University of Neuchatel

Institute of Economic Research

IRENE, Working paper 15-03

CO_2 Emissions and Greenhouse Gas Policy Stringency[1]:

An Empirical Assessment

Marcel Probst and Caspar Sauter***

* *University of Lausanne, Faculty of Business and Economics*

** *University of Neuchatel, Faculty of Economics and Business*

1) Both authors contributed equally to the paper and are listed in alphabetical order.

UNIVERSITÉ DE NEUCHÂTEL

Institut de recherches économiques

CO_2 Emissions and Greenhouse Gas Policy Stringency[1]
-
An Empirical Assessment

Marcel Probst[a], Caspar Sauter[b,*]

[a] *University of Lausanne, Faculty of Business and Economics*
[b] *University of Neuchatel, Faculty of Economics and Business*

Abstract

This paper investigates how greenhouse gas (GHG) policy stringency affects anthropogenic CO_2 emissions using a new GHG policy stringency indicator and a structural spatial VAR approach. We estimate an average country-specific elasticity of CO_2 emissions to GHG policy stringency, and assess the role of channels over which policy stringency affects CO_2 emissions. We then ascertain how GHG policy stringency affects sectoral CO_2 efficiency and the sectoral composition of economies. Results indicate that a country with no GHG regulations can achieve a 15% reduction of its CO_2 emissions by adopting the stringency level of the most regulated country. In addition, increasing GHG policy stringency improves sectoral CO_2 efficiency, and decreases production in CO_2 intensive sectors thereby altering the sectoral composition. At last, policy induced CO_2 reduction costs in terms of GDP are relatively large, but 4 times lower for developing compared to developed countries.

Keywords: CO_2, composition effect, environmental policy stringency, greenhouse gas emissions, impulse response functions, scale effect, spatial VAR, structural VAR, technique effect

1. Introduction

An accelerated warming of the climate system increases the likelihood of "severe, pervasive and irreversible" impacts. Those risks can be mitigated by limiting the rate and magnitude of climate change (IPCC, 2014). To do so, anthropogenic greenhouse-gas (GHG) emissions have to be reduced as they are "extremely likely" to be the dominant cause of the observed global warming

[1] Both authors contributed equally to the paper and are listed in alphabetical order.

☆ JEL classification: Q53, Q54, Q58, O13

* Corresponding author

Email address: caspar.sauter@unine.ch (Caspar Sauter)

(IPCC, 2013). This calls for a tightening of GHG policy regimes and raises a set of questions regarding their effects. Does an increase in the stringency of a countries' GHG policy regime reduce anthropogenic GHG emissions? What are the opportunity costs of a policy induced CO_2 emission reduction? And if CO_2 can be reduced, do stricter GHG policies increase the GHG efficiency of sectors or alter the composition of dirty and clean sectors of an economy? The latter question is important when taking a global perspective, as the impact on global emissions depends on how a reduction in country emissions has been achieved. This paper attempts to answer those questions by empirically investigating the relationship between GHG policy stringency and anthropogenic carbon dioxide emissions.

The literature on environmental policy evaluation contains assessments focusing on a single country or a specific industry (e.g., Cole et al. (2005) or Gamper-Rabindran and Finger (2013)), qualitative assessments of environmental policies (e.g., Aldy et al. (2003), or Taylor et al. (2012)), quantitative assessments of single policy measures (e.g., Anderson and Maria (2011)), as well as model-based ex-ante assessments of environmental policies (e.g., Manne et al. (1995), Tol (1999), Barker et al. (2007) or Clarke et al. (2009)). But, to the best of our knowledge, few papers empirically evaluate the impact of environmental policy stringency on anthropogenic GHG emissions using either panel or country cross-sectional data. In the following review, we exclusively focus on those contributions.

Most of them originate from the literature analyzing the links between economic development and pollution, as well as the links between trade and pollution. Panayotou (1997) finds a significantly negative relation between ambient SO_2 levels and a general policy index reflecting the degree of enforcement of contracts in different political systems. De Bruyn (1997) provides evidence that per capita GDP and environmental policy stringency (proxied by abatement targets from the Convention on Long Range Transboundary Air Pollution) are positively correlated. He points out that this could partly explain why pollution seems to curb downwards at high income levels. Esty and Porter (2005) wrote the first paper which puts the assessment of environmental policy impacts at the center of attention. They use a variety of environmental performance indicators (including SO_2 concentrations) and the environmental regulatory regime index (ERRI) as the policy variable. The latter is based on the World Economics Forum's (WEF) Global Competitiveness Report Survey. Results indicate a significantly negative relation of SO_2 concentrations and environmental policy stringency. However, they state that their results must be seen as preliminary and that causal linkages remain unproven due to data and econometric limitations. Huang and Barker (2012) and Huang et al. (2012) investigate the impact of clean development mechanism (CDM) projects on CO_2 emissions. They provide evidence in support of a CO_2 emission reduction associated with

CDM project developments. A result which can be interpreted as evidence for a negative relationship between pollution and environmental policy stringency. Gani (2012) shows that the general World Bank indicators of political stability, rule of law, and control of corruption are negatively correlated with CO_2 emissions per capita. Aichele and Felbermayr (2013) find that increased stringency, as proxied by the ratification of binding Kyoto commitments, significantly lowers domestic CO_2 emissions in committed countries. Using cross-sectional data for OECD countries, Calbick and Gunton (2014) show that environmental governance, proxied by the WEF's Global Competitiveness Report Executive Opinion Survey, is negatively correlated with per capita GHG emissions, and explains about 7% of its cross-sectional variation.

These findings provide some evidence that more stringent environmental policy is negatively associated with anthropogenic GHG emissions. However, three limitations of the current empirical literature can be identified. Firstly - as noted by Esty and Porter (2005) - it is difficult to obtain good measures of environmental policy stringency. Due to this relative scarcity of sound data, previous contributions use either general government indicators, survey based indexes or policy specific dummies. Moreover, as Sauter (2014) points out, the concepts of environmental policy and environmental policy stringency are rather broad. They potentially encompass a diverse array of measures like the regulation of hunting or the protection of a particular species. Hence, to evaluate the impact of policy stringency on GHG emissions, it is crucial to use an index quantifying GHG policy stringency rather than general environmental policy stringency or - even worse - general government indicators. Secondly, GHG policy stringency and CO_2 emissions, as well as the channels through which those variables influence one another, have not yet been subject to simultaneous analysis. Thirdly, no attention has been put to empirically disentangle the overall effect of GHG policy stringency. Besides reducing absolute production levels, a country's CO_2 emissions may be reduced through a CO_2 efficiency improvement of some or all of its sectors, or by altering the relative production shares of dirty and clean sectors. Since the contribution of Grossman and Krueger (1991), the literature labels those effects as scale, technique and composition effect, respectively.

Focusing on anthropogenic CO_2, we address those limitations by using the newly proposed indicator by Sauter (2014) which allows to quantify country GHG policy stringency. In order to deal with potential endogeneity issues, and in the absence of suitable instruments, we use a spatial structural VAR model proposed by Di Giacinto (2010). Finally, we pursue a two folded estimation strategy. To estimate the size of the overall effect of GHG policy stringency on CO_2 emissions, we use aggregated country data. The country-wide analysis allows us as well to assess over which channels GHG policy stringency operates, and thus to estimate the policy induced scale effect. It also allows to measure opportunity costs of a CO_2 emission reduction in terms of GDP. In order to disentangle the overall country effect, we rely on industry specific country data. We assess if increased GHG policy stringency alters the sectoral composition within countries and increases CO_2 efficiency of sectors. Hence, we do not perform a classical decomposition but empirically estimate GHG policy induced scale, technique and composition effects. We subsequently perform extended robustness tests to asses the validity of our results.

The remainder of the paper is organized as follows: Section 2 describes the data used in the estimation, section 3 outlines our methodological approach, preliminary test results are reported in section 4, results are displayed in section 5, section 6 reports robustness tests which are followed by a discussion in section 7.

2. Data

The economy-wide and the sector level dataset are described in subsections (2.1) and (2.2), respectively. A general overview and summary statistics of the variables is provided in Table (1). The table also contains a column listing papers supporting the variable use. Together, those variables cover the economic, socio-demographic and climatic factors the literature on anthropogenic country GHG emissions finds to be relevant. For a recent summary of this literature, refer to Calbick and Gunton (2014).

2.1. Economy-wide Dataset

The economy-wide dataset covers yearly observations for 46 developed and developing countries (see Table (A3) in the appendix) accounting for 71% of the world's CO_2 emissions over the time range 1990-2010. Anthropogenic CO_2 emissions, GHG policy stringency, GDP, technology and energy prices are considered endogenous. In addition, we include a set of exogenous variables: corruption, cooling degree days and heating degree days, the latter two capture climatic conditions.

Anthropogenic CO_2 emissions in kilo tons and real *GDP* are taken from the World Bank. The variable quantifying *GHG policy stringency* is the "Broad GHG input index" taken from Sauter (2014). The index is a count variable of all laws which aim to reduce GHG emissions. It can therefore be seen as a de-jure indicator which captures statutory laws on the books. By using such a variable, we avoid the conceptual problems faced by previous studies using general environmental policy stringency proxies or general government indicators. Furthermore, this index is - to our best knowledge - the only GHG policy stringency measure covering our sample. The evolution of the index by country is summarized in Figure (A1) in the Appendix. This index also has some limitations. It does not incorporate changes of policy implementation stringency over time. To cope with this issue, we include *corruption* as a proxy for general policy implementation stringency. Also, due to the equal weighting approach, the introduction of each new nation-wide law is considered to correspond to an equal sized increase in GHG policy stringency. However, in the absence of theoretical work allowing to weight different policy measures in terms of GHG policy stringency, any weight approach remains an arbitrary choice. We also considered the use of two alternative measures. Firstly, the most widely used indicator of environmental policy stringency provided by the WEF (World Economic Forum, 2014). This index is survey based and thus measures only perceived environmental policy stringency and is only available from 2004 onward.[2] Secondly, the recently developed index of environmental policy stringency proposed by Botta and Kozluk (2014). This index has, however, a considerably smaller coverage in terms of world CO_2 emissions, excludes developing countries and does not solely focus on GHG policies. The country specific level of *technology* is approximated by the count of filed patents. A patent is taken as an observation the year the patent is filed in a national patent authority. We use the IEA indicator of energy end use prices including taxes as our *energy price* variable. Approximately 20 % of the countries from our dataset are not included in the IEA database. The missing data are computed with the World Bank's (World Bank, 2014) two-years interval country specific data on pump gasoline prices. We then linearly interpolate the country specific World Bank data on the world crude oil price index from the IMF Primary Commodity Prices dataset (IMF, 2014) to fill the two year gaps. After verifying that the within country correlation between the interpolated World Bank pump gasoline price data and the IEA data is sufficiently high, we use the interpolated data on pump gasoline prices as proxy for energy prices for the countries which are not in the IEA dataset.

In addition to the endogenous variables, three exogenous variables are included in our model: The variable *corruption* is used as a proxy for country differences in the implementation stringency of policies. *Climatic conditions* that directly influence the CO_2 emissions are approximated by cooling degree days (CDD) and heating degree days (HDD). The former quantifies the cooling sufficient to neutralize the deviation of surface temperature from a standard comfort level. The latter quantifies the heating sufficient to neutralize the deviation of surface temperature from a standard comfort level.

[2]Nevertheless, we use this index to assess the robustness of our results and obtain qualitatively similar results.

2.2. *Sector-level Dataset*

The sector level dataset covers yearly observations for the time range 1995-2009 for 34 sectors and 35 countries (see Table (A3) in the appendix). The countries in the sector-level dataset account for roughly 57% of world CO_2 emission over the covered period. We keep the same variables as in the economy wide specification but use sectoral data where it is available and appropriate.

Sectoral anthropogenic CO_2 and *sectoral value added* are taken from the World Input Output Database. Given that the *GHG policy stringency* index measures overall country GHG policy stringency, all sectors may, to a greater or lesser extent, be affected. We thus use the country wide policy stringency variable as described in section (2.1). The *energy price* level is also identical to the one in the country-wide specification. For the sector-level estimation, we use the per cent of sector-specific high-skilled working hours as compared to total sector-specific working hours as our measure of *sectoral technology.* A relative increase in working hours of highly skilled is considered to be equivalent to an improvement in the sector-specific technology.

All exogenous variables are identical to the ones described in section (2.1). The climatic and socio-demographic factors influencing country CO_2 emissions stay the same independently of the level of analysis (economy-wide or sectoral). Note that as part of the robustness analysis, we aggregate the sector level dataset in order to dispose of a second economy-wide dataset.

3. Methodology

In order to analyze the direct and indirect effect of policy stringency on CO_2 emissions, we use a spatial VAR. This is because GHG policy stringency, the technology level, energy prices, GDP and CO_2 emissions are interdependent variables. Estimating each individual effect on CO_2 emissions within such an endogenous system would require a series of instrumental variables. Those are either difficult to define, or come with a high cost in terms of data loss. A VAR, however, is suitable to take into account the dynamic structure of our data generating process and allows the use the full dataset. In addition, by embedding all individual linkages into one global estimation, it allows for a subsequent simulation analysis via impulse response functions.
Hence within our VAR, anthropogenic CO_2 emissions, GHG policy stringency and the transmission channels are treated both as endogenous and predetermined variables. In addition, to take into account changes in the external demand for input factors or intermediate goods, we allow the variables to affect one another across national borders by including a spatial lag.

