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Restructuring Reforms for Green Growth[1]

Serhan Cevik[$] João Tovar Jalles[#]

Abstract

Policymakers across the world are striving to tackle the century-defining challenge of climate change without undermining potential growth. This paper examines the impact of structural reforms in the energy sector (electricity and gas) on enviromental outcomes and green growth indicators in a panel of 25 advanced economies during the period 1970-2020. We obtain striking results. First, while structural reforms so far failed in reducing greenhouse gas emissions per capita, there is some evidence for greater effectiveness in lowering emissions per unit of GDP. Second, although energy reforms are not associated with higher supply of renewable energy as a share of total energy supply, they appear to stimulate a sustained increase in environmental inventions and patents per capita over the medium term. We also find strong evidence of nonlinear effects, with market-friendly energy reforms leading to better environmental outcomes and green growth in countries with stronger environmental regulations. Looking forward, therefore, structural reforms should be designed not just for market efficiency but also for green growth.

JEL Classification Numbers:	D31; L43; L51
Keywords: [Type Here]	Structural reforms; environment; green growth; panel data; local projection; environmmental policy

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I. INTRODUCTION

Climate change is the defining challenge of our time, with significant risks to environmental sustainability and socioeconomic wellbeing.[1] The global mean surface temperature has already surged more than 1.1 degrees Celsius (°C) compared with the pre-industrial average, and projections indicate an acceleration in climate change with global temperature rising by as much as 4°C over the next century. This will increase the risk of weather-related natural disasters and cause greater damage to the environment, lives, and livelihoods (Stern 2007; IPCC 2007, 2014, 2019; 2021). The 2015 Paris Climate Accord, ratified by 194 countries including the European Union (EU), seeks to contain global warming below 2°C compared to the preindustrial level through Nationally Determined Contribution (NDC) commitments to reduce emissions. According to the latest Emissions Gap Report, however, carbon dioxide (CO_2) emissions continued to increase since the Paris Agreement by more than 3 percent across the world, and greenhouse gas (GHG) emissions will decline by only 7.5 percent by 2030, whereas keeping global warming below 1.5°C requires a reduction of 55 percent (UNEP, 2021).

Economic growth tends to lead to higher emissions and environmental degradation, but it is possible to achieve "green growth" by shifting the energy matrix away from fossil fuels and increasing efficiency in the distribution and use of energy. These objectives, in turn, require structural reforms and policies designed to alter behavior throughout the economy. In this paper, we strive to close an important gap in the literature by investigating how structural reforms in the energy sector (electricity and gas) can contribute to climate change mitigation, help guard against threats associated with climate change, and thereby promote green growth defined as environmentally sustainable economic growth. This is not a clear-cut question to answer since product market reforms can have conflicting effects simultaneously on energy demand and the supply and composition of energy sources. Furthermore, the extent of which structural reforms in the energy sector affects environmental outcomes and the composition of economic growth depends on the design of structural reforms and the country's environmental policies and institutional capacity to successfully implement structural reforms.

In this paper, we use the local projection (LP) method proposed by Jordà (2005) to investigate how structural reforms in electricity and gas sectors—based on a narrative database of product market reforms looking at public ownership and market access and structure—influence alternative measures of environmental performance and green growth indicators in a panel of 25 countries during the period 1970–2020. We also explore the possibility of nonlinear effects of these electricity and gas sector reforms by taking into account the stringency of initial environmental policies at the time of a reform. We obtain somewhat mixed, but striking results. First, while structural reforms so far failed in bringing about a reduction in CO_2 and GHG emissions per capita, there is some evidence for greater effectiveness in lowering GHG emissions per unit of GDP. Second, although market-oriented electricity and gas sector reforms are not associated with higher supply of

[1] There is a growing literature on economic and financial effects of climate change (Nordhaus, 1991, 1992; Cline, 1992; Dell et al., 2012; Acevedo *et al.*, 2018; Burke and Tanutama, 2019; Kahn *et al.*, 2019; Cevik and Jalles, 2020, 2021, 2022, 2023).

renewable energy as a share of total energy supply, they appear to stimulate a sustained increase in the number of environmental inventions and patents per capita over the medium term. Furthermore, we find strong evidence of nonlinear effects, with market-friendly electricity and gas reforms leading to better environmental outcomes and green growth in countries with stronger environmental regulations. These results have several important implications for the design of structural reforms and policies, which should aim not just for market efficiency but also for green growth. First, decoupling economic growth from GHG emissions is possible through comprehensive reforms and policies aimed at shifting the energy matrix away from fossil fuels.[2] Second, while transitioning energy supply to low-carbon sources is critical, achieving environmentally sustainable growth is also dependent on greater efficiency in the distribution and use of energy.

The remainder of this paper is organized as follows. Section II describes the data used in the empirical analysis. Section III introduces the salient features of our econometric strategy. Section IV presents and discusses the empirical results, including a series of robustness checks. Finally, Section V offers concluding remarks with policy implications.

II. DATA OVERVIEW

We construct a panel dataset of annual observations covering 25 countries over the period 1970–2020, drawn from the Organization for Economic Co-operation and Development (OECD). The dependent variables are alternative indicators of environmental performance and green growth. The first set looks at emissions and energy intensity, while the second set focuses on measures of green growth.[3] For environmental outcomes, we consider three indicators: (i) CO_2 emissions in metric tons per capita, (ii) GHG emissions in metric tons per capita, and (iii) GHG emissions per unit of GDP.[4] For green growth, we consider three indicators to measure environmentally sustainable economic growth: (i) the share of renewable energy supply[5], (ii) the number of environment-related inventions per capita, and (iii) the number of patents for environment-related technologies per capita.

