.600	98.342	744
EINT	8.864	7.575	5.804	1.910	50.134	754
British legal origin						
CO2	0.425	0.374	0.249	0.069	1.847	416
PS	54.723	10.147	56.055	9.750	75.000	416
GDP	2534.128	1581.876	2200.591	711.192	11079.710	406
RENG	73.198	16.379	79.239	34.747	96.842	416
EINT	9.591	7.124	8.170	1.992	57.988	416

Table A - IV.5: CO2 emissions and political stability [baseline and threshold estimates: ARDL (1,2)]

Dependent variable: ΔCO2				
	(1a)	**(1b)**	**(2a)**	**(2b)**
	Long-run estimates			
PS	0.218***	4.177***	0.327***	6.592***
	(0.036)	(0.820)	(0.035)	(1.397)
PS^2		-0.527***		-0.757***
		(0.108)		(0.171)
GDP			0.196***	0.721***
			(0.055)	(0.021)
RENG			-0.770***	0.009
			(0.062)	(0.014)
EINT			0.304***	0.826***
			(0.052)	(0.033)
	Short-run estimates			
ECT	**-0.190*****	**-0.211*****	**-0.214*****	**-0.226*****
	(0.026)	**(0.033)**	**(0.033)**	**(0.041)**
ΔPS	-0.016	-1.705	-0.040	3.224
	(0.075)	(4.377)	(0.079)	(3.455)
$\Delta PS_{(t-1)}$	0.047	1.182	0.042	-1.875
	(0.058)	(3.325)	(0.062)	(2.736)
ΔPS^2		0.180		-0.443
		(0.541)		(0.428)
$\Delta PS^2_{(t-1)}$		-0.136		0.250
		(0.411)		(0.339)
ΔGDP			1.332***	1.057***
			(0.515)	(0.373)
$\Delta GDP_{(t-1)}$			-0.077	-0.077
			(0.147)	(0.154)
ΔRENG			-1.178***	-1.313***
			(0.359)	(0.367)
$\Delta RENG_{(t-1)}$			0.075	0.118
			(0.215)	(0.176)
ΔEINT			0.960*	0.716**
			(0.501)	(0.360)
$\Delta EINT_{(t-1)}$			-0.059	-0.016
			(0.112)	(0.112)
C	-0.393***	-1.982***	-0.356***	-5.042***
	(0.071)	(0.324)	(0.069)	(0.911)
Log Likelihood	1548.222	1663.645	2143.635	2274.176
Groups	47	47	47	47
Observations	1111	1111	1091	1091

Notes: We use the difficult option to avoid difficulty to maximize the likelihood function when nonconcave regions appear during estimation. Standard errors in brackets. ***, **, * denote statistical significance at the 1%, 5%, and 10% level, respectively.

Figure A - IV.1: The estimated relationship between PS and CO2 [CS-ARDL-PMG approach]

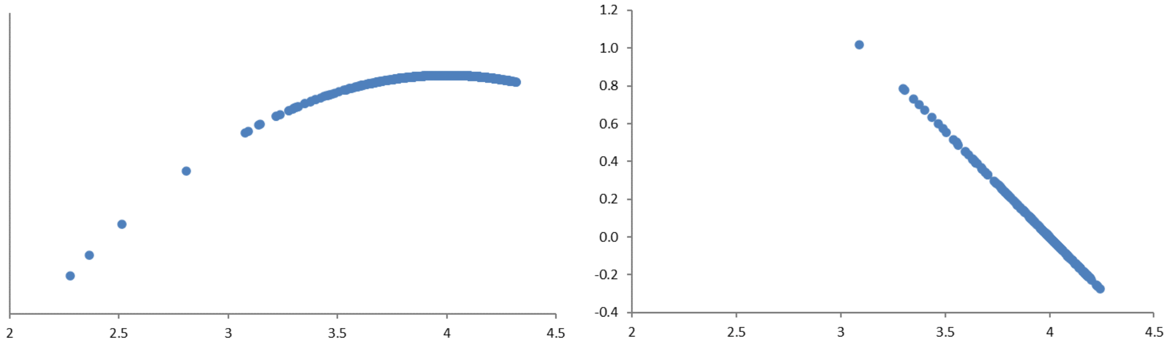

(1a) the estimated relationship CO2/PS (1b) the derivative *dCO2/dPS*

Figure A - IV.2: The estimated relationship between PS and CO2 [AMG approach]

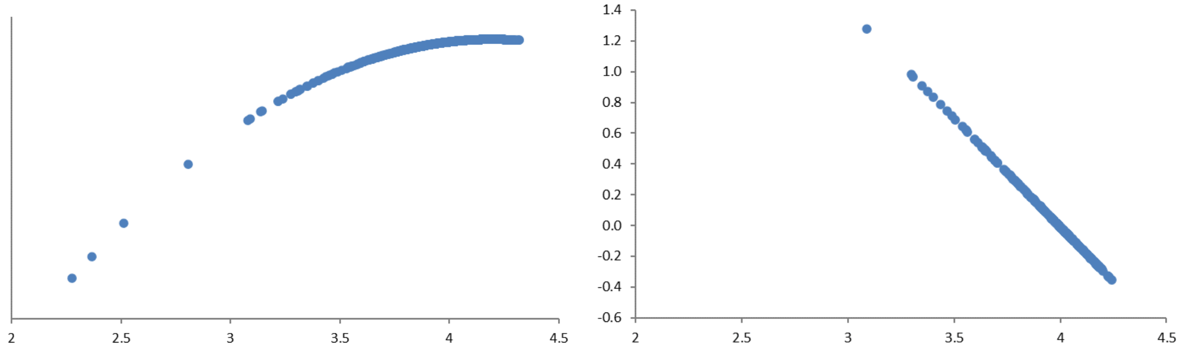

(2a) the estimated relationship CO2/PS (2b) the derivative *dCO2/dPS*

Figure A - IV.3: The estimated relationship between PS and CO2 [DMG approach]

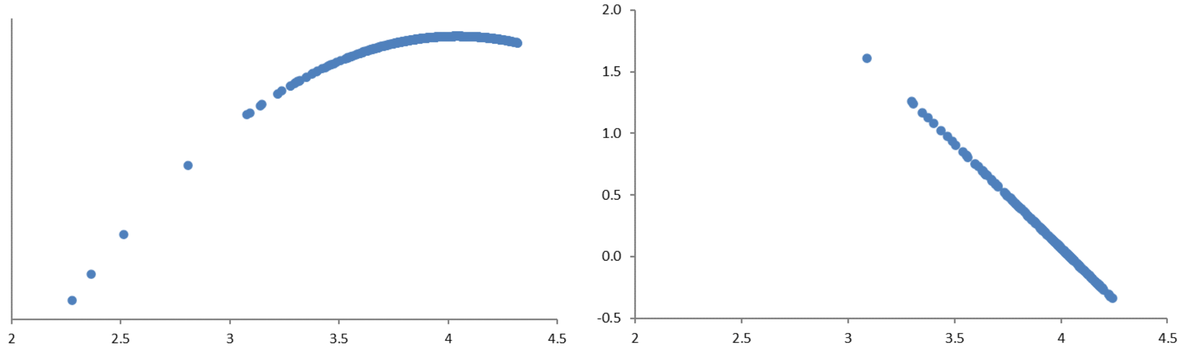

(3a) the estimated relationship CO2/PS (3b) the derivative *dCO2/dPS*

Figure A - IV.4: The estimated relationship between PS and CO2
[PS index computed as simple average]