Table 1: Data: Description, Sources, Support and Descriptive Statistics

Variable Name	Variable Description	Specification	Data Source	Selected Papers supporting Variable Use	Descriptive Statistics	
Country CO2 emissions	Anthropogenic CO2 emissions in kilotons.	Endogenous, economy-wide	World Bank (2014)	-	Mean Min/Max Sd	407664.1 1543.81/8286892 1045659
Sectoral CO2 emissions	Sectoral emissions of CO2 in kilotons.	Endogenous, sector-level	World Input-Output Database (2012)	-	Mean Min/Max Sd	13285.04 0/3326279 94337.46
GHG Policy Stringency	GHG policy stringency index, bound between 0 and 1. Higher values indicate higher stringency.	Endogenous, economy & sector-level	Sauter (2014)	Panayotou (1997), De Bruyn (1997), Hettige et al. (2000), Esty and Porter (2005) Huang and Barker (2012), Huang et al. (2012), Gani (2012) , Calbick and Gunton (2014)	Mean Min/Max Sd	0.21 0/0.99 0.18
Country GDP	GDP, constant USD, 2005.	Endogenous, economy-wide	World Bank (2014)	Neumayer (2002), Stern (2004), Copeland and Taylor (2004), Esty and Porter (2005), Raupach et al. (2007), Rosa and Dietz (2012), Gani (2012), Calbick and Gunton (2014)	Mean Min/Max Sd	7.63E+11 3.52e+08/1.37e+13 1.79E+12
Sectoral Value Added	Sectoral value added, constant 1995 USD.	Endogenous, sector-level	World Input-Output Database (2012)	Neumayer (2002), Stern (2004), Copeland and Taylor (2004),Esty and Porter (2005), Raupach et al. (2007), Rosa and Dietz (2012), Gani (2012), Calbick and Gunton (2014)	Mean Min/Max Sd	25883.51 0/1360052 84965.64
Country Technology	Patent application data based proxy. Higher values indicated higher country technology levels.	Endogenous, economy-wide	World Bank (2014)	Dietz and Rosa (1997), Lindmark (2002), Bruvoll and Medin (2003), Fan et al. (2006), Lantz and Feng (2006), Rosa and Dietz (2012)	Mean Min/Max Sd	88.92 32.05/201.19 23.69
Sectoral Technology	Sectoral high skilled hours in total hours, percentage points, higher values indicated higher sectoral technology levels.	Endogenous, sector-level	World Input-Output Database (2012)	Dietz and Rosa (1997), Lindmark (2002), Bruvoll and Medin (2003), Fan et al. (2006), Lantz and Feng (2006), Rosa and Dietz (2012)	Mean Min/Max Sd	21.81 3.9/61.3 12
Energy price index	IEA energy price index, completed with WB and IMF data (c.f. section). Higher values indicate higher energy price levels.	Endogenous, economy & sector-level	IEA (2014), IMF (2014), World Bank (2014)	Burgess (1990), Moomaw and Unruh (1997), Olsthoorn (2001), Lindmark (2002), Calbick and Gunton (2014)	Mean Min/Max Sd	18388.33 2/384201 60785.35
Corruption	6 point corruption index, bound between 7 and 1. Where 7 indicates no corruption and 1 indicates a high degree of corruption.	Exogenous, economy & sector-level	International Country Risk Guide (2014)	Robbins (2000), Damania (2002), Fredriksson and Svensson (2003), Welsch (2004), Sauter (2014)	Mean Min/Max Sd	3.97 01.06.1967 1.32
CDD	Cooling Degree Day, measured as the annual sum of negative deviations of daily mean surface temperatures from a reference standard of 18.3 degree Celsius.	Exogenous, economy & sector-level	Wheeler (2012)	Considine (2000), Neumayer (2002), York et al. (2003), Isaac and van Vuuren (2009), Calbick and Gunton (2014)	Mean Min/Max Sd	591.84 1/3449 783.32
HDD	Heating Degree Day, measured as the annual sum of positive deviations of daily mean surface temperatures from a reference standard of 18.3 degree Celsius.	Exogenous, economy & sector-level	Wheeler (2012)	Considine (2000), Neumayer (2002), York et al. (2003), Isaac and van Vuuren (2009), Calbick and Gunton (2014)	Mean Min/Max Sd	5318.88 134/10654 2530.37

Following Di Giacinto (2010), our empirical model with the number of temporal lags P looks as follows:

$$\Gamma_0 Y_t = \sum_{p=1}^{P} \Gamma_{1p} Y_{t-p} + \sum_{p=0}^{P} \Gamma_{2p} X_{t-p} + \Psi_i + \Lambda_t + U_t \tag{1}$$

with $Y_t = [I_t, T_t, E_t, \Omega_t, H_t]'$, the vector of the endogenous variables: GHG policy stringency index, technology, energy prices, GDP and CO_2 emissions, respectively. $I_t = [\iota_{1t}, \iota_{2t}, ..., \iota_{Nt}]$, $T_t = [\tau_{1t}, \tau_{2t}, ..., \tau_{Nt}]$, $E_t = [\epsilon_{1t}, \epsilon_{2t}, ..., \epsilon_{Nt}]$, $\Omega_t = [\omega_{1t}, \omega_{2t}, ..., \omega_{Nt}]$ and $H_t = [\eta_{1t}, \eta_{2t}, ..., \eta_{Nt}]$ where I_t, T_t, E_t, Ω_t and H_t are vectors of the panel units $1, ..., N$ (countries or sectors). Ψ_i and Λ_t include a set of dummies to account for panel specific fixed effect and period-specific common shocks, respectively. U_t is a vector of structural error terms where $\sum_{U_t}$ is diagonal, and contains a heterogeneous set of variances. Γ_{1p} and Γ_{2p} assume the following form:

$$\Gamma_p = \begin{pmatrix} A_p^{\iota\iota} & A_p^{\iota\tau} & A_p^{\iota\epsilon} & A_p^{\iota\omega} & A_p^{\iota\eta} \\ A_p^{\tau\iota} & A_p^{\tau\tau} & A_p^{\tau\epsilon} & A_p^{\tau\omega} & A_{\tau\eta p} \\ A_p^{\epsilon\iota} & A_p^{\epsilon\tau} & A_p^{\epsilon\epsilon} & A_p^{\epsilon\omega} & A_p^{\epsilon\eta} \\ A_p^{\omega\iota} & A_p^{\omega\tau} & A_p^{\omega\epsilon} & A_p^{\omega\omega} & A_p^{\omega\eta} \\ A_p^{\eta\iota} & A_p^{\eta\tau} & A_p^{\eta\epsilon} & A_p^{\eta\omega} & A_p^{\eta\eta} \end{pmatrix}$$

$$p = 1, ...P$$

where $A_p^{rk} = \sum_{s=0}^{S} \tilde{\Gamma}_{ps}^{rk} W_s$ and $\tilde{\Gamma}_{ps}^{rk} = diag\{[\gamma_{1ps}^{rk}, \gamma_{2ps}^{rk}, ..., \gamma_{Nps}^{rk}]\}$, with γ^{rk} the coefficient for endogenous variable $k = 1, ..., K$ and sub-equation $r = 1, ..., K$. Also, $s = 1, ..., S$, with s the spatial lag, and the function $diag\{\}$ indicating that the off-diagonal elements are zero. W is a NxN matrix that selects and weighs the neighboring variables. We use an aspatial approach as our baseline model where we set $S = 0$. W_0 then selects the within unit values of each country or sector. Subsequently, we set $S = 1$ in a robustness analysis, where W_1 selects and summarizes the neighboring values. We choose to weigh each neighboring value equally, such that a weight $w_{ij} = \frac{1}{N_j}$ with N_j the number of neighbors. The definition of a neighbor is treated in section 6. Γ_0 is constructed similarly. As in a standard VAR, exclusion restrictions are imposed such that it becomes lower triangular.[3]

In a homogeneous specification, the following constraints are imposed: $\gamma_{ips}^{rk} = \gamma_{jps}^{rk} = \gamma_{ps}^{rk} I_N$. We use this constraint in our country-specific analysis. In order to analyse the composition effect on the one hand, and to see how different sectors or countries react to policy stringency on the other, we

[3]Moreover, on the diagonal, we have $A_p^{rk} = I_N - \sum_{s=1}^{S} \tilde{\Gamma}_{ps}^{rk} W_s$.

can relax this restriction by allowing for heterogeneous effects among some subgroups of countries or sectors. A group-heterogeneous model where we assume a set of coefficients to be homogeneous within a group z is defined as follows: $\tilde{\Gamma}^{rk}_{ps} = diag\{[\gamma^{rk}_{1ps}, ..., \gamma^{rk}_{zps}, ..., \gamma^{rk}_{Zps}]\}$ where $z = 1, 2, .., Z < N$.

In order to identify our model, we impose a series of exclusion restrictions which set some contemporaneous effects in Γ_0 to zero. The ordering of the variables determine these exclusion restrictions. GHG policy stringency is taken first in the ordering. None of our endogenous variables are assumed to impact GHG policy stringency contemporaneously. This is more so the case when considering that the elaboration of a policy may take some time. Technology is also relatively exogenous, in that it is most likely not affected through contemporaneous changes in the remaining endogenous variables. This is because technology is approximated through filed patents, which implies that they have been sufficiently developed in order to qualify for the filing process. In the sector-specific estimation, we argue that the relative number of high-skilled workers may be the result of previously determined capital and R&D investments. It is thus put second in the ordering. Energy prices is put third, as it may directly impact on GDP levels as well as CO_2 emissions. GDP is the fourth variable, because it is likely to be contemporaneously impacted through all the previous variables and exerts a direct influence on GHG emissions. CO_2 emissions, however, are directly impacted by policy stringency, the technological level, energy prices as well as GDP. We thus perform the analysis using the ordering of the variables as described in (1). Note that the results proove to be robust against a series of alternative orderings (see discussion in section 6).

In order to analyze the pass-through effect on a variable given an exogenous change of another variable, we estimate impulse response functions. These impulse response functions portray the reaction function of a given variable as a consequence of a one unit orthogonal shock on another endogenous variable. It allows us, in addition to the the direct effect of GHG policy stringengy, to see the accumulated overall effect of such a policy stringency change, which also include the effect on CO_2 via the transmission channels. The corresponding confidence intervals are computed using a bootstrap procedure with 100 iterations.

3.1. Country-specific Analysis: Methodological Approach

The country-specific analysis allows to measure the overall country-specific effect of the stringency of GHG policy. To illustrate the group-heterogeneous aspatial version of (1), the sub-equation with the CO_2 emissions as the endogenous variable writes as follows:

$$\Delta\eta_{it} = \sum_{p=0}^{P} \gamma_{zp}^{\eta\iota} \Delta\iota_{i,t-p} + \sum_{p=0}^{P} \gamma_{zp}^{\eta\tau} \Delta\tau_{i,t-p} + \sum_{p=0}^{P} \gamma_{zp}^{\eta\epsilon} \Delta\epsilon_{i,t-p} + \sum_{p=0}^{P} \gamma_{zp}^{\eta\omega} \Delta\omega_{i,t-p} \qquad (2)$$
$$+ \sum_{p=1}^{P} \gamma_{zp}^{\eta\eta} \Delta\eta_{i,t-p} + \sum_{p=0}^{P} X'_{i,t-p} \tilde{\Gamma}_{p}^{\eta x} + \psi_i^{\eta} + \lambda_t^{\eta} + u_t^{\eta}$$

where the indexes i and z denote the country and the group specific coefficient values, respectively. The Δ's indicate that the variables are first-differenced. A similar equation is formulated for all remaining endogenous variables and the system of equation is estimated simultaneously through a full information maximum likelihood.

3.2. Sector-level Analysis: Methodological Approach

We use a sectoral analysis to disentangle the overall effect of environmental policy stringency on CO_2 emissions. This approach allows to asses to what extent the country-wide change in CO_2 emissions is due to sectoral CO_2 efficiency changes, and to what extent it stems from changes in value added of dirty and clean sectors. In the sectoral analysis, the index i in (2) denotes a country-sector. The policy stringency index as well as energy prices remain the same as in the country-specific analysis and are assumed to be identical across all sectors within a country. In addition, neighboring effects are added to (2) to account for possible externalities for a given sector. Value added, technology as well as CO_2 emissions are measured at the sector-country level. The matrix of controls X remains the same as in the country-wide specification. Groups z are defined over 4 different levels of CO_2 emission intensity per country. Each group contains approximatively 290 country-sector units.

4. Integration Properties and Lag Length Selection

A Harris and Tzavalis (1999) panel unit root test (HT test) is used to test for non-stationarity of each of the variables. This test is based on pooled ADF statistics and is consistent with a panel dimension $N \to \infty$ and a fixed time dimension T.[4] The test is carried out with demeaned cross-sections to account for panel fixed effects, and a common time trend. Results are reported in Table (A1) in the appendix. For most of the variables in our economy-wide dataset, the null hypothesis of all panels containing a unit root cannot be rejected. We conclude that the GHG policy stringency index as well as the log of technology, GDP, CO_2, corruption, cooling day degrees and heating day

[4]Simulation results of Harris and Tzavalis (1999) indicate that the test has good size and power properties for N greater than 25, a condition which is satisfied in our sample.

degrees have a unit root and proceed by first differencing those variables. Even though the test rejects the null for energy prices, we still proceed by first differencing this variable. This is because the nature of the test is such that it remains silent about the proportion of panels that do contain unit roots. In addition, treating all endogenous variables identically facilitates the interpretation of the IRFs. Rerunning a Harris and Tzavalis (1999) test on the differentiated variables confirms the stationarity of the variables with unit roots. We apply the same transformations of the counterparts of those variables in the sector-wide dataset, even though there the HT test rejects the null hypothesis in all variables. This is again justified by the limited information that such tests reveal, and because the country-wide tests hinge towards non-stationarity. Note that we include, for every sub-equation, a panel-specific dummy variable after first differencing, which controls for different average growth rates of all our endogenous variables.

In order to select the panel VAR specifications which achieves the best performance in terms of log likelihood score, a number of alternative temporal lags structures are estimated for each model and the preferred specification is selected on the basis of the evidence provided by the AIC and BIC criteria. Results are reported in Table (A2) in the appendix. Note that due to the limited time series lengths, the more parsimonious suggestion of AIC and BIC is taken. For all specifications (with one only exception), AIC and BIC criteria both indicate the use of a specification with one temporal lag, for all sub-equations.

5. Results

5.1. Countrywide Semi-elasticity of CO_2 to GHG Policy Stringency

All coefficients of our country-wide baseline specification are displayed in Table (2). We observe a significantly negative direct contemporaneous semi-elasticity of CO_2 to GHG policy stringency of 16.6%. This direct effect on CO_2 reflects, for example, the impact of new or stricter command and control instruments. Given that an increase in stringency is in general preceded by a political debate, such an increase may be anticipated in advance. It is hence little surprising that the effect can be observed contemporaneously.[5] In addition, the direct effect of both GDP and technology on CO_2 are significantly positive. Previous contributions find mixed results on the CO_2-technology relation (for a summary, see Lantz and Feng (2006)). We use a general proxy for technology and do not specifically consider green technology. The qualitative results on technology may be justified by the possibility that new technologies might not be less emission intensive than older ones, which would explain why technological development impacts positively on CO_2 emissions.

[5]We also run an alternative estimation with a forward lag for the GHG policy stringency index to allow for a larger forward looking horizon. See discussion in section 6.

Table 2: Homogeneous Country-wide Specification with 1 Lag

Variable and Statistics	CO2 L0	CO2 L1	GDP L0	GDP L1	Energy Price L0	Energy Price L1	Technology L0	Technology L1	GHG Pol. String. L0	GHG Pol. String. L1
GHG Pol. String.	-0.166***	0.039	-0.044**	0.015	0.045	-0.159***	-0.086	-0.188*	-	-0.019
	(0.004)	(0.511)	(0.012)	(0.370)	(0.352)	(0.001)	(0.444)	(0.093)	-	(0.576)
ln(Technology)	0.027**	0.013	0.012***	0.007*	-0.015	0.010	-	0.020	-	0.003
	(0.014)	(0.235)	(0.004)	(0.077)	(0.160)	(0.353)	-	(0.561)	-	(0.272)
ln(Energy prices)	-0.019	0.033	-0.014	0.007	-	0.034	-	-0.091	-	0.004
	(0.386)	(0.133)	(0.103)	(0.390)	-	(0.312)	-	(0.102)	-	(0.373)
ln(GDP)	0.617***	-0.036	-	0.386***	-	0.050	-	0.069	-	-0.008
	(0.000)	(0.517)	-	(0.000)	-	(0.291)	-	(0.531)	-	(0.466)
ln(CO2)	-	-0.129***	-	0.008	-	-0.060***	-	0.173***	-	0.003
	-	(0.000)	-	(0.381)	-	(0.009)	-	(0.000)	-	(0.642)
ln(Corruption)	-0.003	0.003	0.006	0.003	-0.004	0.006	0.001	-0.013	0.001	-0.001
	(0.795)	(0.787)	(0.206)	(0.531)	(0.722)	(0.592)	(0.950)	(0.453)	(0.695)	(0.788)
ln(CDD)	-0.001	-0.003	0.003***	0.000	-0.004	0.002	-0.007	-0.007	-0.003**	-0.001
	(0.856)	(0.304)	(0.004)	(0.798)	(0.106)	(0.365)	(0.228)	(0.261)	(0.014)	(0.355)
ln(HDD)	0.088***	-0.062***	0.001	0.008	0.054***	-0.020	0.087*	-0.094*	0.001	-0.007**
	(0.000)	(0.005)	(0.950)	(0.373)	(0.002)	(0.260)	(0.061)	(0.053)	(0.688)	(0.044)
Time FE/Country FE	Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes	
Obs.	920		920		920		920		920	
AIC	-4278.15		-5858.61		-4176.63		-2954.85		-6097.26	
BIC	-3907.56		-5492.77		-3815.55		-2598.52		-5745.68	
R2	0.22		0.57		0.10		0.13		0.18	

Column titles indicate the sub-equations. L0: contemporaneous effect, L1: effect from one time lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

Furthermore, we identify the main channels which amplify or curb the observed direct effect of stringency on emissions. As main channel is defined a variable that is both significantly affected by the policy stringency and which significantly affects CO_2 emissions.

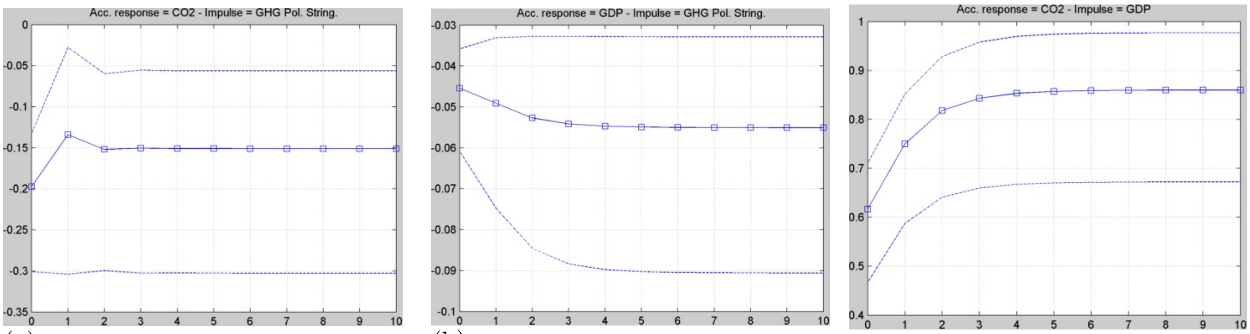
We observe a significant negative contemporaneous reaction of GDP to GHG policy stringency and a positive reaction of CO_2 to GDP. GDP can therefore be considered a channel which amplifies the negative effect of policy stringency on CO_2 emissions. This result shows that policy stringency operates partly over a scale effect. In addition, we find evidence for an amplifying technology channel, although less strong than GDP, as policy stringency impacts negatively on technological development and technological development positively affects CO_2 emissions. Thus, a higher GHG policy stringency might slow down overall technological advancement by inhibiting the development of emission intensive technologies, which in turn would explain the decrease in CO_2 emissions.

We further compute IRFs to capture the overall effect of an exogenous shock of policy stringency on CO_2.[6] A shock corresponds to a one unit increase in the policy stringency - i.e., passing from zero stringency to the highest observed stringency. Figure (1a) displays the IRF of a positive stringency shock on CO_2. Increasing GHG policy stringency by one unit reduces country CO_2 emissions on average by 15 % in the long run.

In addition, Figure (1b) displays the cumulative pass-through effect of a positive policy strin-

[6]Figure (A2) in the appendix displays the complete set of IRFs from the CO_2 equation as well all IRFs with GHG policy stringency shocks.

Figure 1: Impulse Response Functions: Country-wide Specification with 1 Lag, 10% Confidence Interval



(a) Response of CO_2 to a Unit Shock of GHG Pol. String.

(b) Response of GDP to a Unit Shock of GHG Pol. String.

(c) Response of CO_2 to a Unit Shock of GDP

gency shock on GDP and Figure (1c) the cumulative pass-through effect of a positive GDP shock on CO_2. Both Figures illustrate the presence of a scale effect: On the one hand, the effect of a positive stringency shock on GDP is significantly negative. And on the other hand, the effect of a positive GDP shock on CO_2 is significantly positive.

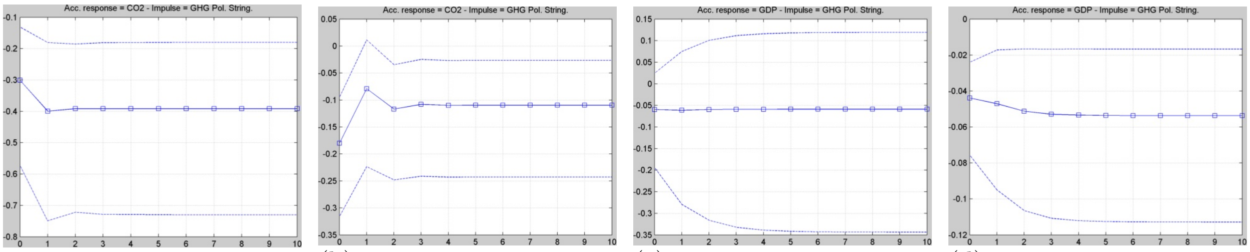
5.1.1. Opportunity Costs of Policy Induced CO_2 Emission Reductions

Figure (1a) and (1b) allow to compare the overall reaction of CO_2 and GDP to a unit shock in GHG policy stringency. Thus, they reveal information about the ex-post average opportunity cost of a tightening of GHG policy stringency. Results suggest that a policy induced CO_2 emissions reduction of 1%, cost on average 0.35% of GDP in the long run. Those opportunity costs are rather high, especially when compared to the numerous ex-ante estimations of the costs of greenhouse gas emission reductions (e.g., Barker et al. (2007), Clarke et al. (2009) or Tavoni and R.S.J.Tol (2010)). Most of those ex-ante modeling approaches assume, however, a cost-effective implementation of greenhouse gas mitigation policies. But, as Leahy and Tol (2012) state: "There is no reason to assume that climate policy would be designed as recommended in an economics textbook. As a result, emission abatement may be considerably more expensive than typically assumed". Some papers assess the cost of specific greenhouse gas policies ex-post and suggest that some existing GHG policies do cost considerably more compared to least cost solutions (e.g., Jenkins (2010) or Leahy and Tol (2012)). Our results confirm this.

We subsequently assess whether there is a difference in the opportunity costs of GHG policies for developing and developed countries. As a developed country, we define those countries whose GDP per capita at the beginning of our measurement period, in 1990, is among the 50% highest. The developing countries are defined to be the remaining ones. For developing countries, Figure (2a) and (2c) reveal that a policy induced CO_2 emission reduction of 1%, costs on average 0.13%

of GDP. The opportunity costs are almost 4 times higher for developed countries, as a GHG policy induced 1% CO_2 emission reduction costs on average 0.5% of GDP for those countries as displayed in Figure (2b) and (2d). A result which confirms the frequently advanced argument of relatively cheap abatement opportunities in developing countries. Moreover, the difference in opportunity costs is mostly driven by the significantly stronger negative reaction of CO_2 emissions to a policy shock in developing compared to developed countries. A finding which is consistent with the "low-hanging fruit" argument invoked during the preparation phase of the Kyoto Protocols' Clean Development Mechanism (see for instance Narain and Van't Veld (2008)).

Figure 2: IRFs for a GHG Policy Stringency Shock, Developed vs. developing Countries, 10% Confidence Interval



(a) Response of CO_2: Developing Country (b) Response of CO_2: Developed Country (c) Response of GDP: Developing Country (d) Response of GDP: Developed Country

5.2. Disentangling the Overall Effect: Composition and Technique Effect

There are three potential ways to achieve a country-wide reduction in CO_2 emissions: by reducing the overall scale of production, by increasing the CO_2 efficiency within all or some of the sectors, or by increasing the share of the clean sectors. Our economy-wide results suggest that increased policy stringency reduces the overall scale of production, but remains silent about the two other potential effects. Working with sectoral data and defining group-heterogeneity allows us to separate potential policy induced technique and composition effects. To do so, we define the groups z based on country-specific emission intensity, which is defined by sectoral CO_2 emissions per sectoral value added. The first group contains the cleanest sectors and is labeled "very clean". This group includes sectors whose emission intensities at the beginning of our time period in 1995 are among the lowest 25% in a country. Similarly, the second group (labeled "clean"), third group (labeled "dirty") and fourth group (labeled "very dirty") contain sectors with CO_2 emission intensities between the 25^{th} and 50^{th} percentile, between the 50^{th} and 75^{th} percentile, and amongst the top 25%, respectively. Because this categorization of sectors is perfomed using a within-country criterium, the labelling of a given sector may differ across countries.
Coefficients from all sub-equations are displayed in Table (A7.1) and (A7.2) in the appendix.

5.2.1. Composition Effect

If GHG policy stringency operates over a composition effect, we expect to observe a significantly different reaction of sectoral value added to GHG policy stringency across the sectoral groups z: The dirty sectors' value added should decrease significantly more than the clean sectors' value added. This is confirmed by the results. We find a significant negative cumulative effect over both time lags of GHG policy stringency on sectoral value added for the very dirty sector group (see Table (3)). The cumulative effects over both lags for the dirty, clean and very clean sector groups are not significant.

Table 3: Composition Effect: Sector Specification

Variable and Statistics	Value Added Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-0.043**	0.036*	-0.010	0.044*	-0.035	0.038	-0.099***	-0.025
	(0.041)	(0.094)	(0.682)	(0.082)	(0.262)	(0.249)	(0.007)	(0.504)
ln(Technology)	0.004	0.004	0.005	-0.001	0.002	-0.003	0.007	-0.005
	(0.186)	(0.175)	(0.172)	(0.764)	(0.626)	(0.512)	(0.226)	(0.443)
ln(Energy prices)	-0.041***	-0.000	-0.037***	-0.009	-0.022**	-0.011	0.030**	-0.013
	(0.000)	(0.955)	(0.000)	(0.371)	(0.038)	(0.330)	(0.028)	(0.393)
ln(Value Added)	-	0.149***	-	0.071***	-	0.094***	-	0.028
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.103)
ln(CO2)	-	0.003	-	0.008**	-	0.013**	-	0.036***
	-	(0.333)	-	(0.023)	-	(0.020)	-	(0.000)
ln(Corruption)	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003
	(0.352)	(0.172)	(0.352)	(0.172)	(0.352)	(0.172)	(0.352)	(0.172)
ln(CDD)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.163)	(0.151)	(0.163)	(0.151)	(0.163)	(0.151)	(0.163)	(0.151)
ln(HDD)	-0.003	0.004	-0.003	0.004	-0.003	0.004	-0.003	0.004
	(0.515)	(0.387)	(0.515)	(0.387)	(0.515)	(0.387)	(0.515)	(0.387)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.04							

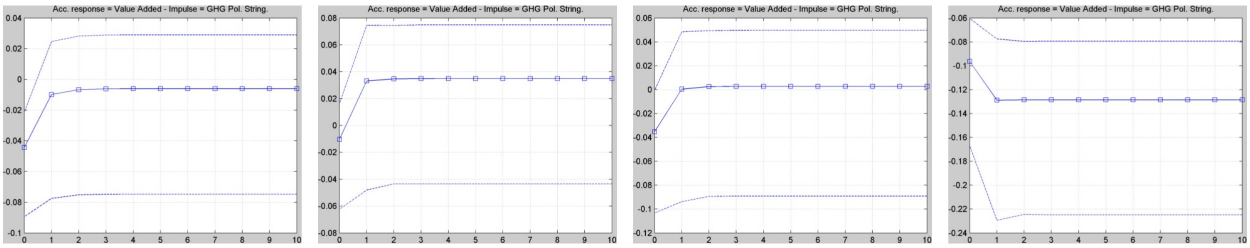
Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

Furthermore, Table (3) and Table (A7.1) (Appendix) show that no main channel can be identified as contributing to a differentiated reaction of value added to GHG policy stringency depending on the cleanness of the sectors. However, an interesting result concerns the potential energy price channel. Although GHG policy stringency has no significant cumulative impact on energy prices[7], value added reacts as expected significantly negative to higher energy prices for the very clean, the clean and the dirty sector group. Higher energy prices, however, increase the value added of the very dirty sector group, a finding which can be related to the presence of energy producing sectors in this group.

[7]See section 7 for a discussion of this result

The pass-through effects - which are for each group mostly driven by the direct effect of stringency on sectoral value added - confirm the existence of a policy induced composition effect. The IRFs relevant for this discussion are displayed in Figure (3). The complete set of IRFs from the CO_2 equation as well all IRFs with GHG policy stringency shocks are shown in Figures (A3), (A4), (A5) and (A6) in the appendix. The long run pass-through effect of a unit shock of GHG policy stringency on value added for the very clean, the clean and the dirty group are not significantly different from zero. But the one for the very dirty group is significantly negative and different from the very clean and clean sector groups.

Figure 3: IRF's for a GHG Policy Stringency Shock on Sectoral Value Added, 10% Confidence Interval



(a) Very clean sectors (b) Clean sectors (c) Dirty sectors (d) Very dirty sectors

Results provide therefore evidence pointing towards the existence of a policy induced composition effect: a stricter GHG policy regime does alter the composition of clean and dirty sectors. It does so by reducing the value added of very dirty sectors, while not significantly affecting the value added of the other groups.