(4a) the estimated relationship CO2/PS (4b) the derivative *dCO2/dPS*

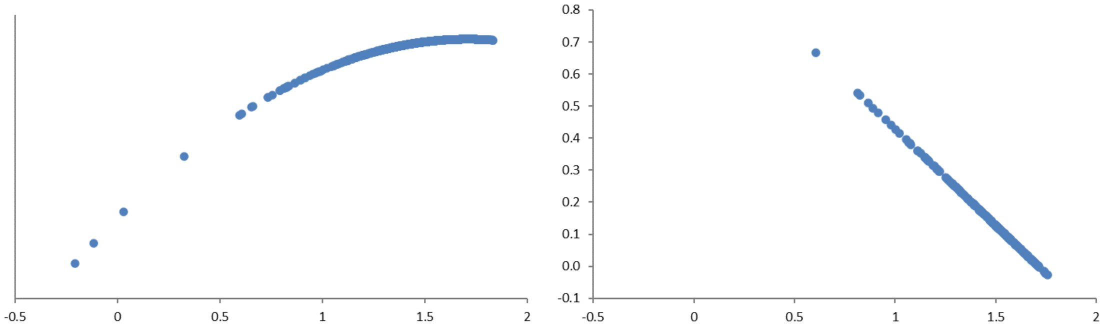


Figure A - IV.5: The estimated relationship between PS and CO2
[PS index computed as geometric mean]

(5a) the estimated relationship CO2/PS (5b) the derivative *dCO2/dPS*

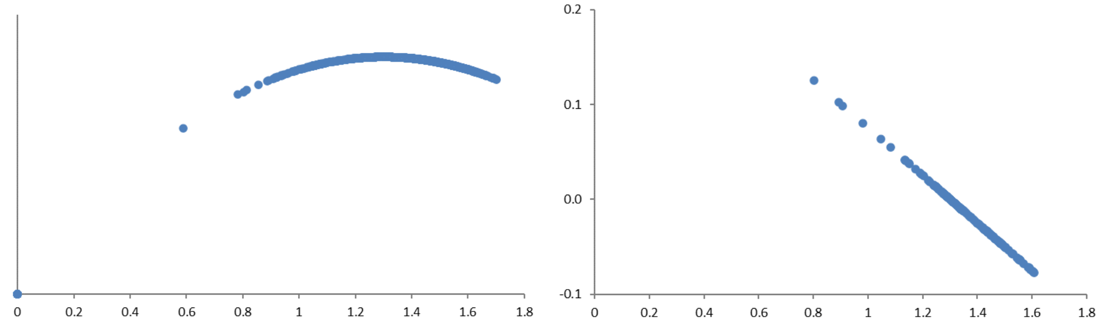


Figure A - IV.6: The estimated relationship between PS and CO2
[PS index computed as harmonic mean]

(6a) the estimated relationship CO2/PS (6b) the derivative *dCO2/dPS*

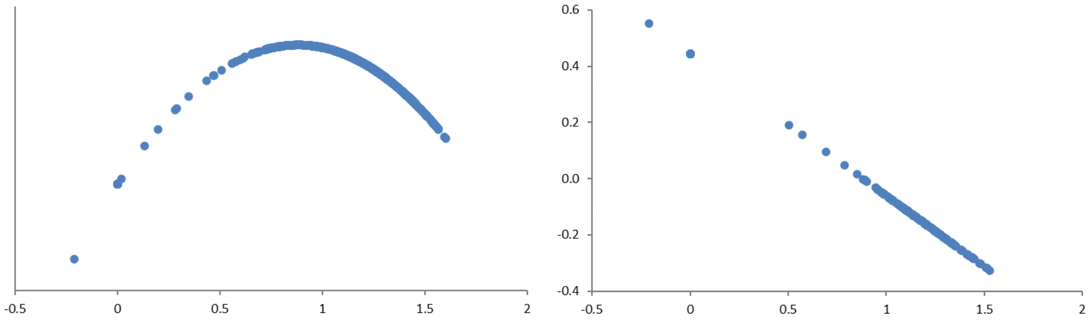
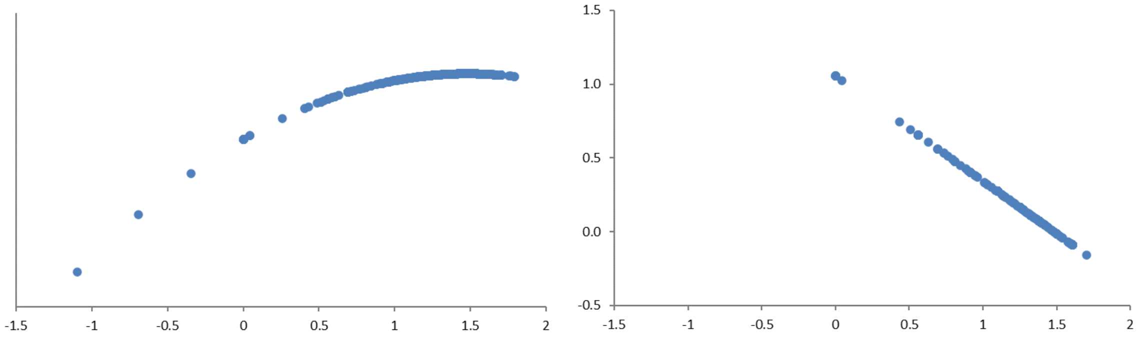


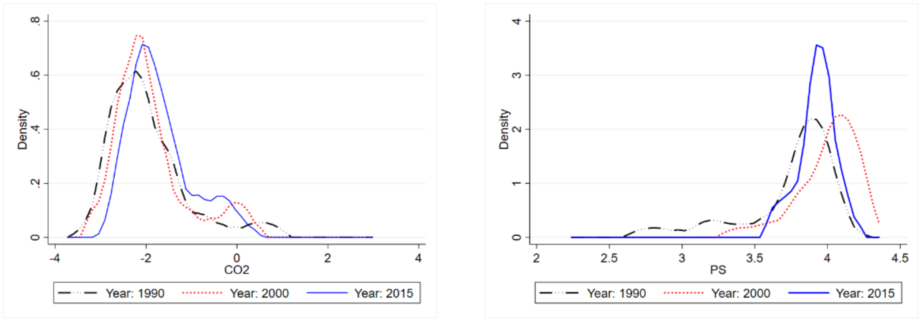
Figure A - IV.7: The estimated relationship between PS and CO2
[PS index computed as median]



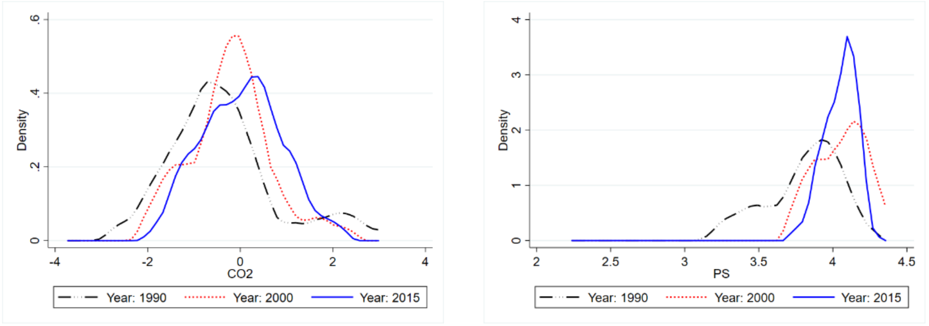
(7a) the estimated relationship CO2/PS (7b) the derivative *dCO2/dPS*

Figure A - IV.8: CO2 and PS kernel density plots [subsamples]
(a) CO2 **(b) PS**

LICs



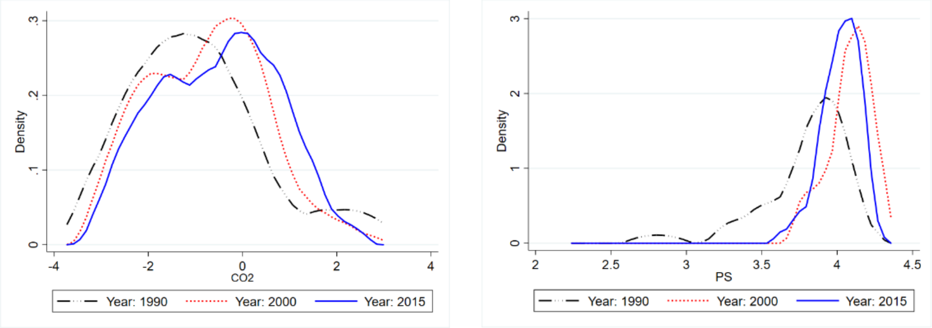
LMICs



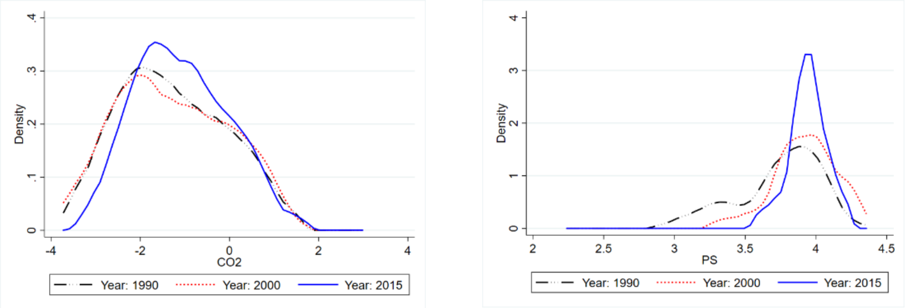
Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