5.2.2. Technique Effect

If increased GHG policy stringency raises CO_2 efficiency of sectors, we expect to find a negative effect of stringency on the sectoral CO_2 coefficients. As Table (4) suggests, a policy induced technique effect is present for all sectors. Those direct effects of stricter policies - potentially operating over stricter command and control instruments - lower CO_2 intensity in all sector groups and can thus be interpreted as classical technique effects. I.e., all other things - including sectoral value added - equal, an increase in stringency lowers sectoral CO_2. This effect presents a lower bound of the technique effect, as we also hold constant the technology and energy channel, two channels which potentially contribute to the technique effect.

Moreover, we can identify some tendency: the cleaner a sector group, the stronger the negative effect of GHG policy stringency on CO_2 emissions (with the exception of the dirty sector group). Note that this result does not imply that absolute average abatement due to the technique effect is highest in the clean sector groups. On the contrary, given that average group CO_2 emissions

Table 4: Technique Effect: Sector Specification

Variable and Statistics	CO$_2$ Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-0.271***	0.023	-0.197***	0.030	-0.082*	0.017	-0.176***	-0.017
	(0.000)	(0.653)	(0.000)	(0.543)	(0.088)	(0.736)	(0.000)	(0.722)
ln(Technology)	0.001	0.008	0.011*	0.014**	0.010*	-0.002	0.004	-0.005
	(0.842)	(0.271)	(0.079)	(0.023)	(0.090)	(0.703)	(0.419)	(0.366)
ln(Energy prices)	-0.111***	-0.059***	-0.073***	-0.057***	-0.087***	-0.063***	-0.009	-0.012
	(0.000)	(0.003)	(0.000)	(0.002)	(0.000)	(0.001)	(0.600)	(0.503)
ln(Value Added)	0.102***	0.036**	0.110***	0.068***	0.079***	0.002	0.064***	0.042***
	(0.000)	(0.025)	(0.000)	(0.000)	(0.000)	(0.810)	(0.000)	(0.000)
ln(CO2)	-	-0.079***	-	-0.097***	-	-0.080***	-	-0.051***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.003)
ln(Corruption)	-0.019***	-0.017***	-0.019***	-0.017***	-0.019***	-0.017***	-0.019***	-0.017***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(CDD)	0.006***	-0.005***	0.006***	-0.005***	0.006***	-0.005***	0.006***	-0.005***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
ln(HDD)	0.011	-0.008	0.011	-0.008	0.011	-0.008	0.011	-0.008
	(0.205)	(0.349)	(0.205)	(0.349)	(0.205)	(0.349)	(0.205)	(0.349)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.09							

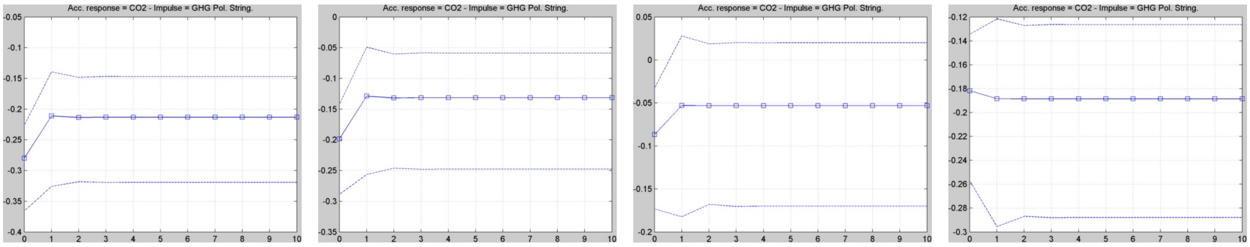
Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

are considerably higher in the very dirty sector group, absolute abatement due to the direct effect is highest in this group despite the fact that cleaner sectors display a stronger negative reaction. The latter result can be explained by two complementary arguments. It may be very costly and technically difficult to increase CO_2 efficiency in heavily CO_2 intensive sectors such as energy producing sectors. If technical difficulties and costs are high enough, firms in dirty sectors may prefer to relocate production instead of complying with regulation. Our results from the composition effect analysis supports this argument. On the other hand, firms in cleaner sectors may not need to change central parts of their production technology but can substitute inputs (such as non-renewable energy) more readily to comply with regulations. Additionally, a second - policy related - argument can be made. The regulation of GHGs started well before 1995 targeting initially CO_2 intensive sectors, only later in time regulation included also rather clean sectors. Thus, as our sectoral sample starts only in 1995, it is possible that we do not capture initial policy induced technique effects in very dirty sectors.

5.3. The Sectoral Overall Effect: A Combination of Composition and Technique Effect

Given that an increase in GHG policy stringency alters the composition of sectors and increases the CO_2 efficiency of all sectors, it is interesting to analyze the overall effect of policy stringency on sectoral CO_2 emissions. Figure (4) displays the pass-through effects capturing the joint impact of direct and indirect effects of GHG policy stringency on emissions. For the very clean group, the pass-through effect is roughly -2.1% and significant. The one for the second group is about -1.4% and significant. The one for the third group is roughly -0.5 % but not significant. At last, the pass-through effect for very dirty sectors is approximately -1.9% and also significant.

Figure 4: IRF's for a GHG Policy Stringency Shock on CO2, 10% Confidence Intervals



(a) Very clean sectors (b) Clean sectors (c) Dirty sectors (d) Very dirty sectors

Given that CO_2 reacts positively to value added for all groups, the composition effect acts as an important channel in the very dirty sector group, which amplifies the impact from the technique effect on CO_2 emissions considerably.

6. Robustness

We conduct an extensive robustness check including different specifications, using a different dataset, a different environmental policy stringency index, as well as using a spatial variant of the DiGiacinto model.

6.1. Countrywide Robustness Results: Alternative Data, Forward Lag and Spatial Specification

In a first step, we introduce a forward lag for GHG policy stringency to allow for a larger potential forward looking horizon. Results indicate that no significant changes happen to all variables at the lead of a GHG policiy stringency change, and that results for the lags are qualitatively identical, and quantitatively similar as in the baseline model. Moreover, a VAR estimation may typically be criticized for its dependence on the variable ordering. Hence, we also estimate specifications with our baseline lag length using different orderings of the endogenous variables. Besides the ordering described in equation (1), we test all five alternative orderings one obtains by varying the positions of gdp, technology and energy prices. All results remain robust both qualitatively and quantitatively and are provided upon request.

In a second step, we assess the robustness of our results to different data. Firstly, we use the baseline dataset and replace the GHG policy stringency variable by the one provided by the WEF (see World Economic Forum (2014)). Our main results - the negative impact of GHG policy stringency on CO_2 and GDP - stay qualitatively the same (cf. Table (A4) in the appendix). Secondly, we aggregate our sector-specific dataset to produce an alternative economy-wide dataset and re-estimate the baseline model. Results can be found in Table (A5) in the Appendix. Again, our two main results are robust.

Finally, we estimate a spatial version of the baseline model. By doing so, we additionally control for externalties such as changes in the demand from trading partners. We rely upon aggregated trade data from the UN Comtrade Database (2015) to construct the W matrix. This matrix essentially defines which countries are considered as neighbors. For each country, we define as a neighbor one of the 5 countries which have the highest import share with respect to the country under consideration. An import share is defined as being total imports by a foreign country over total value added of the country under consideration. Results are displayed in Table (A6) in the Appendix. The results are robust when controlling for such externalities.

6.2. Sectoral Robustness Results: Different Group Definitions and Spatial Specification

Not only the country-wide but also the sectoral results are robust to any specification. Using the same grouping structure, we test specifications with the 5 alternative orderings as we did for the country-wide specification. In addition, we test the use of a different grouping structure with two and three groups instead of four. Again, the main result stay qualitatively the same: as a reaction to a policy shock, value added of rather dirty sectors decreases significantly while the value added of rather clean sectors does not react significantly different to zero. In addition, we also find consistent evidence for the existence of a technique effect, and this effect is stronger the cleaner the sector group. These results are also provided upon request.

In addition, we estimate a spatial version of the sectoral baseline model. By doing so, we additionally control for externalities such as changes in the demand for input goods of trade partners. We use trade flow data from the input output matrix provided by the World Input-Output Database (2012) to define the W matrix. For each sector in a given country, we define as a neighbor one of the 20 sectors from any other country which have the highest import share with respect to the sector under consideration. Note that sectors within the same country are not considered neighbors. This is because we use country-wide policy stringency measures and energy price levels. An import share is defined as being total imports by a sector in a foreign country over total value added of the sector under consideration. Coefficients of all sub-equations are displayed in Table (A8.1), (A8.2) and (A8.3). We find again strong evidence for the existence of a policy induced composition effect. As value added of very dirty sectors reacts significantly negative to stringency while the one from the other groups does not show a significant reaction. Evidence suggests as well that more stringent GHG policy regimes increase CO_2 efficiency in all sector groups.

7. Discussion

By using a relatively large panel dataset including countries responsible for roughly 71 % of the world's CO_2 emissions over the sample period, a new GHG policy stringency indicator and a structural spatial panel VAR approach, we are able to avoid several limitations of earlier contributions attempting to measure policy induced CO_2 emission reductions. Our results from the country-wide analysis show that increasing the stringency of a country's GHG policy regime does reduce its CO_2 emissions, which is good news from a national environmental policy perspective. In addition, a country with no GHG regulations could achieve a 15% reduction of its' CO_2 emissions by adopting the stringency level of the most stringent country in the sample. Our results also reveal the existence of a policy induced scale effect, as national GHG policy stringency impacts negatively on a countries' GDP. Opportunity costs of policy induced CO_2 reductions in terms of GDP are relatively high, but 4 times lower for developing countries compared to developed countries. Being robust to alternative specifications, a different environmental policy stringency variable, as well as to a different dataset, those results confirm and extend the fragmented evidence of earlier contributions (cf. Esty and Porter (2005)).

A sectoral analysis then allows to disentangle the overall effect of GHG policy stringency and shows the existence of a policy induced composition and technique effect. Increasing the stringency of a GHG policy regime alters the composition of dirty and clean sectors in an economy. It does so by decreasing the size of the dirtiest 25% of sectors while not significantly impacting on the production scale of cleaner sectors. Moreover, increasing GHG policy stringency improves CO_2 efficiency in sectors. This technique effect is present for all sector groups. Those results are also robust to different specifications and when controlling for externalities, such as changes in a trade partners' demand for input goods. From a global perspective, the existence of a policy induced technique effect is desirable, as reducing CO_2 intensities of dirty sectors is beneficial for the climate. A more nuanced statement has to be made when it comes to the policy induced composition effect. If the composition effect is mainly due to absolute reduction of the production in highly CO_2 intensive sectors, it would be beneficial for the global climate system. If, however, production relocation accounts for the main bulk of the composition effect, then it is unclear to which extent this effect of a stricter policy regime decreases global GHG emissions, if at all. Additional research is needed to analyze how exactly the composition effect is achieved. Should further research confirm that the policy induced composition effect is mainly due to production relocation, a global - instead of national - policy response is indispensable. The latter argument would additionally reinforce the frequently advanced call for a global policy response due to the inherent global public good nature of the problem at hand (see for instance: IPCC (2001)).

An interesting additional result concerns the energy price channel, one out of several channels over which GHG policies could potentially operate. Country-wide results show that GDP and CO_2 both react negatively to a change in energy prices. Sector-level results suggest that the same holds for all except the dirtiest sector group in the sample. GHG policy stringency, on the other hand, does not seem to raise energy prices. A possible explanation is that international competitiveness concerns dominate policy makers' decisions and lead them to not or only sparely design policies operating over increased energy prices.

In short, our results indicate that by increasing the stringency of GHG policy regimes, policy efforts can reduce national CO_2 emissions up to a certain extent. Prospects are therefore encouraging that one can limit the rate and magnitude of climate change and thereby reduce climate change induced risks as advocated by IPCC (2014). However, the presence of a policy induced composition effect might limit the extent to which global emissions are reduced by national policies. This would be especially true if emission outsourcing is found to be the main driver of this composition effect. On the other hand, it seems as if policy makers have so far been reluctant to design policies operating over increased energy prices. A finding which suggests that by using this channel more extensively, there might still be scope for further CO_2 emission reductions in the future. Such policies would, however, have to be carefully designed and should take into account the heterogeneous response of sector value added and CO_2.

References

Aichele, R., Felbermayr, G., 2013. The effect of the kyoto protocol on carbon emissions. Journal of Policy Analysis and Management 32 (4), 731–757.

Aldy, J., Barrett, S., Stavins, R., 2003. Thirteen plus one: A comparison of global climate policy architectures. Working Paper Series rwp 03-012, Harvard University, John F. Kennedy School of Government.

Anderson, B., Maria, C. D., 2011. Abatement and allocation in the pilot phase of the EU ETS. Environmental and Resource Economics 48 (1), 83–103.

Barker, T., Bashmakov, I., Alharthi, A., Amann, M., Cifuentes, L., Drexhage, J., Duan, M., O., E., Flannery, B., Grubb, M., Hoogwijk, M., Ibitoye, F., Jepma, C., Pizer, W., Yamaji, K., 2007. Mitigation from a cross-sectoral perspective. In: Metz, B. (Ed.), Climate Change 2007: Mitigation - Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Botta, E., Kozluk, T., 2014. Measuring environmental policy stringency in OECD countries: A composite index approach. OECD Economics Department Working Papers 1177, OECD Publishing.

Bruvoll, A., Medin, H., 2003. Factors behind the environmental kuznets curve. a decomposition of the changes in air pollution. Environmental and Resource Economics 24 (1), 27–48.

Burgess, J. C., 1990. The contribution of efficient energy pricing to reducing carbon dioxide emissions. Energy Policy 18 (5), 449 – 455.

Calbick, K., Gunton, T., 2014. Differences among OECD countries' ghg emissions: Causes and policy implications. Energy Policy 67 (C), 895–902.

Clarke, L., Edmonds, J., Krey, V., Richels, R., Rose, S., Tavoni, M., 2009. International climate policy architectures: Overview of the EMF22 international scenarios. Energy Economics 31 (S2), 64–81.

Cole, M. A., Elliott, R. J., Shimamoto, K., 2005. Industrial characteristics, environmental regulations and air pollution: an analysis of the uk manufacturing sector. Journal of Environmental Economics and Management 50 (1), 121–143.

Considine, T. J., 2000. The impacts of weather variations on energy demand and carbon emissions. Resource and Energy Economics 22 (4), 295 – 314.

Copeland, B. R., Taylor, M. S., 2004. Trade, growth, and the environment. Journal of Economic Literature 42 (1), 7–71.

Damania, R., 2002. Environmental controls with corrupt bureaucrats. Environment and Development Economics (03), 407–427.

De Bruyn, S. M., 1997. Explaining the environmental kuznets curve: structural change and international agreements in reducing sulphur emissions. Environment and Development Economics 2 (04), 485–503.

Di Giacinto, V., 2010. On vector autoregressive modeling in space and time. Journal of Geographical Systems 12 (2), 125–154.

Dietz, T., Rosa, E., 1997. Effects of population and affluence on CO2 emissions. Proceedings of the National Academy of Sciences 94 (1), 175–179.

Esty, D. C., Porter, M. E., 2005. National environmental performance: an empirical analysis of policy results and determinants. Environment and Development Economics 10 (04), 391–434.

Fan, Y., Liu, L.-C., Wu, G., Wei, Y.-M., 2006. Analyzing impact factors of CO2 emissions using the STIRPAT model. Environmental Impact Assessment Review 26 (4), 377 – 395.

Fredriksson, P. G., Svensson, J., 2003. Political instability, corruption and policy formation: the case of environmental policy. Journal of Public Economics 87 (7-8), 1383–1405.

Gamper-Rabindran, S., Finger, S., 2013. Does industry self-regulation reduce pollution? responsible care in the chemical industry. Journal of Regulatory Economics 43 (1), 1–30.

Gani, A., 2012. The relationship between good governance and carbon dioxide emissions: Evidence from developing economies. Journal of Economic Development 37 (1), 77–93.

Grossman, G. M., Krueger, A. B., 1991. Environmental impacts of a north american free trade agreement. NBER Working Papers 3914, National Bureau of Economic Research, Inc.

Harris, R. D., Tzavalis, E., 1999. Inference for unit roots in dynamic panels where the time dimension is fixed. Journal of Econometrics 91 (2), 201–226.

Hettige, H., Mani, M., Wheeler, D., 2000. Industrial pollution in economic development: the environmental kuznets curve revisited. Journal of Development Economics 62 (2), 445–476.

Huang, Y., Barker, T., 2012. The clean development mechanism and low carbon development: A panel data analysis. Energy Economics 34 (4), 1033–1040.

Huang, Y., He, J., Tarp, F., 2012. Is the clean development mechanism effective for emission reductions? Tech. Rep. UNU-WIDER Research Paper, World Institute for Development Economic Research (UNU-WIDER).

IEA, 2014. Indices of real and nominal end-use energy prices.

IMF, 2014. IMF primary commodity prices.

International Country Risk Guide, 2014.

IPCC, 2001. Climate Change 2001: Mitigation: Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, p. 607.

IPCC, 2013. Summary for policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–28.

IPCC, 2014. Summary for policymakers. In: Climate Change 2014: Impacts, Adapation, and Vulnerability. Part A: Global and Sectoral Aspects. Contributino of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–32.

Isaac, M., van Vuuren, D. P., 2009. Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. Energy Policy 37 (2), 507 – 521.

Jenkins, D., 2010. The value of retrofitting carbon-saving measures into fuel poor social housing. Energy Policy 38 (2), 832–839.

Lantz, V., Feng, Q., 2006. Assessing income, population, and technology impacts on co2 emissions in canada: Where's the EKC? Ecological Economics 57 (2), 229–238.

Leahy, E., Tol, R., 2012. Greener homes: an ex-post estimate of the cost of carbon dioxide emission reduction using administrative micro-data from the republic of ireland. Environmental Economics and Policy Studies 14 (3), 219–239.

Lindmark, M., 2002. An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in sweden 1870 – 1997. Ecological Economics 42 (1–2), 333 – 347.

Manne, A., Mendelsohn, R., Richels, R., 1995. MERGE : A model for evaluating regional and global effects of ghg reduction policies. Energy Policy 23 (1), 17–34.

Moomaw, W. R., Unruh, G. C., 1997. Are environmental kuznets curves misleading us? the case of CO2 emissions.

Environment and Development Economics 2, 451–463.

Narain, U., Van't Veld, K., 2008. The clean development mechanism's low-hanging fruit problem: When might it arise, and how might it be solved? Environmental and Resource Economics 40 (3), 445–465.

Neumayer, E., 2002. Can natural factors explain any cross-country differences in carbon dioxide emissions? Energy Policy 30 (1), 7 – 12.

Olsthoorn, X., 2001. Carbon dioxide emissions from international aviation: 1950 – 2050. Journal of Air Transport Management 7 (2), 87 – 93.

Panayotou, T., 1997. Demystifying the environmental kuznets curve: turning a black box into a policy tool. Environment and Development Economics 2 (04), 465–484.

Raupach, M. R., Marland, G., Ciais, P., Le Qur, C., Canadell, J. G., Klepper, G., Field, C. B., 2007. Global and regional drivers of accelerating co2 emissions. Proceedings of the National Academy of Sciences 104 (24), 10288–10293.

Robbins, P., 2000. The rotten institution: corruption in natural resource management. Political Geography 19 (4), 423 – 443.

Rosa, E. A., Dietz, T., 2012. Human drivers of national greenhouse-gas emissions. Nature Climate Change 2, 581–586.

Sauter, C., 2014. How should we measure environmental policy stringency? a new approach. IRENE Working Papers 14-01, IRENE Institute of Economic Research.

Stern, D. I., 2004. The rise and fall of the environmental kuznets curve. World Development 32 (8), 1419–1439.

Tavoni, M., R.S.J.Tol, 2010. Counting only the hits? the risk of underestimating the costs of stringent climate policy: A letter. Climatic Change 100 (3), 769–778.

Taylor, C., Pollard, S., Rocks, S., Angus, A., 2012. Selecting policy instruments for better environmental regulation: a critique and future research agenda. Environmental Policy and Governance 22 (4), 268–292.

Tol, R., 1999. Spatial and temporal efficiency in climate policy: Applications of FUND. Environmental & Resource Economics 14 (1), 33–49.

UN Comtrade Database, 2015. International trade statistics database.

Welsch, H., 2004. Corruption, growth, and the environment: a cross-country analysis. Environment and Development Economics 9 (05), 663–693.

Wheeler, D., 2012. Energy and country performance ratings 2001 – 2010. Working Papers 301, Center for Global Development.

World Bank, 2014. World development indicators.

World Economic Forum, 2014. The global competitiveness report 2014 - 2015. Switzerland, pp. 53–96.

World Input-Output Database, 2012.

York, R., Rosa, E. A., Dietz, T., 2003. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. Ecological Economics 46 (3), 351 – 365.

Acknowledgements

We are grateful to J-M. Grether, M. Brulhart and N. Mathys for useful guidance and comments. Furthermore, we would like to express our gratitude to V. Di Giacinto for his valuable comments and MATLAB codes. In addition, we thank the Swiss National Science Foundation for partially funding this paper in the framework of the SNF project Nb. 138625 "Inequalities, geography and emission".

8. Appendix

Table A1: Harris Tzavalis Test Statistics:

Variable	P-value
ln(CO2)	0.4842
ln(Sectoral CO2)	0.000
ln(GDP)	0.9868
ln(Sectoral GDP)	0.0000
ln(Technology)	0.9955
ln(Sectoral Technology)	0.0000
ln(Energy price)	0.0000
GHG Pol. String.	0.9871
ln(Corruption)	0.3528
ln(CDD)	0.000
ln(HDD)	0.000
H0: All panels contain a unit root	

Table A2: Lag Length Selection: AIC BIC by Equation

Country-wide Analysis										
Nb. of Lags	CO2 Equ.		GDP Equ.		Energy Price Equ.		Technology Equ.		GHG Pol. String. Equ.	
	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
1 Lag	-4278.15	-3907.56*	-5858.61*	-5492.77*	-4176.63*	-3815.55*	-2954.85*	-2598.52*	-6097.26*	-5745.68*
2 Lags	-4192.1	-3788.16	-5611.34	-5212.09	-3936.09	-3541.54	-2978.8	-2588.95	-5787.15	-5401.99
3 Lags	-4286.53*	-3850.39	-5343.87	-4912.36	-4148.87	-3722	-2887.38	-2465.15	-5686.48	-5268.89
1 Lead/1 Lag	-4211.12	-3807.17	-5609.64	-5210.39	-3936.76	-3542.21	-2980.65	-2590.79	-5757.65	-5372.49
Sector Analysis										
Nb. of Lags	CO2 Equ.		GDP Equ.		Energy Price Equ.		Technology Equ.		GHG Pol. String. Equ.	
	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC	BIC
1 Lag	-52183.79*	-42923.08*	-66561.19*	-57330.96*	-79661.74*	-70462*	-49621.22*	-40451.97*	-117878.4*	-108739.63*
2 Lags	-50976.3	-38943.62	-61282.9	-52876.31	-76255.6	-68122	-48792.7	-39763.11	-112967.19	-107242.95
1 Lead/1 Lag	-48671.26	-39334.33	-61779.3	-52472.52	-73764.3	-64487.7	-47236	-39219.23	-110506.37	-101290.12

* Indicates the preferred specification by AIC or BIC

Table A3: Countries and Sectors

Country-wide Specification	Sector Specification		
Countries	**Countries**	**Sectorcode**	**Sector description**
Albania	Australia	15t16	Food, beverages and tobacco
Australia	Austria	17t18	Textiles and textile
Austria	Belgium	19	Leather, leather and footwear
Belgium	Brazil	20	Wood and Cork
Bosnia and Herzegovina	Bulgaria	21t22	Pulp, paper, printing and publishing
Brazil	Canada	23	Coke, refined petroleum and nuclear fuel
Bulgaria	China	24	Chemicals and chemical
Canada	Cyprus	25	Rubber and plastics
Chile	Czech Republic	26	Other non-metallic minerals
China	Denmark	27t28	Basic metals and fabricated metals
Croatia	Estonia	29	Machinery, NEC
Cyprus	Finland	30t33	Electrical and optical equipment
Czech Republic	France	34t35	Transport equipment
Denmark	Germany	36t37	Manufactruing NEC, Recycling
Estonia	Hungary	50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
Finland	India	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
France	Ireland	52	Retail trade, except of motor vehicles and motorcycles; repair of household goods
Germany	Italy	60	Other Inland transport
Hungary	Japan	61	Other Water transport
Iceland	Korea	62	Other Air transport
India	Latvia	63	Other Supporting and auxiliary transport activities; activities of travel agencies
Ireland	Lithuania	64	Post and telecommunications
Israel	Luxembourg	70	Real estate activities
Italy	Malta	71t74	Renting of m&eq and other business activities
Japan	Mexico	AtB	Agriculture, hunting, forestry and fishing
Korea, Rep.	Netherlands	C	Mining and quarrying
Latvia	Poland	E	Electricity, gas and water supply
Lithuania	Portugal	F	Construction
Luxembourg	Romania	H	Hotels and restaurants
Macedonia, FYR	Slovak Republic	J	Financial intermediation
Malta	Slovenia	L	Public admin and defence, compulsory social security
Mexico	Spain	M	Education
Netherlands	Sweden	N	Health and social work
New Zealand	United Kingdom	O	Other community, social and personal services
Norway			
Poland			
Portugal			
Romania			
Slovak Republic			
Slovenia			
South Africa			
Spain			
Sweden			
Switzerland			
United Kingdom			
United States			

Figure A1: GHG Policy Stringency Index

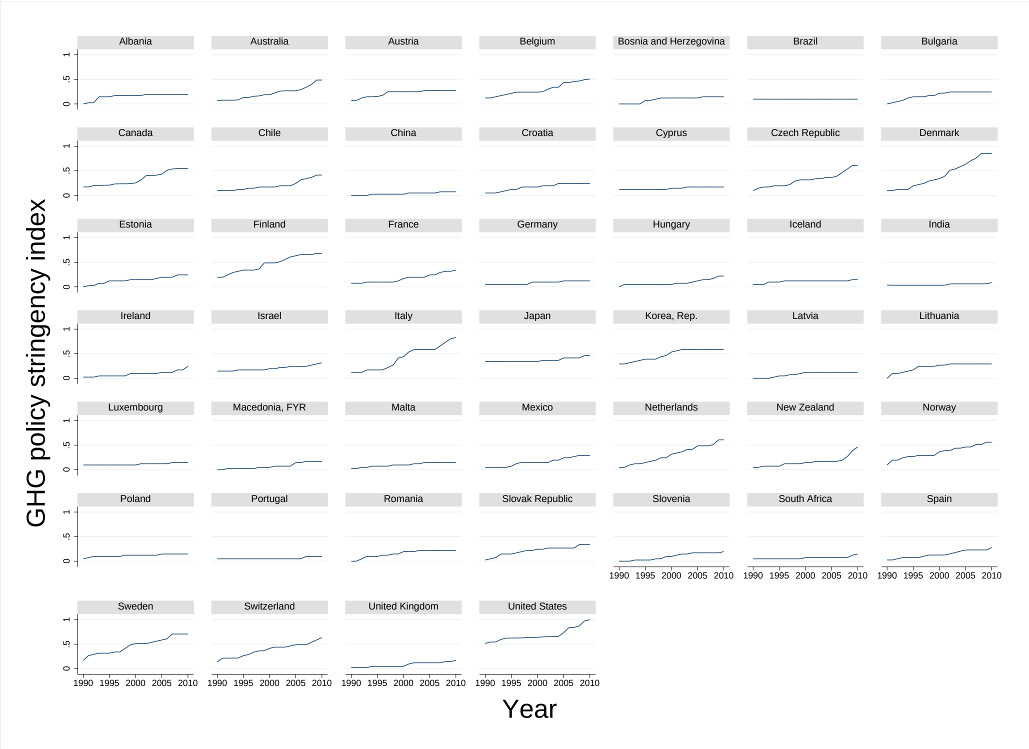
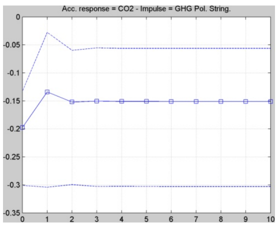
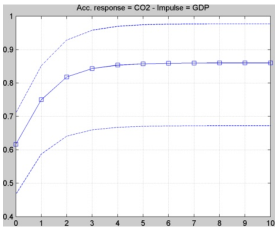


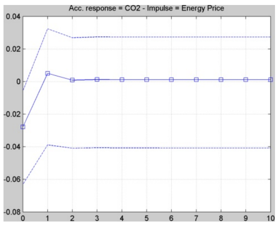
Figure A2: Impulse Response Functions: Homogeneous Country-wide Specification with 1 Lag



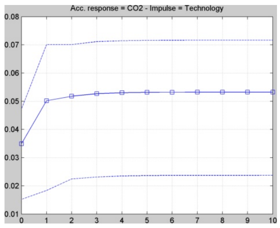
(a) CO_2 - GHG Pol. String.