(**Figure A - IV.8:** continued)

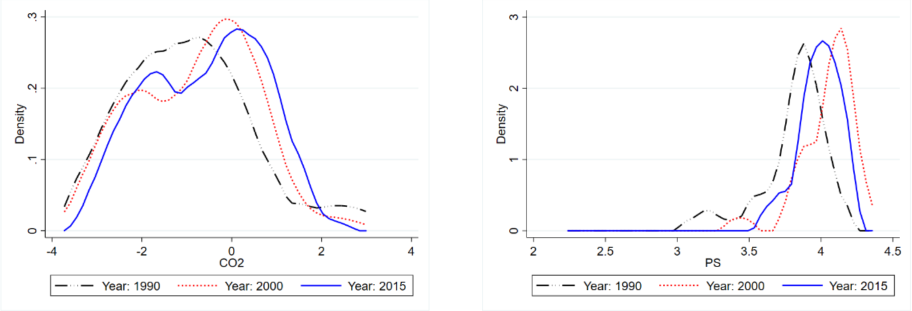
Kyoto < 2005



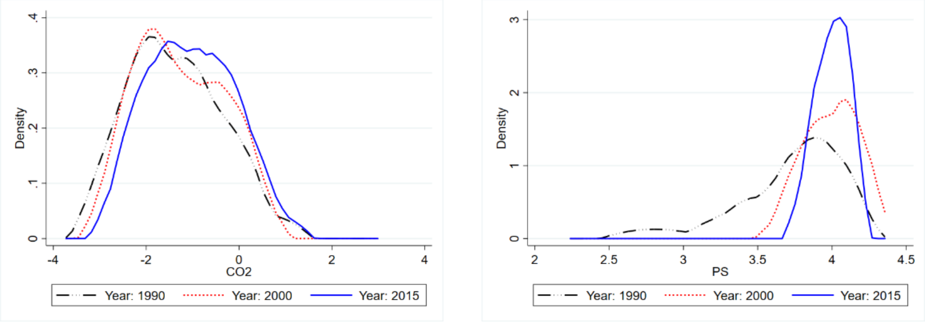
Kyoto >= 2005



French legal origin



British legal origin

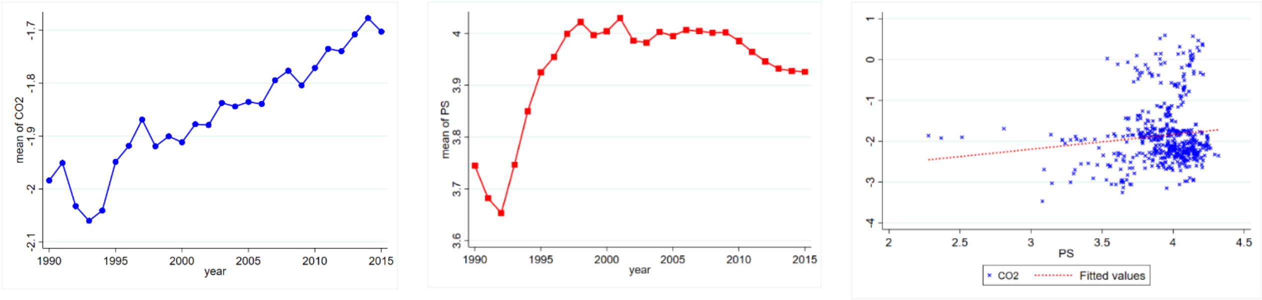


Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

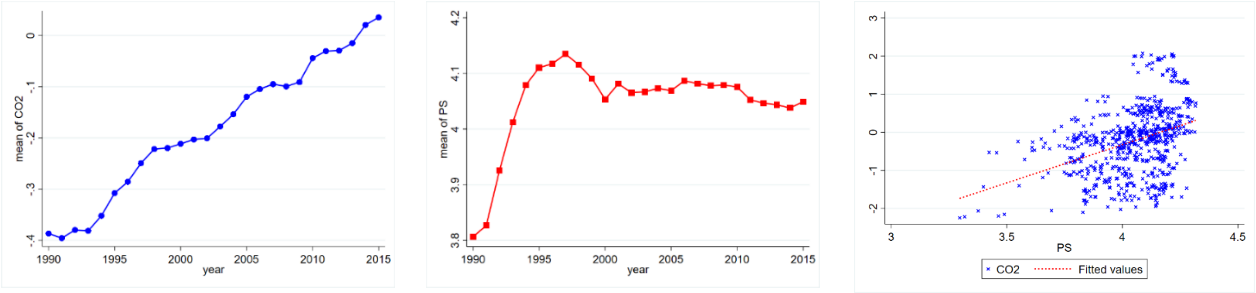
Figure A - IV.9: CO2 and PS evolution over time and scatterplot [subsamples]

(f) CO2 **(g) PS** **(h) CO2 versus PS**

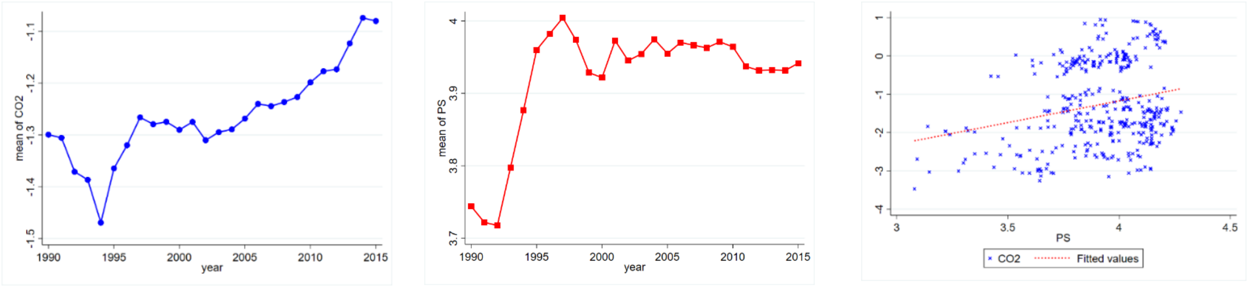
LICs



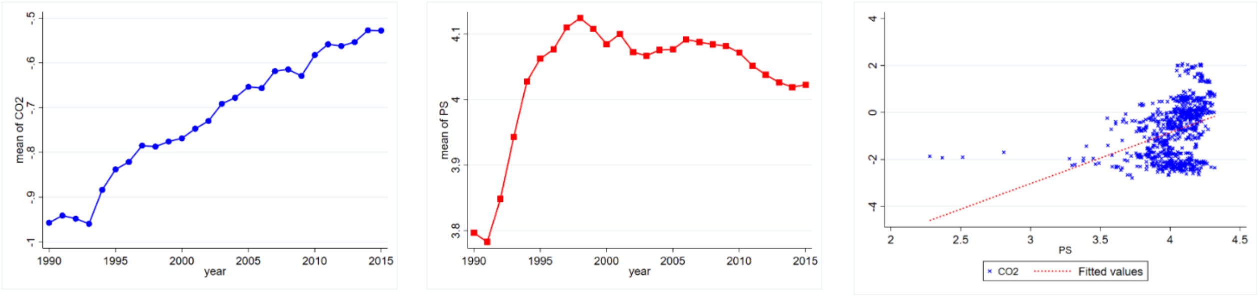
LMICs



Kyoto < 2005



Kyoto >= 2005

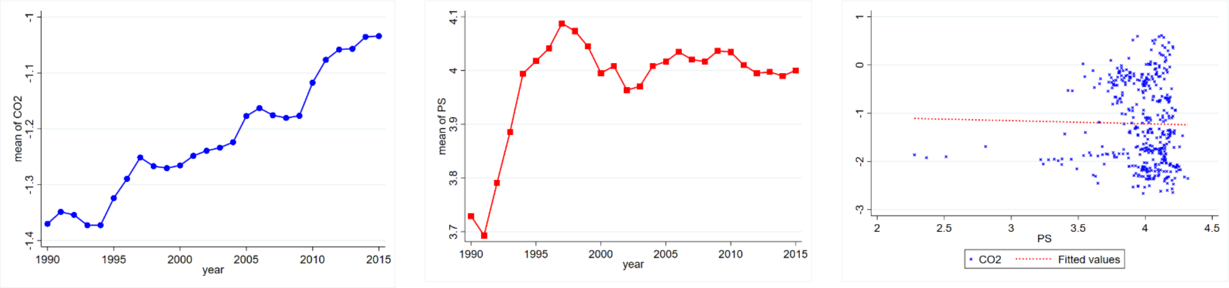


Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

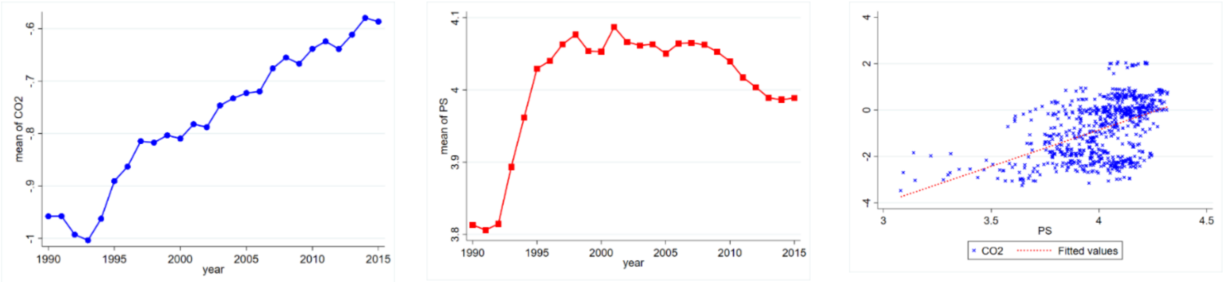
(**Figure A - IV.9:** continued)

(a) CO2 **(b) PS** **(c) CO2 versus PS**

British legal origin



French legal origin



Notes: The plots refer to the natural logarithmic values of CO2 and PS variable.

Table A - IV.6: Countries' classification by agriculture average over 1990-2015

No.	CO2-PS pattern	Country	Mean_AGRI
1	[inverted-U shaped]	Sierra Leone	49.027
2	[inverted-U shaped]	Guinea-Bissau	47.393
3	[inverted-U shaped]	Myanmar	41.500
4	[inverted-U shaped]	Niger	38.017
5	[inverted-U shaped]	Togo	35.365
6	[inverted-U shaped]	Mali	34.791
7	[inverted-U shaped]	Malawi	32.280
8	[inverted-U shaped]	Uganda	32.254
9	[inverted-U shaped]	Madagascar	27.383
10	[U-shaped]	Papua New Guinea	27.318
11	[U-shaped]	Mozambique	27.064
12	M. increasing	Nigeria	24.815
13	[inverted-U shaped]	Vietnam	23.985
14	M. increasing	Haiti	22.801
15	[inverted-U shaped]	Bangladesh	21.336
16	M. increasing	Mongolia	20.944
17	M. increasing	Cameroon	16.539
18	[inverted-U shaped]	Sri Lanka	16.456
19	[inverted-U shaped]	Honduras	15.535
20	[U-shaped]	Yemen, Rep.	14.293
21	M. increasing	Zambia	13.943
22	[U-shaped]	Morocco	13.700
23	[inverted-U shaped]	Bolivia	12.508
24	[U-shaped]	Tunisia	10.653
25	M. increasing	El Salvador	8.552
26	M. decreasing	Congo, Rep.	7.034
27	[inverted-U shaped]	Angola	6.770

Table A - IV.7: Countries' classification by agriculture median over 1990-2015

No.	CO2-PS pattern	Country	Median_AGRI
1	[inverted-U shaped]	Sierra Leone	49.842
2	[inverted-U shaped]	Guinea-Bissau	45.877
3	[inverted-U shaped]	Myanmar	41.798
4	[inverted-U shaped]	Niger	39.048
5	[inverted-U shaped]	Mali	35.058
6	[inverted-U shaped]	Togo	34.943
7	[inverted-U shaped]	Malawi	31.142
8	[U-shaped]	Papua New Guinea	27.566
9	[inverted-U shaped]	Madagascar	26.618
10	[inverted-U shaped]	Uganda	26.190
11	[U-shaped]	Mozambique	25.764
12	M. increasing	Nigeria	24.698
13	[inverted-U shaped]	Vietnam	22.785
14	M. increasing	Haiti	22.214
15	[inverted-U shaped]	Bangladesh	20.198
16	M. increasing	Mongolia	19.067
17	M. increasing	Cameroon	15.727
18	M. increasing	Zambia	14.035
19	[inverted-U shaped]	Sri Lanka	13.829
20	[inverted-U shaped]	Honduras	13.366
21	[U-shaped]	Morocco	13.196
22	[U-shaped]	Yemen, Rep.	13.108
23	[inverted-U shaped]	Bolivia	12.960
24	[U-shaped]	Tunisia	9.662
25	M. increasing	El Salvador	7.041
26	M. decreasing	Angola	6.250
27	[inverted-U shaped]	Congo, Rep.	6.030

Table A - IV.8: Countries' classification by industry mean over 1990-2015

No.	CO2-PS pattern	Country	Mean_IND
1	M. decreasing	Congo, Rep.	60.534
2	[inverted-U shaped]	Angola	57.575
3	[U-shaped]	Yemen, Rep.	40.532
4	M. increasing	Haiti	34.504
5	[U-shaped]	Papua New Guinea	33.663
6	[inverted-U shaped]	Vietnam	33.436
7	M. increasing	Zambia	31.871
8	M. increasing	Mongolia	29.999
9	M. increasing	Nigeria	29.110
10	[inverted-U shaped]	Honduras	28.016
11	[inverted-U shaped]	Bolivia	27.910
12	[inverted-U shaped]	Sri Lanka	27.845
13	[U-shaped]	Tunisia	27.747
14	M. increasing	Cameroon	27.507
15	[U-shaped]	Morocco	26.051
16	M. increasing	El Salvador	25.060
17	[inverted-U shaped]	Bangladesh	23.507
18	[inverted-U shaped]	Myanmar	22.482
19	[inverted-U shaped]	Mali	20.032
20	[inverted-U shaped]	Sierra Leone	18.861
21	[inverted-U shaped]	Uganda	18.637
22	[inverted-U shaped]	Togo	18.068
23	[U-shaped]	Mozambique	17.980
24	[inverted-U shaped]	Malawi	17.538
25	[inverted-U shaped]	Niger	16.923
26	[inverted-U shaped]	Madagascar	16.041
27	[inverted-U shaped]	Guinea-Bissau	13.313