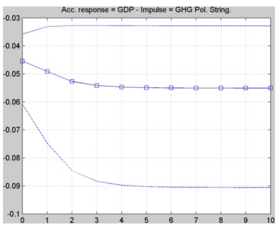
(b) CO_2 - Value Added



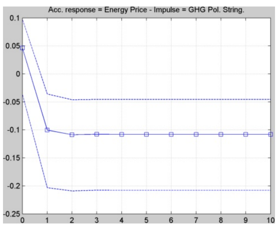
(c) CO_2 - Energy Prices



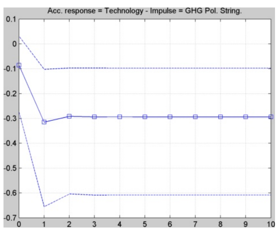
(d) CO_2 - Technology



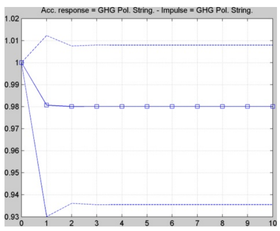
(e) Value Added - GHG Stringency



(f) Energy Prices - GHG Stringency



(g) Technology - GHG Stringency



(h) GHG Stringency - GHG Stringency

Note: The first variable in the caption corresponds to the response variable, whereas the second variable corresponds to the impulse variable. 10 % confidence intervals.

Table A4: Homogeneous Country-wide Specification with 1 Lag, WEF Environmental Policy Stringency Index

Variable and Statistics	CO2		GDP		Energy Price		Technology		WEF Pol. String.	
	L0	L1	L0	L1	L0	L1	L0	L1	L0	L1
WEF Pol. String.	-0.102***	-0.144***	0.023***	-0.068***	0.189***	-0.727***	0.033***	0.802***	-	-0.004
	(0.005)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	-	(0.224)
ln(Technology)	0.021***	-0.019***	-0.008***	-0.006***	0.020***	-0.031***	-	-0.474***	-	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	-	(0.000)	-	(0.860)
ln(Energy prices)	0.060***	0.004	-0.045***	-0.035***	-	-0.345***	-	0.184***	-	-0.000
	(0.000)	(0.477)	(0.000)	(0.000)	-	(0.000)	-	(0.000)	-	(0.393)
ln(GDP)	0.626***	-0.406***	-	0.304***	-	-0.558***	-	0.668***	-	-0.000
	(0.000)	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.640)
ln(CO2)	-	-0.174***	-	-0.038***	-	0.023***	-	0.216***	-	-0.000
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.658)
ln(Corruption)	0.030	0.043*	0.014	-0.008	0.007	-0.007	0.149	-0.191***	0.000	0.000
	(0.186)	(0.067)	(0.193)	(0.396)	(0.852)	(0.823)	(0.000)	(0.000)	(0.380)	(0.759)
ln(CDD)	0.005*	0.005***	0.013***	0.008***	-0.002***	0.016***	-0.025***	-0.009***	0.000	0.000
	(0.066)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.405)	(0.989)
ln(HDD)	0.072***	0.105***	-0.002***	0.064*	0.036***	-0.282***	0.311***	0.192***	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.335)	(0.834)
Time FE/Country FE	Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes	
Obs.	322		322		322		322		322	
Pseudo R2	0.386		0.675		0.053		0.132		0.497	

Column titles indicate the sub-equations. L0: contemporaneous effect, L1: effect from one time lag. * $p<0.1$, ** $p<0.05$, *** $p<0.01$, p-values in parenthesis

Table A5: Homogeneous Country-wide Specification with 1 Lag, Aggregated Sector Dataset

Variable and Statistics	CO2		GDP		Energy Price		Technology		GHG Pol. String.	
	L0	L1	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-0.109**	-0.015	-0.046**	0.040**	0.037	-0.066	0.272***	0.167	-	-0.064
	(0.042)	(0.796)	(0.015)	(0.049)	(0.501)	(0.248)	(0.000)	(0.131)	-	(0.154)
ln(Technology)	-0.004	0.004	0.003	0.003	0.006	0.024***	-	-0.112***	-	-0.002
	(0.668)	(0.679)	(0.369)	(0.268)	(0.480)	(0.009)	-	(0.000)	-	(0.357)
ln(Energy prices)	-0.019	-0.003	-0.015	-0.004	-	0.049	-	-0.017	-	0.009
	(0.474)	(0.921)	(0.177)	(0.752)	-	(0.305)	-	(0.708)	-	(0.119)
ln(GDP)	0.453***	0.172*	-	0.404***	-	-0.083	-	-0.493**	-	-0.028
	(0.000)	(0.066)	-	(0.000)	-	(0.375)	-	(0.037)	-	(0.296)
ln(CO2)	-	-0.106**	-	0.011	-	-0.014	-	0.184	-	-0.021**
	-	(0.027)	-	(0.254)	-	(0.603)	-	(0.269)	-	(0.011)
ln(Corruption)	0.001	-0.014	0.003	0.011**	-0.003	0.027**	-0.027	-0.013	0.004	-0.001
	(0.954)	(0.198)	(0.515)	(0.031)	(0.815)	(0.029)	(0.135)	(0.453)	(0.143)	(0.821)
ln(CDD)	0.009**	0.003	0.002	0.003**	-0.002	0.006*	0.019	-0.007	-0.001	0.001
	(0.013)	(0.369)	(0.210)	(0.037)	(0.627)	(0.065)	(0.537)	(0.261)	(0.500)	(0.654)
ln(HDD)	0.010	-0.067***	-0.010	0.027***	0.067**	0.004	-0.055**	-0.094*	0.002	0.002
	(0.684)	(0.005)	(0.314)	(0.007)	(0.020)	(0.899)	(0.020)	(0.053)	(0.704)	(0.662)
Time FE/Country FE	Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes		Yes/Yes	
Obs.	490		490		490		490		490	
Pseudo R2	0.26		0.60		0.17		0.07		0.26	

Column titles indicate the sub-equations. L0: contemporaneous effect, L1: effect from one time lag. * $p<0.1$, ** $p<0.05$, *** $p<0.01$, p-values in parenthesis

Table A6: Homogeneous Country-wide Specification with 1 Lag, Spatial

Variable and Statistics	CO2				GDP			
	L0	L1	N0	N1	L0	L1	N0	N1
GHG Pol. String.	-0.223***	0.114*	0.040	-0.541**	-0.044**	0.018	0.047	-0.140*
	(0.000)	(0.057)	(0.855)	(0.013)	(0.019)	(0.337)	(0.583)	(0.100)
ln(Technology)	-0.000	-0.002	0.019	-0.012	-0.002	-0.004	0.005	0.004
	(0.989)	(0.814)	(0.227)	(0.392)	(0.382)	(0.148)	(0.369)	(0.481)
ln(Energy prices)	-0.007	0.018	-0.035	-0.059	-0.015*	0.008	-0.011	0.006
	(0.748)	(0.440)	(0.580)	(0.335)	(0.094)	(0.379)	(0.586)	(0.767)
ln(GDP)	0.567***	-0.118**	0.041	0.317***	-	0.375***	0.155***	-0.068*
	(0.000)	(0.016)	(0.736)	(0.003)	-	(0.000)	(0.000)	(0.091)
ln(CO2)	-	-0.129***	0.178***	-0.027	-	0.013	-	0.023
	-	(0.000)	(0.001)	(0.669)	-	(0.130)	-	(0.304)
ln(Corruption)	-0.006	-0.002	-	-	0.004	0.002	-	-
	(0.555)	(0.853)	-	-	(0.355)	(0.579)	-	-
ln(CDD)	-0.002	-0.006**	-	-	0.003***	-0.001	-	-
	(0.465)	(0.031)	-	-	(0.005)	(0.646)	-	-
ln(HDD)	0.098***	-0.110***	-	-	-0.001	0.009	-	-
	(0.000)	(0.000)	-	-	(0.903)	(0.361)	-	-
Time FE/Country FE	Yes/Yes				Yes/Yes			
Obs.	920				920			
R2	0.21				0.59			

Variable and Statistics	Energy Price				Technology			
	L0	L1	N0	N1	L0	L1	N0	N1
GHG Pol. String.	0.085*	-0.123**	-0.197	-0.289**	-0.057	0.021	0.763*	-0.626
	(0.080)	(0.011)	(0.152)	(0.046)	(0.670)	(0.877)	(0.096)	(0.157)
ln(Technology)	0.006	0.006	0.000	0.009	-	0.182***	-0.032	-0.029
	(0.467)	(0.407)	(0.971)	(0.440)	-	(0.000)	(0.347)	(0.348)
ln(Energy prices)	-	0.025	0.103**	-0.066	-	-0.078	-	-0.328**
	-	(0.447)	(0.011)	(0.122)	-	(0.239)	-	(0.011)
ln(GDP)	-	0.064	-	0.020	-	-0.008	-	0.166
	-	(0.181)	-	(0.791)	-	(0.943)	-	(0.423)
ln(CO2)	-	-0.044*	-	-0.062	-	0.039	-	0.155
	-	(0.058)	-	(0.167)	-	(0.496)	-	(0.228)
ln(Corruption)	-0.003	-0.014	-	-	0.015	-0.001	-	-
	(0.767)	(0.198)	-	-	(0.299)	(0.959)	-	-
ln(CDD)	-0.004	0.003	-	-	-0.008	-0.010	-	-
	(0.147)	(0.369)	-	-	(0.234)	(0.168)	-	-
ln(HDD)	0.050***	-0.067***	-	-	0.012	-0.025	-	-
	(0.003)	(0.005)	-	-	(0.794)	(0.607)	-	-
Time FE/Country FE	Yes/Yes				Yes/Yes			
Obs.	920				920			
R2	0.11				0.29			

Variable and Statistics	GHG Pol. String.			
	L0	L1	N0	N1
GHG Pol. String.	-	-0.026	0.027	0.240***
	-	(0.441)	(0.661)	(0.001)
ln(Technology)	-	-0.001	-	-0.003
	-	(0.724)	-	(0.313)
ln(Energy prices)	-	-0.003	-	0.033*
	-	(0.684)	-	(0.052)
ln(GDP)	-	0.009	-	-0.064*
	-	(0.470)	-	(0.061)
ln(CO2)	-	0.002	-	0.000
	-	(0.799)	-	(0.986)
ln(Corruption)	0.000	-0.001	-	-
	(0.984)	(0.723)	-	-
ln(CDD)	-0.003**	-0.001	-	-
	(0.027)	(0.296)	-	-
ln(HDD)	0.002	-0.006	-	-
	(0.768)	(0.436)	-	-
Time FE/Country FE	Yes/Yes			
Obs.	920			
R2	0.18			

Column titles indicate the sub-equations. L0: contemporaneous effect, L1: effect from one time lag, N0: contemporaneous effect from one spatial lag, N1: effect from one time and one spatial lag. * $p<0.1$, ** $p<0.05$, *** $p<0.01$, p-values in parenthesis

Table A7.1: Heterogeneous Sector Specification with 1 Lag (Continued on Next Page)

Variable and Statistics	CO2 Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-0.271***	0.023	-0.197***	0.030	-0.082*	0.017	-0.176***	-0.017
	(0.000)	(0.653)	(0.000)	(0.543)	(0.088)	(0.736)	(0.000)	(0.722)
ln(Technology)	0.001	0.008	0.011*	0.014**	0.010*	-0.002	0.004	-0.005
	(0.842)	(0.271)	(0.079)	(0.023)	(0.090)	(0.703)	(0.419)	(0.366)
ln(Energy prices)	-0.111***	-0.059***	-0.073***	-0.057***	-0.087***	-0.063***	-0.009	-0.012
	(0.000)	(0.003)	(0.000)	(0.002)	(0.000)	(0.001)	(0.600)	(0.503)
ln(Value Added)	0.102***	0.036**	0.110***	0.068***	0.079***	0.002	0.064***	0.042***
	(0.000)	(0.025)	(0.000)	(0.000)	(0.000)	(0.810)	(0.000)	(0.000)
ln(CO2)	-	-0.079***	-	-0.097***	-	-0.080***	-	-0.051***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.003)
ln(Corruption)	-0.019***	-0.017***	-0.019***	-0.017***	-0.019***	-0.017***	-0.019***	-0.017***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(CDD)	0.006***	-0.005***	0.006***	-0.005***	0.006***	-0.005***	0.006***	-0.005***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)	(0.001)
ln(HDD)	0.011	-0.008	0.011	-0.008	0.011	-0.008	0.011	-0.008
	(0.205)	(0.349)	(0.205)	(0.349)	(0.205)	(0.349)	(0.205)	(0.349)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.09							

Variable and Statistics	Value Added Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-0.043**	0.036*	-0.010	0.044*	-0.035	0.038	-0.099***	-0.025
	(0.041)	(0.094)	(0.682)	(0.082)	(0.262)	(0.249)	(0.007)	(0.504)
ln(Technology)	0.004	0.004	0.005	-0.001	0.002	-0.003	0.007	-0.005
	(0.186)	(0.175)	(0.172)	(0.764)	(0.626)	(0.512)	(0.226)	(0.443)
ln(Energy prices)	-0.041***	-0.000	-0.037***	-0.009	-0.022**	-0.011	0.030**	-0.013
	(0.000)	(0.955)	(0.000)	(0.371)	(0.038)	(0.330)	(0.028)	(0.393)
ln(Value Added)	-	0.149***	-	0.071***	-	0.094***	-	0.028
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.103)
ln(CO2)	-	0.003	-	0.008**	-	0.013**	-	0.036***
	-	(0.333)	-	(0.023)	-	(0.020)	-	(0.000)
ln(Corruption)	0.002	0.003	0.002	0.003	0.002	0.003	0.002	0.003
	(0.352)	(0.172)	(0.352)	(0.172)	(0.352)	(0.172)	(0.352)	(0.172)
ln(CDD)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.163)	(0.151)	(0.163)	(0.151)	(0.163)	(0.151)	(0.163)	(0.151)
ln(HDD)	-0.003	0.004	-0.003	0.004	-0.003	0.004	-0.003	0.004
	(0.515)	(0.387)	(0.515)	(0.387)	(0.515)	(0.387)	(0.515)	(0.387)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.04							