Table A - IV.9: Countries' classification by industry median over 1990-2015

No.	CO2-PS pattern	Country	Median_IND
1	M. decreasing	Congo, Rep.	64.403
2	[inverted-U shaped]	Angola	56.918
3	[U-shaped]	Yemen, Rep.	42.707
4	[U-shaped]	Papua New Guinea	34.390
5	[inverted-U shaped]	Vietnam	33.232
6	M. increasing	Haiti	33.147
7	M. increasing	Zambia	32.124
8	M. increasing	Mongolia	30.811
9	M. increasing	Nigeria	28.277
10	[inverted-U shaped]	Bolivia	28.044
11	[U-shaped]	Tunisia	27.929
12	[inverted-U shaped]	Sri Lanka	27.489
13	[inverted-U shaped]	Honduras	27.317
14	M. increasing	Cameroon	27.184
15	[U-shaped]	Morocco	26.127
16	M. increasing	El Salvador	25.184
17	[inverted-U shaped]	Bangladesh	23.117
18	[inverted-U shaped]	Myanmar	21.537
19	[inverted-U shaped]	Uganda	20.173
20	[inverted-U shaped]	Mali	19.648
21	[U-shaped]	Mozambique	17.862
22	[inverted-U shaped]	Niger	17.212
23	[inverted-U shaped]	Togo	17.194
24	[inverted-U shaped]	Malawi	16.420
25	[inverted-U shaped]	Madagascar	15.713
26	[inverted-U shaped]	Sierra Leone	15.074
27	[inverted-U shaped]	Guinea-Bissau	13.451

Table A - IV.10: Countries' classification by unemployment mean over 1990-2015

No.	CO2-PS pattern	Country	Mean_UNEMP
1	M. decreasing	Congo, Rep.	17.395
2	[inverted-U shaped]	Angola	17.155
3	[U-shaped]	Tunisia	14.853
4	M. increasing	Zambia	13.145
5	[U-shaped]	Morocco	11.457
6	M. increasing	Haiti	11.381
7	[U-shaped]	Yemen, Rep.	11.200
8	[inverted-U shaped]	Sri Lanka	8.265
9	[inverted-U shaped]	Malawi	7.352
10	[inverted-U shaped]	Mali	6.513
11	M. increasing	El Salvador	6.415
12	M. increasing	Mongolia	5.856
13	M. increasing	Cameroon	5.776
14	[inverted-U shaped]	Guinea-Bissau	4.411
15	[inverted-U shaped]	Honduras	4.019
16	[inverted-U shaped]	Madagascar	3.961
17	M. increasing	Nigeria	3.909
18	[inverted-U shaped]	Sierra Leone	3.689
19	[inverted-U shaped]	Bangladesh	3.494
20	[U-shaped]	Mozambique	3.022
21	[inverted-U shaped]	Bolivia	2.982
22	[U-shaped]	Papua New Guinea	2.614
23	[inverted-U shaped]	Uganda	2.393
24	[inverted-U shaped]	Togo	1.986
25	[inverted-U shaped]	Vietnam	1.947
26	[inverted-U shaped]	Niger	1.347
27	[inverted-U shaped]	Myanmar	1.030

Table A - IV.11: Countries' classification by unemployment median over 1990-2015

No.	CO2-PS pattern	Country	Median_UNEMP
1	[inverted-U shaped]	Angola	20.532
2	M. decreasing	Congo, Rep.	20.028
3	[U-shaped]	Tunisia	15.074
4	M. increasing	Zambia	13.19
5	M. increasing	Haiti	12.158
6	[U-shaped]	Yemen, Rep.	11.591
7	[U-shaped]	Morocco	11.59
8	[inverted-U shaped]	Sri Lanka	7.9
9	[inverted-U shaped]	Malawi	7.76
10	[inverted-U shaped]	Mali	6.9
11	M. increasing	El Salvador	6.68
12	M. increasing	Cameroon	6.089
13	M. increasing	Mongolia	5.91
14	[inverted-U shaped]	Madagascar	4.47
15	[inverted-U shaped]	Guinea-Bissau	4.452
16	[inverted-U shaped]	Honduras	4.02
17	M. increasing	Nigeria	3.947
18	[inverted-U shaped]	Bangladesh	3.591
19	[inverted-U shaped]	Sierra Leone	3.53
20	[inverted-U shaped]	Bolivia	3.15
21	[U-shaped]	Mozambique	3.135
22	[U-shaped]	Papua New Guinea	2.698
23	[inverted-U shaped]	Uganda	2.256
24	[inverted-U shaped]	Togo	1.979
25	[inverted-U shaped]	Vietnam	1.964
26	[inverted-U shaped]	Niger	1.439
27	[inverted-U shaped]	Myanmar	1.065

Table A - IV.12: Countries' classification by globalization mean over 1990-2015

No.	CO2-PS pattern	Country	Mean_GLOB
1	[U-shaped]	Tunisia	60.279
2	[U-shaped]	Morocco	57.853
3	M. increasing	El Salvador	57.310
4	[inverted-U shaped]	Honduras	56.164
5	[inverted-U shaped]	Bolivia	55.910
6	[inverted-U shaped]	Sri Lanka	54.471
7	M. increasing	Nigeria	53.074
8	M. increasing	Zambia	50.649
9	M. increasing	Mongolia	50.360
10	[U-shaped]	Yemen, Rep.	47.554
11	[inverted-U shaped]	Togo	45.703
12	M. decreasing	Congo, Rep.	45.473
13	[U-shaped]	Papua New Guinea	44.860
14	[inverted-U shaped]	Uganda	44.236
15	[inverted-U shaped]	Vietnam	44.148
16	M. increasing	Cameroon	43.864
17	[inverted-U shaped]	Mali	43.384
18	[U-shaped]	Mozambique	40.250
19	[inverted-U shaped]	Angola	39.866
20	[inverted-U shaped]	Malawi	39.355
21	M. increasing	Haiti	39.066
22	[inverted-U shaped]	Niger	38.905
23	[inverted-U shaped]	Bangladesh	38.629
24	[inverted-U shaped]	Madagascar	38.307
25	[inverted-U shaped]	Guinea-Bissau	36.439
26	[inverted-U shaped]	Sierra Leone	35.982
27	[inverted-U shaped]	Myanmar	29.131

Table A - IV.13: Countries' classification by globalization median over 1990-2015

No.	**CO2-PS pattern**	**Country**	**Median_GLOB**
1	[U-shaped]	Tunisia	60.274
2	M. increasing	El Salvador	59.513
3	[U-shaped]	Morocco	59.022
4	[inverted-U shaped]	Honduras	58.823
5	[inverted-U shaped]	Bolivia	58.282
6	[inverted-U shaped]	Sri Lanka	55.324
7	M. increasing	Mongolia	54.148
8	M. increasing	Nigeria	53.065
9	M. increasing	Zambia	51.432
10	[U-shaped]	Yemen, Rep.	46.853
11	M. increasing	Cameroon	45.111
12	[inverted-U shaped]	Mali	44.753
13	M. decreasing	Congo, Rep.	44.388
14	[inverted-U shaped]	Togo	44.008
15	[inverted-U shaped]	Uganda	43.997
16	[U-shaped]	Papua New Guinea	43.652
17	[inverted-U shaped]	Vietnam	42.879
18	[U-shaped]	Mozambique	42.044
19	[inverted-U shaped]	Malawi	40.831
20	[inverted-U shaped]	Angola	40.560
21	[inverted-U shaped]	Bangladesh	38.940
22	M. increasing	Haiti	38.481
23	[inverted-U shaped]	Madagascar	37.275
24	[inverted-U shaped]	Guinea-Bissau	36.930
25	[inverted-U shaped]	Niger	36.919
26	[inverted-U shaped]	Sierra Leone	32.092
27	[inverted-U shaped]	Myanmar	30.373

Table A - IV.14: Countries' classification by forest rents mean over 1990-2015

No.	CO2-PS pattern	Country	Mean_FORESTR
1	[inverted-U shaped]	Guinea-Bissau	17.605
2	[inverted-U shaped]	Uganda	15.567
3	[inverted-U shaped]	Sierra Leone	11.567
4	[U-shaped]	Mozambique	10.325
5	[inverted-U shaped]	Niger	9.231
6	[inverted-U shaped]	Malawi	8.890
7	[inverted-U shaped]	Togo	7.616
8	[inverted-U shaped]	Madagascar	6.618
9	[inverted-U shaped]	Myanmar	5.099
10	M. decreasing	Congo, Rep.	4.544
11	M. increasing	Zambia	4.504
12	[U-shaped]	Papua New Guinea	4.042
13	[inverted-U shaped]	Mali	3.619
14	M. increasing	Cameroon	3.185
15	M. increasing	Nigeria	2.450
16	[inverted-U shaped]	Vietnam	1.995
17	[inverted-U shaped]	Honduras	1.636
18	[inverted-U shaped]	Angola	1.140
19	M. increasing	Haiti	0.864
20	M. increasing	Mongolia	0.792
21	M. increasing	El Salvador	0.674
22	[inverted-U shaped]	Bolivia	0.586
23	[inverted-U shaped]	Bangladesh	0.266
24	[inverted-U shaped]	Sri Lanka	0.237
25	[U-shaped]	Morocco	0.231
26	[U-shaped]	Tunisia	0.170
27	[U-shaped]	Yemen, Rep.	0.039

Table A - IV.15: Countries' classification by forest rents median over 1990-2015

No.	CO2-PS pattern	Country	Mean_FORESTR
1	[inverted-U shaped]	Guinea-Bissau	17.184
2	[inverted-U shaped]	Uganda	14.686
3	[inverted-U shaped]	Sierra Leone	11.014
4	[inverted-U shaped]	Niger	9.223
5	[U-shaped]	Mozambique	8.759
6	[inverted-U shaped]	Malawi	8.652
7	[inverted-U shaped]	Togo	6.934
8	[inverted-U shaped]	Madagascar	6.671
9	[inverted-U shaped]	Myanmar	4.863
10	M. decreasing	Zambia	4.506
11	M. increasing	Papua New Guinea	3.934
12	[U-shaped]	Congo, Rep.	3.889
13	[inverted-U shaped]	Mali	3.194
14	M. increasing	Cameroon	3.040
15	M. increasing	Nigeria	2.014
16	[inverted-U shaped]	Honduras	1.467
17	[inverted-U shaped]	Vietnam	1.236
18	[inverted-U shaped]	Angola	0.990
19	M. increasing	Haiti	0.811
20	M. increasing	Mongolia	0.598
21	M. increasing	El Salvador	0.584
22	[inverted-U shaped]	Bolivia	0.548
23	[inverted-U shaped]	Bangladesh	0.225
24	[U-shaped]	Morocco	0.211
25	[inverted-U shaped]	Sri Lanka	0.192
26	[U-shaped]	Tunisia	0.158
27	[U-shaped]	Yemen, Rep.	0.036

Table A - IV.16: Countries' classification by military in politics mean over 1990-2015

No.	CO2-PS pattern	Country	Mean_MilitaryPol
1	M. increasing	Mongolia	5
2	M. increasing	Zambia	4.846
3	[inverted-U shaped]	Malawi	4.099
4	[U-shaped]	Papua New Guinea	4.001
5	[U-shaped]	Morocco	3.923
6	[U-shaped]	Tunisia	3.906
7	M. increasing	Cameroon	3.706
8	[U-shaped]	Yemen, Rep.	3.694
9	[inverted-U shaped]	Mali	3.259
10	[inverted-U shaped]	Bolivia	2.865
11	[U-shaped]	Mozambique	2.801
12	[inverted-U shaped]	Sri Lanka	2.713
13	[inverted-U shaped]	Honduras	2.673
14	M. increasing	El Salvador	2.665
15	[inverted-U shaped]	Vietnam	2.461
16	[inverted-U shaped]	Bangladesh	2.394
17	[inverted-U shaped]	Niger	2.344
18	[inverted-U shaped]	Madagascar	1.884
19	[inverted-U shaped]	Uganda	1.878
20	[inverted-U shaped]	Angola	1.615
21	[inverted-U shaped]	Sierra Leone	1.591
22	M. increasing	Nigeria	1.455
23	[inverted-U shaped]	Guinea-Bissau	1.447
24	M. increasing	Haiti	1.051
25	[inverted-U shaped]	Togo	0.753
26	[inverted-U shaped]	Myanmar	0.557
27	M. decreasing	Congo, Rep.	0.461

Table A - IV.17: Countries' classification by military in politics median over 1990-2015

No.	CO2-PS pattern	Country	Median_MilitaryPol
1	M. increasing	Mongolia	5
2	M. increasing	Zambia	5
3	[U-shaped]	Papua New Guinea	4.375
4	M. increasing	Cameroon	4
5	[inverted-U shaped]	Malawi	4
6	[U-shaped]	Morocco	4
7	[U-shaped]	Tunisia	4
8	[U-shaped]	Yemen, Rep.	4
9	[inverted-U shaped]	Mali	3.5
10	[inverted-U shaped]	Bolivia	3
11	[inverted-U shaped]	Honduras	3
12	M. increasing	El Salvador	2.73
13	[inverted-U shaped]	Bangladesh	2.5
14	[inverted-U shaped]	Sierra Leone	2.25
15	[inverted-U shaped]	Niger	2.105
16	[inverted-U shaped]	Vietnam	2.085
17	[inverted-U shaped]	Angola	2
18	[U-shaped]	Mozambique	2
19	M. increasing	Nigeria	2
20	[inverted-U shaped]	Sri Lanka	2
21	[inverted-U shaped]	Uganda	2
22	[inverted-U shaped]	Guinea-Bissau	1.5
23	[inverted-U shaped]	Madagascar	1.25
24	[inverted-U shaped]	Togo	1
25	M. increasing	Haiti	0.25
26	[inverted-U shaped]	Myanmar	0.25
27	M. decreasing	Congo, Rep.	0

Table A - IV.18: List of Non-Annex I parties of the Kyoto Protocol to the UNFCCC based on UN Treaty Collection-Status of Treaties

Non-Annex I Party	Signature	Ratification	Accession
Angola			8 May 2007
Bangladesh			22 October 2001
Bolivia	09 July 1998	30 November 1999	
Burkina Faso			31 March 2005
Cameroon			28 August 2002
Congo, Dem. Rep			23 March 2005
Congo Rep.			12 February 2007
Côte d'Ivoire			23 April 2007
Egypt	15 March 1999	12 January 2005	
El Salvador	08 June 1998	30 November 1998	
Ethiopia			14 April 2005
Gambia			01 June 2001
Ghana			30 May 2003
Guinea			07 September 2000
Guinea-Bissau			18 November 2005
Haiti			06 July 2005
Honduras	25 February 1999	19 July 2000	
India			26 August 2002
Indonesia	13 July 1998	03 December 2004	
Kenya			25 February 2005
Liberia			5 November 2002
Madagascar			24 September 2003
Malawi			26 October 2001
Mali	27 January 1999	28 March 2002	
Moldova			22 April 2003
Mongolia			15 December 1999
Morocco			25 January 2002
Mozambique			18 January 2005
Myanmar			13 August 2003
Nicaragua	07 July 1998	18 November 1999	
Niger	23 October 1998	30 September 2004	
Nigeria			10 December 2004
Pakistan			11 January 2005
Papua New Guinea	02 March 1999	28 March 2002	
Philippines	15 April 1998	20 November 2003	
Senegal			20 July 2001
Sierra Leone			10 November 2006
Sri Lanka			3 September 2002
Tanzania			26 August 2002
Togo			2 July 2004
Tunisia			22 January 2003
Uganda			25 March 2002
Ukraine	15 March 1999	12 April 2004	
Vietnam	03 December1998	25 September 2002	
Yemen			15 September 2004
Zambia	05 August 1998	07 July 2006	
Zimbabwe			30 June 2009

Notes: The information corresponds to April 2020 status of Non-Annex I parties, retrieved from the following webpage: https://treaties.un.org/Pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-a&chapter=27&clang=_en.

General Conclusion

1. Key findings

The ongoing societal transformations place the relationship between economic development and environmental quality among the central and most debatable topics in economics and many other related areas.