Variable and Statistics	Energy Price Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	0.035*	-0.063***	0.035**	-0.061***	0.034*	-0.061***	0.040**	-0.051***
	(0.057)	(0.001)	(0.043)	(0.001)	(0.064)	(0.001)	(0.025)	(0.005)
ln(Technology)	0.007**	0.024***	0.007**	0.024***	0.007**	0.025***	0.007**	0.025***
	(0.023)	(0.000)	(0.015)	(0.000)	(0.026)	(0.000)	(0.028)	(0.000)
ln(Energy prices)	-	0.058***	-	0.057***	-	0.056***	-	0.055***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)
ln(Value Added)	-	0.002	-	0.003	-	0.011**	-	0.003
	-	(0.705)	-	(0.673)	-	(0.027)	-	(0.185)
ln(CO2)	-	-0.004*	-	0.001	-	-0.001	-	-0.004
	-	(0.090)	-	(0.833)	-	(0.769)	-	(0.331)
ln(Corruption)	-0.002	0.027***	-0.002	0.027***	-0.002	0.027***	-0.002	0.027***
	(0.275)	(0.000)	(0.275)	(0.000)	(0.275)	(0.000)	(0.275)	(0.000)
ln(CDD)	-0.002***	0.006***	-0.002***	0.006***	-0.002***	0.006***	-0.002***	0.006***
	(0.002)	(0.000)	(0.002)	(0.000)	(0.002)	(0.000)	(0.002)	(0.000)
ln(HDD)	0.071***	0.008	0.071***	0.008	0.071***	0.008	0.071***	0.008
	(0.000)	(0.110)	(0.000)	(0.110)	(0.000)	(0.110)	(0.000)	(0.110)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.17							

Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

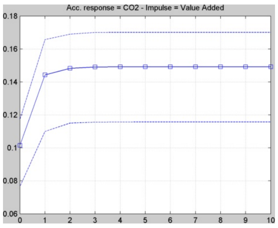
Table A7.2: Heterogeneous Sector Specification with 1 Lag (Continued)

Variable and Statistics	Technology Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	0.126***	0.047	0.163***	0.012	0.159***	0.033	0.126***	0.043
	(0.009)	(0.372)	(0.000)	(0.815)	(0.001)	(0.522)	(0.005)	(0.384)
ln(Technology)	-	-0.082***	-	-0.086***	-	-0.086***	-	-0.090***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)
ln(Energy prices)	-	-0.016	-	-0.013	-	-0.018	-	-0.012
	-	(0.220)	-	(0.283)	-	(0.174)	-	(0.329)
ln(Value Added)	-	-0.026**	-	-0.060***	-	-0.032**	-	-0.003
	-	(0.030)	-	(0.000)	-	(0.012)	-	(0.657)
ln(CO2)	-	0.010*	-	-0.004	-	-0.022***	-	0.006
	-	(0.093)	-	(0.517)	-	(0.006)	-	(0.329)
ln(Corruption)	-0.017***	0.012***	-0.017***	0.012***	-0.017***	0.012***	-0.017***	0.012***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(CDD)	0.022***	0.015***	0.022***	0.015***	0.022***	0.015***	0.022***	0.015***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ln(HDD)	-0.035***	0.030***	-0.035***	0.030***	-0.035***	0.030***	-0.035***	0.030***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.08							

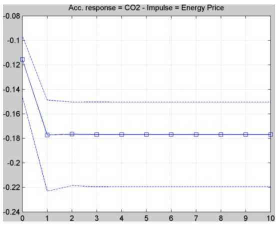
Variable and Statistics	GHG Policy Stringency Equation							
	Very Clean		Clean		Dirty		Very Dirty	
	L0	L1	L0	L1	L0	L1	L0	L1
GHG Pol. String.	-	-0.060***	-	-0.060***	-	-0.058***	-	-0.042***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.007)
ln(Technology)	-	-0.004***	-	-0.004***	-	-0.004***	-	-0.004***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)
ln(Energy prices)	-	0.010***	-	0.010***	-	0.010***	-	0.010***
	-	(0.000)	-	(0.000)	-	(0.000)	-	(0.000)
ln(Value Added)	-	0.000	-	-0.000	-	-0.000	-	-0.000
	-	(0.956)	-	(0.968)	-	(0.746)	-	(0.938)
ln(CO2)	-	-0.000	-	-0.000	-	0.000	-	0.000
	-	(0.787)	-	(0.793)	-	(0.730)	-	(0.995)
ln(Corruption)	0.002***	0.000	0.002***	0.000	0.002***	0.000	0.002***	0.000
	(0.000)	(0.271)	(0.000)	(0.271)	(0.000)	(0.271)	(0.000)	(0.271)
ln(CDD)	-0.002***	0.000	-0.002***	0.000	-0.002***	0.000	-0.002***	0.000
	(0.000)	(0.410)	(0.000)	(0.410)	(0.000)	(0.410)	(0.000)	(0.410)
ln(HDD)	0.003***	-0.001*	0.003***	-0.001*	0.003***	-0.001*	0.003***	-0.001*
	(0.000)	(0.054)	(0.000)	(0.054)	(0.000)	(0.054)	(0.000)	(0.054)
Time FE/Country FE	Yes/Yes							
Obs.	920							
Pseudo R2	0.25							

Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag. * $p<0.1$, ** $p<0.05$, *** $p<0.01$, p-values in parenthesis

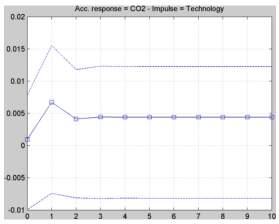
Figure A3: Impulse Response Functions Very Clean Sector



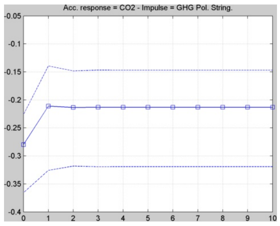
(a) CO_2 - Value Added



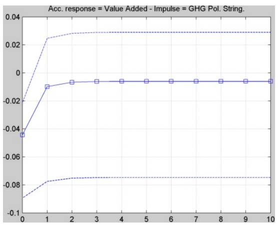
(b) CO_2 - Energy Prices



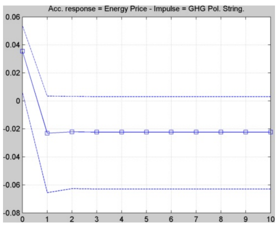
(c) CO_2 - Technology



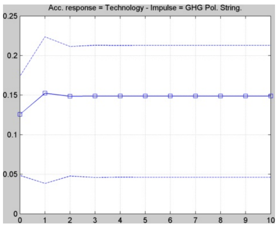
(d) CO_2 - GHG Stringency



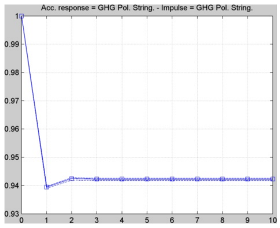
(e) Value Added - GHG Stringency



(f) Energy Prices - GHG Stringency



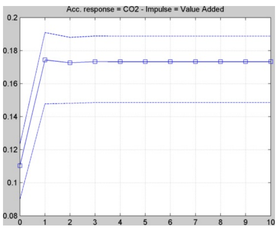
(g) Technology - GHG Stringency



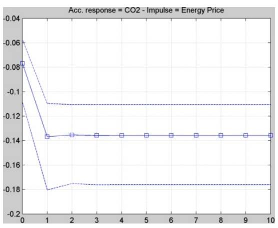
(h) GHG Stringency - GHG Stringency

Note: The first variable in the caption corresponds to the response variable, whereas the second variable corresponds to the impulse variable. 10% confidence intervals.

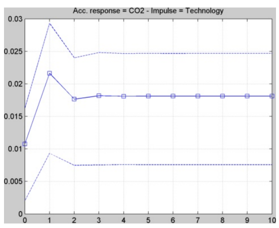
Figure A4: Impulse Response Functions Clean Sector



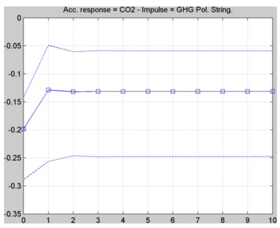
(a) CO_2 - Value Added



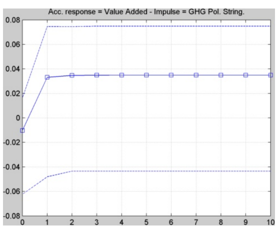
(b) CO_2 - Energy Prices



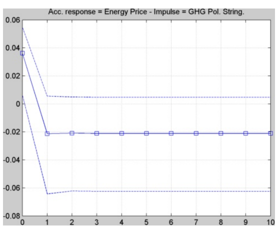
(c) CO_2 - Technology



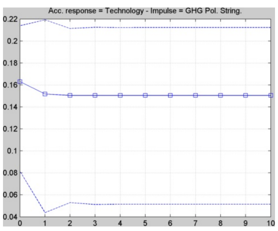
(d) CO_2 - GHG Stringency



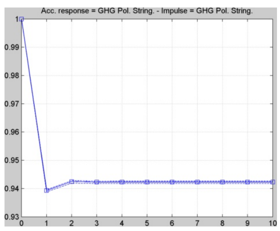
(e) Value Added - GHG Stringency



(f) Energy Prices - GHG Stringency



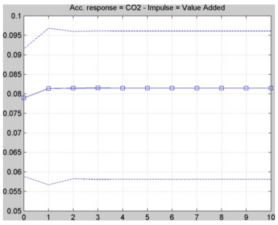
(g) Technology - GHG Stringency



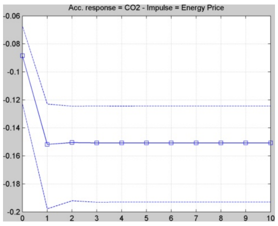
(h) GHG Stringency - GHG Stringency

Note: The first variable in the caption corresponds to the response variable, whereas the second variable corresponds to the impulse variable. 10% confidence intervals.

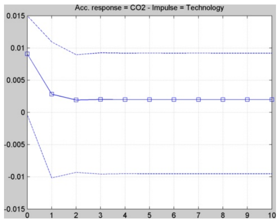
Figure A5: Impulse Response Functions Dirty Sector



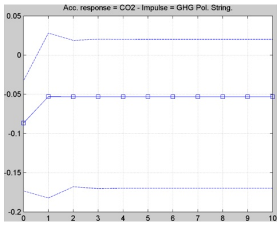
(a) CO_2 - Value Added



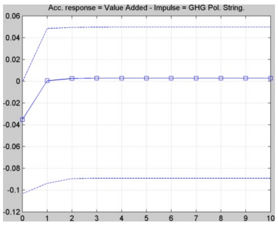
(b) CO_2 - Energy Prices



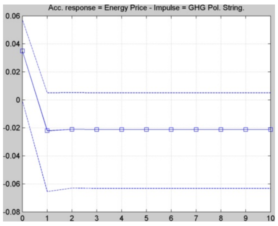
(c) CO_2 - Technology



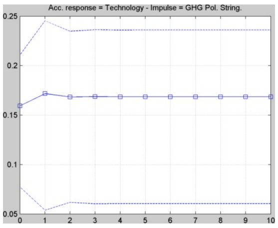
(d) CO_2 - GHG Stringency



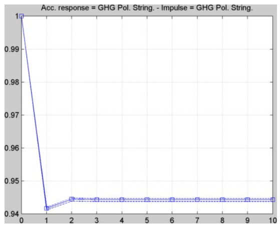
(e) Value Added - GHG Stringency



(f) Energy Prices - GHG Stringency



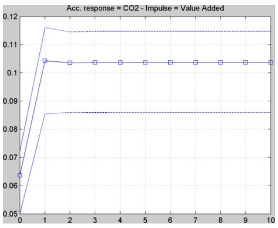
(g) Technology - GHG Stringency



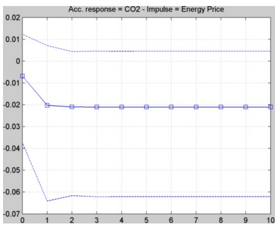
(h) GHG Stringency - GHG Stringency

Note: The first variable in the caption corresponds to the response variable, whereas the second variable corresponds to the impulse variable. 10% confidence intervals.

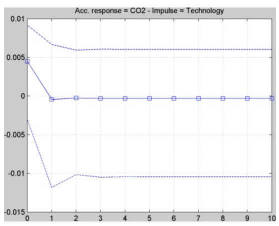
Figure A6: Impulse Response Functions Very Dirty Sector



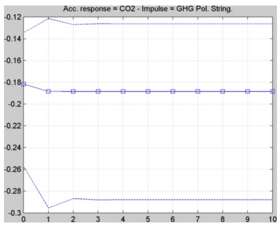
(a) CO_2 - Value Added



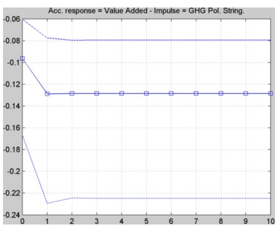
(b) CO_2 - Energy Prices



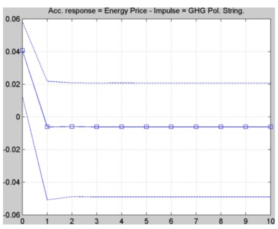
(c) CO_2 - Technology



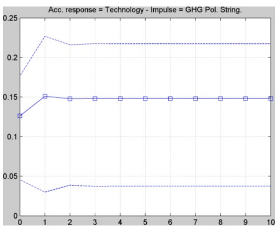
(d) CO_2 - GHG Stringency



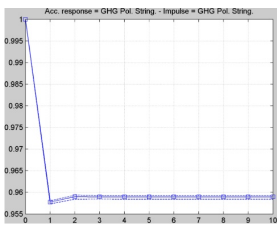
(e) Value Added - GHG Stringency



(f) Energy Prices - GHG Stringency



(g) Technology - GHG Stringency



(h) GHG Stringency - GHG Stringency

Note: The first variable in the caption corresponds to the response variable, whereas the second variable corresponds to the impulse variable. 10% confidence intervals.