Although the strand of literature regarding the effects of economic development on environmental degradation has a history of several decades, the complexity of the link and the empirical and theoretical findings that do not provide a solid consensus seems to instigate even more the flourishing of the research in the field. However, many aspects still need to be elucidated and understood in more depth, especially with respect to transition and developing economies, whereas the dynamics of economic phenomena make this mission much challenging. Indeed, a deeper understanding of the implications that the relationship between economic development and environmental pollution has on society as a whole is a topic of interest not only for academia but also for decision-making bodies responsible for designing, implementing, and monitoring the sustainable development policies.

This thesis explored the link between economic development and environmental quality, by looking holistically at the effects of economic development, in terms of its economic, social, and political dimensions, on the environmental pollution for developing and transition economies. It comprises four chapters, first corresponding to a literature survey, and each of the next three provided an empirical essay, which addresses different aspects of the potential impact of economic development on environmental quality.

Chapter I brought together, within a literature survey, the theoretical aspects behind the EKC hypothesis and a substantial number of the last's decade empirical works examining the pollution-growth nexus via the EKC hypothesis. It also provided a short descriptive practical exercise, whose purpose was to offer supplementary intuitions on this debatable topic relative to theoretical and empirical aspects unveiled by the literature review. This first essay of the thesis contributed to the literature by giving various essential insights regarding the link between economic growth and environmental pollution in developing and transition economies. First, our updated empirical survey—which covered both the time-series and panel data studies, and offered some new perspectives on modeling the pollution-growth nexus—revealed that a considerable number of papers found a long-term link between environmental degradation and economic growth. This result not only consolidates the EKC's innate nature but also may signal that the suggestions and progress put forward by the economic and econometric theory have facilitated the improvement of the related research design. Second, several of these works revealed a bell-shaped pattern between indicators, indicating that the EKC hypothesis may be at work. In this direction, we can build around the intuition that industrialized economies have represented a model for developing and transition states in terms of how they have managed to cope with the potential environmental threats posed by economic growth. Certainly, having already an example in this regard, it is much easier for developing economies to address this fight against pollution and to learn from the mistakes of their predecessors to succeed in switching the increasing pollution trend in favor of the environment, even for lower income levels (Munasinghe, 1999; Dinda, 2004; Yao et al., 2019). However, some of these studies that initially unveiled a bell-shaped pattern later concluded that the turning point was outside the income range. In such cases, the identification strategy may lack rigorousness (see e.g. Bernard et al., 2014) and/or the findings may suggest that the pollution is increasing along with economic growth (see e.g. Cole et al., 1997; Stern & Common, 2001; Lieb, 2003). Indeed, either of the two emerges, demands a reassessment of the research design (e.g. model specification, assumptions, econometric methodology, identification strategy) to detect and correct the potential weaknesses and/or ambiguities. Third, our short illustrative empirical exercise pointed out the importance of employing complementary techniques, even the simplest, to ensure the findings' robustness.

Chapter II studied the link between CO2 and GDP for CEE economies over the period 1996-2015. On the one hand, the findings unveiled an increasing nonlinear link between indicators at the aggregate level. Mainly, we found that the relationship changed its concavity for a computed GDP level at around 19,900 US$. Thus, in the proximity of this GDP value, the increase in CO2 remains relatively steady, while the impact's amplitude increases once we move to the right and left of this estimated value. Moreover, the results showed a strongly negative significant effect of economic freedom on environmental degradation, emphasizing that the transition process from a planned towards a market economy had beneficial consequences on the environment. Opposite, not surprisingly, energy consumption was found to increase CO2 emissions. These aggregated findings remained qualitatively unchanged when we employed different estimation techniques, enlarged the cointegration vector with various exogenous factors, and substituted the environmental quality indicators. On the other hand, at the disaggregated level, the CO2-GDP nexus was described by a wide spectrum of patterns. The estimates revealed more pronounced nonlinearities in countries such as Croatia, Estonia, Poland, and Slovakia, where a third-order polynomial link was at work, followed by Bulgaria, Czech Republic, Hungary, and Latvia, which showed a quadratic relationship. More precisely, an inverted-*N* (*N*) curve was found in Poland and Slovakia (Croatia and Estonia), while the pattern seemed to be concave (convex) in the Czech Republic and Hungary (Bulgaria and Latvia). Moreover, the findings unveiled a linearly increasing relationship in Lithuania and the lack of a statistically significant link in Romania and Slovenia.

In **Chapter III**, we explored how external disturbances to output and urbanization reflect on the aggregated and sector-specific CO2. In doing so, we focused on a broad group of developing economies spanned over 1992-2015. We assumed a transmission mechanism that comprised both energy efficiency and renewable energy—two of the main tools used worldwide in fighting climate change. From the aggregate perspective, shocks to GDP, urbanization, and energy intensity triggered, both on impact and cumulated over a twenty-year horizon, an increase of CO2 emissions. Particularly, concerning the long-term responsiveness of CO2 in the aftermath of output and urbanization shocks, the pattern suggested that a threshold effect compatible with traditional and urbanization-related EKC may be at work. Conversely, positive external disturbances to renewable energy led to a decrease in current and future levels of CO2 in our group of developing economies. Likewise, as expected, the results showed an inertial behavior of CO2 emissions during the period analyzed. Although the findings were robust across an extensive set of alternative specifications (i.e. different order of variables into the transmission channel, when we applied several restrictions with respect to both *N* and *T* dimensions and included several additional exogenous factors into the model), they varied depending on the countries' level of development and their Kyoto Protocol ratification/accession status. Besides, the sectoral-specific analysis revealed that the CO2 from transport, buildings, and non-combustion sector are more likely to increase in the future, considering that external shocks to GDP and urbanization triggered a decrease only in emissions related to power-industry and other industrial combustion sector.

Chapter IV focused on the effect of political stability on environmental quality. We contributed to the related literature by looking at the long-run impact of political stability as a whole (captured by the ICRG index) on CO2 pollution while allowing different short-run dynamics between variables. First, we found that over the period 1990-2015 for a broad sample of low and lower-middle income economies, the link between indicators was characterized by a threshold effect. More precisely, political stability significantly reduced CO2 pollution after exceeding the threshold value of roughly 66.47, expressed in political stability index points. Thus, according to the ICRG index, this value corresponds to a moderate level of political stability. Second, this result was strongly robust when we employed a set of alternative estimation techniques, included several additional control factors, altered the sample based on various criteria, disaggregated the PS index on subcomponents, used different computation methods of the composite PS index, and provided an alternative approach in searching for a potential threshold effect. Third, these findings seemed to be sensitive to various structural characteristics (i.e. the level of economic development, Kyoto Protocol ratification/accession status, and legal inheritance) and alternative global and local environmental degradation measures. Finally, the country-specific analysis revealed the complexity of the CO2-political stability nexus. Disregarding cases for which the relationship between variables was not statistically significant, one the one hand, the estimates showed that political stability might increase CO2 emissions in countries such as Morocco, Mozambique, Papua New Guinea, Tunisia, Yemen (where a U-shaped curve was at work) and also Cameroon, El Salvador, Haiti, Mongolia, Nigeria, and Zambia (where a positive link was unveiled). On the other hand, a decreasing trend in CO2 along with an increase in political stability was documented for countries where the relationship follows either a bell-shaped (Angola, Bangladesh, Bolivia, Guinea-Bissau, Honduras, Madagascar, Malawi, Mali, Myanmar, Niger, Sierra Leone, Sri Lanka, Togo, Uganda, Vietnam) or a decreasing pattern (Republic of the Congo).

2. Policy implications, and future research avenues

At the global level, the overall mission to foster sustainable development is also outlined through the well-known 17 Sustainable Development Goals (SDGs), the upgraded successor of the Millennium Development Goals (MDGs), both defined under the United Nations' (UN) umbrella. This comprehensive set of goals—which are planned to be achieved by 2030—revolves in a cohesive manner around the fundamental pillars of economic development, including its economic, social, and political aspects, and, more importantly, the mutuality between them. Moreover, achieving them requires all society entities' combined effort, from population to various non(governmental) organizations and associations. Thus, bearing in mind these goals and other sub- and supra-(national) related objectives, it becomes imperative to formulate environmental policies appropriate to particular contexts in order to ease the environmental quality enhancement while promoting economic development. The present thesis contributing to the augmentation of knowledge regarding economic development effects on environmental quality in developing and transition countries may provide some valuable policy recommendations in this direction.