Table A8.1: Heterogeneous Spatial Sector Specification with 1 Lag (Continued on Next Page)

Variables and Statistics	CO2 Equation															
	Very clean				Clean				Dirty				Very dirty			
	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1
GHG Pol. String.	-0.265***	0.007	0.154	0.066	-0.195***	-0.004	0.040	-0.069	-0.088*	-0.001	0.008	-0.012	-0.162***	-0.029	0.059	-0.222
	(0.000)	(0.885)	(0.288)	(0.657)	(0.000)	(0.938)	(0.762)	(0.613)	(0.073)	(0.991)	(0.951)	(0.935)	(0.000)	(0.547)	(0.660)	(0.114)
ln(Technology)	0.004	0.006	-0.029*	0.009	0.009	0.012**	-0.004	0.002	0.009	-0.001	0.010	-0.020	0.001	-0.006	-0.010	-0.036**
	(0.598)	(0.433)	(0.061)	(0.537)	(0.138)	(0.048)	(0.752)	(0.861)	(0.132)	(0.894)	(0.507)	(0.156)	(0.813)	(0.245)	(0.482)	(0.010)
ln(Energy prices)	-0.153***	-0.138***	0.076*	-0.013	-0.093***	-0.114***	0.060	-0.056	-0.114***	-0.136***	0.059	-0.036	-0.034	-0.069***	0.084**	0.026
	(0.000)	(0.000)	(0.088)	(0.780)	(0.000)	(0.000)	(0.132)	(0.175)	(0.000)	(0.000)	(0.167)	(0.418)	(0.105)	(0.002)	(0.042)	(0.558)
ln(Value Added)	0.090***	0.036**	0.013	0.007	0.093***	0.065***	0.018	-0.030	0.081***	0.007	-0.005	0.019	0.043***	0.034***	-0.004	0.023*
	(0.000)	(0.024)	(0.495)	(0.726)	(0.000)	(0.000)	(0.399)	(0.175)	(0.000)	(0.534)	(0.718)	(0.225)	(0.000)	(0.000)	(0.734)	(0.068)
ln(CO2)	-	-0.079***	0.035**	-0.009	-	-0.099***	-0.012	-0.021	-	-0.084***	-0.014	-0.018	-	-0.058***	-0.026	0.009
	-	(0.000)	(0.035)	(0.625)	-	(0.000)	(0.424)	(0.174)	-	(0.000)	(0.453)	(0.371)	-	(0.002)	(0.127)	(0.659)
ln(Corruption)	-0.014***	-0.026***	-	-	-0.014***	-0.026***	-	-	-0.014***	-0.026***	-	-	-0.014***	-0.026***	-	-
	(0.002)	(0.000)	-	-	(0.002)	(0.000)	-	-	(0.002)	(0.000)	-	-	(0.002)	(0.000)	-	-
ln(CDD)	0.004***	-0.007***	-	-	0.004***	-0.007***	-	-	0.004***	-0.007***	-	-	0.004***	-0.007***	-	-
	(0.009)	(0.000)	-	-	(0.009)	(0.000)	-	-	(0.009)	(0.000)	-	-	(0.009)	(0.000)	-	-
ln(HDD)	-0.020*	-0.040***	-	-	-0.020*	-0.040***	-	-	-0.020*	-0.040***	-	-	-0.020*	-0.040***	-	-
	(0.063)	(0.000)	-	-	(0.063)	(0.000)	-	-	(0.063)	(0.000)	-	-	(0.063)	(0.000)	-	-
Time FE/Country FE	yes/yes															
Pseudo R2	0.093															
Obs.	16660															

Variables and Statistics	Value Added Equation															
	Very clean				Clean				Dirty				Very dirty			
	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1
GHG Pol. String.	-0.047**	0.022	0.015	0.162**	-0.014	0.041*	-0.003	-0.091	-0.043	0.052	-0.263***	-0.157*	-0.082**	-0.019	-0.062	-0.004
	(0.017)	(0.281)	(0.805)	(0.013)	(0.550)	(0.092)	(0.960)	(0.208)	(0.175)	(0.119)	(0.003)	(0.090)	(0.031)	(0.615)	(0.569)	(0.970)
ln(Technology)	0.005	0.004	0.006	0.025***	0.006	-0.001	-0.002	0.009	0.005	-0.000	-0.007	-0.029***	0.010	-0.001	0.010	-0.046***
	(0.143)	(0.222)	(0.366)	(0.000)	(0.128)	(0.858)	(0.763)	(0.192)	(0.304)	(0.977)	(0.496)	(0.002)	(0.128)	(0.896)	(0.412)	(0.000)
ln(Energy prices)	-0.035***	0.005	-0.030	-0.015	-0.042***	-0.009	-0.004	-0.020	-0.033**	-0.016	0.053**	-0.011	-0.001	-0.035*	0.071**	0.070**
	(0.000)	(0.583)	(0.110)	(0.455)	(0.000)	(0.380)	(0.832)	(0.348)	(0.019)	(0.296)	(0.034)	(0.679)	(0.960)	(0.082)	(0.029)	(0.044)
ln(Value Added)	-	0.150***	-0.015*	-0.010	-	0.075***	-0.012	0.005	-	0.090***	0.032***	0.011	-	0.020	0.023	0.027*
	-	(0.000)	(0.087)	(0.250)	-	(0.000)	(0.231)	(0.640)	-	(0.000)	(0.001)	(0.257)	-	(0.261)	(0.112)	(0.078)
ln(CO2)	-	0.005	-	0.005	-	0.009**	-	-0.010	-	0.013**	-	0.004	-	0.039***	-	0.015
	-	(0.174)	-	(0.528)	-	(0.014)	-	(0.166)	-	(0.015)	-	(0.763)	-	(0.000)	-	(0.389)
ln(Corruption)	0.005*	0.000	-	-	0.005*	0.000	-	-	0.005*	0.000	-	-	0.005*	0.000	-	-
	(0.063)	(0.882)	-	-	(0.063)	(0.882)	-	-	(0.063)	(0.882)	-	-	(0.063)	(0.882)	-	-
ln(CDD)	0.001	0.001	-	-	0.001	0.001	-	-	0.001	0.001	-	-	0.001	0.001	-	-
	(0.213)	(0.216)	-	-	(0.213)	(0.216)	-	-	(0.213)	(0.216)	-	-	(0.213)	(0.216)	-	-
ln(HDD)	-0.006	-0.002	-	-	-0.006	-0.002	-	-	-0.006	-0.002	-	-	-0.006	-0.002	-	-
	(0.267)	(0.760)	-	-	(0.267)	(0.760)	-	-	(0.267)	(0.760)	-	-	(0.267)	(0.760)	-	-
Time FE/Country FE	yes/yes															
Pseudo R2	0.038															
Obs.	16660															

Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag, N0: contemporaneous effect from one spatial lag, N1: effect from one time and one spatial lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

Table A8.2: Heterogeneous Sector Specification with 1 Lag (Continued)

Variables and Statistics	Energy Price															
	Very clean				Clean				Dirty				Very dirty			
	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1
GHG Pol. String.	0.026	-0.055***	-0.091	-0.161***	0.027	-0.055***	0.035	-0.071	0.026	-0.058***	0.017	-0.021	0.044**	-0.060***	-0.191***	0.067
	(0.156)	(0.003)	(0.110)	(0.007)	(0.125)	(0.002)	(0.509)	(0.200)	(0.151)	(0.002)	(0.762)	(0.723)	(0.018)	(0.002)	(0.001)	(0.282)
ln(Technology)	0.008***	0.024***	0.003	-0.004	0.008***	0.025***	0.001	-0.001	0.008**	0.026***	-0.003	-0.006	0.008**	0.025***	0.001	0.004
	(0.009)	(0.000)	(0.681)	(0.498)	(0.006)	(0.000)	(0.890)	(0.805)	(0.015)	(0.000)	(0.641)	(0.329)	(0.014)	(0.000)	(0.928)	(0.569)
ln(Energy prices)	-	0.049***	-0.003	-0.018	-	0.047***	-0.007	-0.015	-	0.038***	0.002	0.005	-	0.061***	0.019	-0.034*
	-	(0.000)	(0.839)	(0.348)	-	(0.000)	(0.626)	(0.407)	-	(0.006)	(0.913)	(0.800)	-	(0.000)	(0.248)	(0.089)
ln(Value Added)	-	0.002	-	0.002	-	0.003	-	0.012	-	0.010**	-	0.003	-	0.003	-	0.006
	-	(0.688)	-	(0.834)	-	(0.652)	-	(0.134)	-	(0.032)	-	(0.473)	-	(0.208)	-	(0.462)
ln(CO2)	-	-0.004*	-	-0.032***	-	0.001	-	-0.005	-	-0.001	-	-0.023***	-	-0.002	-	0.018**
	-	(0.079)	-	(0.000)	-	(0.684)	-	(0.382)	-	(0.896)	-	(0.005)	-	(0.644)	-	(0.043)
ln(Corruption)	-0.004*	0.028***	-	-	-0.004*	0.028***	-	-	-0.004*	0.028***	-	-	-0.004*	0.028***	-	-
	(0.054)	(0.000)	-	-	(0.054)	(0.000)	-	-	(0.054)	(0.000)	-	-	(0.054)	(0.000)	-	-
ln(CDD)	-0.002**	0.006***	-	-	-0.002**	0.006***	-	-	-0.002**	0.006***	-	-	-0.002**	0.006***	-	-
	(0.010)	(0.000)	-	-	(0.010)	(0.000)	-	-	(0.010)	(0.000)	-	-	(0.010)	(0.000)	-	-
ln(HDD)	0.066***	0.012**	-	-	0.066***	0.012**	-	-	0.066***	0.012**	-	-	0.066***	0.012**	-	-
	(0.000)	(0.016)	-	-	(0.000)	(0.016)	-	-	(0.000)	(0.016)	-	-	(0.000)	(0.016)	-	-
Time FE/Country FE	yes/yes															
Pseudo R2	0.179															
Obs.	16660															

Variables and Statistics	Technology															
	Very clean				Clean				Dirty				Very dirty			
	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1
GHG Pol. String.	0.128***	0.158***	0.000	0.000	0.128***	0.158***	-0.000	-0.000	0.128***	0.158***	-0.000	0.000	0.128***	0.158***	-0.000	0.000
	(0.000)	(0.000)	(0.937)	(0.966)	(0.000)	(0.000)	(0.765)	(0.988)	(0.000)	(0.000)	(0.911)	(0.975)	(0.000)	(0.000)	(0.777)	(0.957)
ln(Technology)	-	-0.135***	-0.000	0.000	-	-0.135***	0.000	0.000	-	-0.135***	-0.000	0.000	-	-0.135***	-0.000	-0.000
	-	(0.000)	(0.929)	(0.984)	-	(0.000)	(0.979)	(0.935)	-	(0.000)	(0.995)	(0.998)	-	(0.000)	(0.902)	(0.895)
ln(Energy prices)	-	0.134***	-	-0.000	-	0.134***	-	0.000	-	0.134***	-	-0.000	-	0.134***	-	-0.000
	-	(0.000)	-	(0.913)	-	(0.000)	-	(0.991)	-	(0.000)	-	(0.858)	-	(0.000)	-	(0.978)
ln(Value Added)	-	-0.000	-	0.000	-	-0.000	-	0.000	-	-0.000	-	-0.000	-	-0.000	-	-0.000
	-	(0.883)	-	(0.942)	-	(0.869)	-	(0.984)	-	(0.862)	-	(0.983)	-	(0.918)	-	(0.818)
ln(CO2)	-	0.000		0.000	-	-0.000		-0.000	-	-0.000		-0.000	-	0.000		-0.000
	-	(0.971)		(0.982)	-	(0.956)		(0.907)	-	(0.860)		(0.985)	-	(0.922)		(0.805)
ln(Corruption)	-0.059***	0.022***	-	-	-0.059***	0.022***	-	-	-0.059***	0.022***	-	-	-0.059***	0.022***	-	-
	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-
ln(CDD)	0.022***	0.014***	-	-	0.022***	0.014***	-	-	0.022***	0.014***	-	-	0.022***	0.014***	-	-
	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-
ln(HDD)	-0.124***	0.136***	-	-	-0.124***	0.136***	-	-	-0.124***	0.136***	-	-	-0.124***	0.136***	-	-
	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-
Time FE/Country FE	yes/yes															
Pseudo R2	0.092															
Obs.	16660															

Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag, N0: contemporaneous effect from one spatial lag, N1: effect from one time and one spatial lag. * p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis

Table A8.3: Heterogeneous Sector Specification with 1 Lag (Continued)

Variables and Statistics	GHG Policy Stringency Equation															
	Very clean				Clean				Dirty				Very dirty			
	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1	L0	L1	NL0	NL1
GHG Pol. String.	-	-0.061***	0.000	0.000	-	-0.061***	-0.000	-0.000	-	-0.061***	0.000	-0.000	-	-0.061***	-0.000	0.000
	-	(0.000)	(0.985)	(0.953)	-	(0.000)	(0.954)	(0.963)	-	(0.000)	(0.996)	(0.974)	-	(0.000)	(0.956)	(0.982)
ln(Technology)	-	-0.003***	-	0.000	-	-0.003***	-	-0.000	-	-0.003***	-	-0.000	-	-0.003***	-	-0.000
	-	(0.000)	-	(0.995)	-	(0.000)	-	(1.000)	-	(0.000)	-	(0.994)	-	(0.000)	-	(0.978)
ln(Energy prices)	-	0.011***	-	-0.000	-	0.011***	-	0.000	-	0.011***	-	-0.000	-	0.011***	-	0.000
	-	(0.000)	-	(0.961)	-	(0.000)	-	(0.968)	-	(0.000)	-	(0.991)	-	(0.000)	-	(0.995)
ln(Value Added)	-	-0.000	-	0.000	-	-0.000	-	-0.000	-	-0.000	-	-0.000	-	-0.000	-	0.000
	-	(0.933)	-	(0.950)	-	(0.952)	-	(0.994)	-	(0.908)	-	(0.997)	-	(0.924)	-	(0.957)
ln(CO2)	-	-0.000	-	-0.000	-	-0.000	-	0.000	-	0.000	-	-0.000	-	-0.000	-	0.000
	-	(0.823)	-	(0.980)	-	(0.953)	-	(0.910)	-	(1.000)	-	(0.960)	-	(0.961)	-	(0.908)
ln(Corruption)	-0.010***	-0.014***	-	-	-0.010***	-0.014***	-	-	-0.010***	-0.014***	-	-	-0.010***	-0.014***	-	-
	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-
ln(CDD)	-0.002**	-0.001*	-	-	-0.002**	-0.001*	-	-	-0.002**	-0.001*	-	-	-0.002**	-0.001*	-	-
	(0.041)	(0.098)	-	-	(0.041)	(0.098)	-	-	(0.041)	(0.098)	-	-	(0.041)	(0.098)	-	-
ln(HDD)	-0.016***	-0.009***	-	-	-0.016***	-0.009***	-	-	-0.016***	-0.009***	-	-	-0.016***	-0.009***	-	-
	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-	(0.000)	(0.000)	-	-
Time FE/Country FE	yes/yes															
Pseudo R2	0.218															
Obs.	16660															

Column titles indicate the sector groups. L0: contemporaneous effect, L1: effect from one time lag, N0: contemporaneous effect from one spatial lag, N1: effect from one time and one spatial lag.
* p<0.1, ** p<0.05, *** p<0.01, p-values in parenthesis