In light of **Chapter I**, several developing and transition economies managed to switch their increasing pollution trend in the context of ongoing economic growth. Also, some of them achieved the tipping point for a lower income level than their industrialized counterparts. Therefore, from a policy perspective, they can provide solid know-how for states which are still facing increasing environmental degradation as they move towards high industrialization. However, developed countries' strategies to cope with rising pollution following economic expansion should not be forgotten either, whether they have led to positive results or have revealed some practices less suited to different situations which require improvement. Furthermore, considering both the progress of statistics/econometrics and economic theories in the field, the policy implications should be formulated following a rigorous analysis. Thus, it becomes essential to guarantee, to a certain extent, the robustness of the results. Not to mention that it is generally acknowledged that the pollution-growth patterns [and when the relationship form allows, their computed threshold(s)] are closely related to the sample, period, empirical methodology, and variables considered. As such, ensuring the accuracy of the results, which are usually the cornerstone of adjacent policies, becomes even more crucial.

Chapter II's findings showed that despite a positive aggregated effect of economic growth on CO2, some CEE countries succeeded in decreasing associated emissions and fostering economic growth. In this vein, two main policy recommendations could be formulated. On the one hand, judging from the aggregate standpoint, the policymakers need to focus more on the environmental conditions of CEE countries to limit the adverse effects that economic growth may have on the quality of the environment. On the other hand, tackling the country-peculiarities more in-depth may help improve environmental policies at the disaggregated level and contribute to the readjustment of those at the EU level. Indeed, with regard to the latter, more comprehensive integration of country-level heterogeneities into the overall EU environmental objectives would probably be an added value from the policy perspective. Moreover, some imminent correlations that must be interpreted prudently indicate that a future reduction in CO2 in the context of economic expansion may be more easily attained in countries with green and significant industry sectors, where the high labor productivity upholds complex techniques.

Chapter III provided valuable insights regarding the current and future behavior of aggregated and sectoral-specific CO2 emissions following external disturbances to output and urbanization, and, more importantly, how renewables and energy efficiency interplay in this transmission channel. Given the relatively fast industrialization and urbanization process in developing economies, it brought attention to the crucial implications they may imply on CO2 pollution. Thus, based on our findings, the growth-promoting, and urban planning policy design need to better account for the potentially harmful consequences they may cause to the environment. Indeed, all of these, together with defining preventive measures and implementing appropriate environmental policies, may facilitate the change of the upward trend of pollution earlier and for a lower degree of urbanization and economic growth. More on this matter, while renewable energy has proven to be a vital factor in reducing pollution, the greater incentive of energy efficiency projects can provide additional benefits to environmental quality. Besides, considering that more accentuated increases in CO2 may be encountered mostly in lower-middle income countries and those states which ratified/acceded to the Kyoto Protocol before it entered into force, their governments must pay increased attention upon environmental conditions and periodically reevaluate the associated strategies to ensure greater effectiveness. Likewise, the policy actions should be extensively directed towards the sectors with the highest propensity to increase CO2 levels, namely the transport, buildings, and non-combustion sector.

The last chapter (**Chapter IV**) strived to draw attention to the implications of the political system's stance on CO2 pollution in countries that are more likely to face political distress episodes–developing economies. First, the aggregated findings revealed that reaching a relatively moderate to a high level of political stability can help in improving environmental conditions. In this regard, effective and tight synergy among governmental and nongovernmental structures could boost political stability, which, in turn, may ease policy implementation. Accordingly, more appropriate and efficient environmental policies can be designed, while also their monitoring and adaptation can be carried out under more favorable circumstances. Second, in light of heterogeneities unveiled regarding the aggregated relationship, special attention should be paid to the group of states for which political stability has a positive effect on CO2 (i.e. economies with a lower-middle income, civil law inheritance, and those which ratified or acceded to the Kyoto Protocol after 2005). On the one hand, in these countries, possible political unrest episodes may hamper the achievement of political stability optimum that would generate a decrease in CO2. From a policy perspective, for example, trying to address the business environment's needs, along with those of various ethnic groups, can significantly reduce the potentially related strikes. Thus, the balance of the political framework would be less affected. On the other hand, a positive impact of political stability on CO2 may occur following the more relaxed decision-makers' attitude that, eventually, may spur the adoption of less stringent policies. In this manner, continuous monitoring of the environmental quality can signal some potential deviations from the desired trajectory and, thus, urging the adoption of consistent decisions. Given that additional political stability seemed to exacerbate the emissions of different local and global pollutants, the above may also be applied in their case; all the more that, usually, local pollutants are also intensely regulated at the national level, and the international pressure may be lower compared to global pollutants. Third, following the country-specific analysis, political stability should be improved in some developing countries to impact environmental quality positively. While only an in-depth analysis at countries' level can help determine more accurately the specific triggers (both formal and informal ones) of political instabilities, a simple descriptive analysis—that must be treated with much caution—indicate that the industrialization process, high unemployment/globalization, limited involvement of the military in politics, and from an environmental perspective a lower forest rents share in GDP, may induce different political-related disequilibria. Therefore, by approaching these aspects more closely, one can identify possible political disturbances' sources and apply coercive measures. Concurrently, the quality of the environment may benefit following these actions.

Being unlikely to find a formula that fits all contexts, the additional results unveiled by this thesis suggest that increasing economic freedom (especially in CEE countries) and energy efficiency, together with the gradual transition to renewable energy sources, may be decisive factors in ensuring sustainable development. Moreover, the intuitions that can be derived following the overall thesis' conclusions may also indicate that (i) a fruitful international collaboration, along with (ii) implementation of appropriate policies such as environmentally-friendly measures, low-carbon growth strategies, the internalization of externalities, or the adoption of regulations against pollution-havens, could boost the environmental quality in developing and transition countries, and provide long-term sustainability.

The present thesis offered new empirical evidence and insights on a contemporary but at the same time, controversial topic, namely, the relationship between economic development and environmental quality. However, given the phenomena' dynamism, the results should not be seen as final answers, but as efforts to understand some of the consequences that economic development has on environmental quality in developing and transition economies. Also, through our findings, we hope to smooth the path to new research in this direction.

Naturally, the first chapter could be redesigned into a meta-analysis to better assess the literature in the field and provide measurable findings regarding the sources of potential differences in the pollution-growth nexus, seen through the prism of EKC. Seeking answers that complement the conclusions drawn on the grounds of our three empirical essays, future work may emerge in several directions. First, given that the energy sector is a major contributor to CO2 pollution, exploiting the effect of more disaggregated energy sources (see e.g. Antonakakis et al., 2017; Naminse & Zhuang, 2018) on CO2 could provide valuable knowledge on those specific items that need to be adjusted in order to minimize the associated pollution. Second, regarding the environmental quality responsiveness to various (imminent) disturbances, assessing the impact of different types of crises on CO2 may enhance the comprehension of associated dynamics (see e.g. Jalles, 2019). Third, it would be quite insightful and challenging to look at more disaggregated country-specific data to discern better the heterogeneities revealed by investigating the economic development-environmental quality nexus at the aggregated (macroeconomic) level. Fourth, tackling the impact of (unexpected) changes in environmental regulation at the national level, and particularly the way firms adjust their activity to cope with such fluctuations (possibly in relation to their production factors, and particularly research and development investment, see Alam et al., 2019), could provide a clearer understanding of this area. Fifth, examining the population's awareness in relation to environmental objectives and their integration in governments' welfare function, possibly from a political economy perspective, could foster our comprehension of motivations and challenges related to the promotion of environmental-friendly economic development. Finally, regarding the econometric strategy, especially the nonlinear modeling between indicators, future research may consider employing—if conjecture allows—complementary approaches such as Panel Threshold Regression (PTR) (see Hansen, 1999) and Panel Smooth Threshold Regression (PSTR) (see Gonzalez et al., 2005) models, different semi- and non-parametric techniques, and even empirical methodologies that move beyond the classical time-domain.

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General Conclusion

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