The main explanatory variables of interest are structural reforms in the energy sector based on a narrative database of major policy changes in product market regulation. Two sectors are considered out of seven covered: electricity and gas, which represent the energy sector. The

[2] Since the COP23 in 2017, the objective has been "to maintain the global momentum to decouple output from greenhouse gas emissions" (Gough, 2017). However, the extent to which decoupling is taking place remains a matter of dispute. Cohen *et al*. (2018; 2022) analyze the relationship between real GDP growth and CO_2 emissions across 178 countries from 1960 to 2018 and find some evidence of decoupling in recent years. IMF (2021) and Black *et al*. (2022) provide detailed assessments.

[3] There are alternative measures of "green growth" in the literature. The most comprehensive framework is developed by the OECD and covers a set of 12 indicators including energy use per unit of GDP and GHG emissions per unit of GDP (OECD, 2017).

[4] This measure of GHG emissions excludes land use, land-use change and forestry.

[5] Note that before 2010 the share of renewables was very small.

original database of major reforms in product market regulation is put together by Duval *et al*. (2018) and updated by Wiese *et al*. (2023) until 2020. This dataset was built in two steps. First, for each of country and aforementioned policy area, Duval *et al*. (2018) and Wiese *et al*. (2023) record all legislative and regulatory actions mentioned in all past OECD Economic Surveys—the regular country surveys published by the OECD—published over the period 1970-2020 , as well as additional country-specific sources.[6] Second, among all those actions, the authors identify major measures (liberalizing/deregulating and tightening/regulating type of reforms) as those that met at least one of three alternative criteria: (i) a narrative criterion based on OECD staff's judgement on the significance of the reform at the time of adoption[7]; (ii) whether the reform was mentioned again in subsequent Economic Surveys, as opposed to only once when the measured is adopted[8]; (iii) the magnitude of the change in the corresponding OECD indicator, when available.[9] When only the third condition is met, an extensive search through other available domestic and national sources, including through the internet, is performed to identify the policy action underpinning the change in the indicator. The approach considers not only reforms but also "counter-reforms"—i.e., policy changes in the opposite direction (increase in regulation or decrease in flexibility). For each country, our reform variable in each area takes value 0 in non-reform years, 1 in reform years, and -1 in counter-reform years. In Appendix Table A1, we present a selected set of examples of identified reforms in the areas of electricity and gas. Appendix Figure A1 shows the temporal dynamics of country-specific reforms in electricity and gas.

It should be acknowledged that the criteria Duval *et al.* (2018) and Wiese *et al.* (2023) applied to identify major reforms, as transparent as they are, are not the only possible option—there is no single, objective way to distinguish between major and minor reforms. Furthermore, the authors do not distinguish among different major reforms—all of them are treated equally, even though some have likely been more important than others in practice. Finally, by design, the dataset does not attempt to measure and compare policy settings across countries, and as such is no substitute for other publicly available indicators produced by other institutions.

[6] The list of countries in our sample includes Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

[7] The OECD Economic Survey uses strong normative language to define the action at the time is taken, suggestive of an important measure (for example, "major reform"). In this respect, the methodology is related to the "narrative approach" used by Romer and Romer (1989, 2004, 2010, and 2017) and Devries et al. (2011) to identify monetary and fiscal shocks and periods of high financial distress.

[8] The policy action is mentioned repeatedly across different editions of the OECD Economic Survey for the country considered, and/or in the retrospective summaries of key past reforms that are featured in some editions, which is also indicative of a major action.

[9] When available, the existing OECD indicator of the regulatory stance in the area considered displays a very large change (in the 5th percentile of the distribution of the cumulative change in the indicator over three years—to accommodate possibly gradual phasing-in of otherwise major reforms). The OECD indicators used for the purpose of this paper, are the indicators of product market regulation in the gas and electricity sectors.

Our empirical objective in this paper is to identify and trace out the environmental performance after major product market reforms in the energy sector, namely electricity and gas. This dataset has several strengths compared to indirect methods used in other papers that rely exclusively on changes in OECD policy indicators. The structural reform database used in this paper (i) identifies the precise nature and exact timing of major legislative and regulatory actions in key product market policy areas; (ii) detects the precise reforms that underpin what otherwise looks like a gradual decline in OECD policy indicators without any obvious or noticeable break; (iii) captures reforms in areas for which OECD indicators exist but do not cover all relevant policy dimensions; and (iv) documents and describes the precise legislative and regulatory actions that underpin observed large changes in OECD indicators over a long period of time. Finally, compared with alternative data sources documenting policy changes in energy markets, the approach taken by Duval *et al.* (2018) allows identifying a rather limited set of major legislative and regulatory reforms, as opposed to just a long list of actions that in some cases would be expected to have little or no bearing on macroeconomic outcomes. This is particularly useful for empirical analyses that seeks to identify, and then estimate, the dynamic effects of reform shocks.

Table 1 presents stylized facts on structural reforms (taking the value 1) in the energy sector—that is, decreases in regulation or increase in market flexibility—and counter-reforms—that is, increases in regulation or decrease in market flexibility. The latter are relatively rare events in product markets (while they can account for up to 25 percent of total shocks in the labor market). Figure 1 and Figure 2 provide the number and distribution of reforms identified in the sample, respectively, and illustrate the heterogeneity of reform efforts across product market regulatory areas and countries. These have been more frequently implemented in telecommunications and air transport. The vast majority of product market reforms in our sample were implemented during the 1990s and the 2000s.[10] In terms of geographical distribution, EU countries took more actions than non-EU countries on average, reflecting the greater scope for action in the former group.

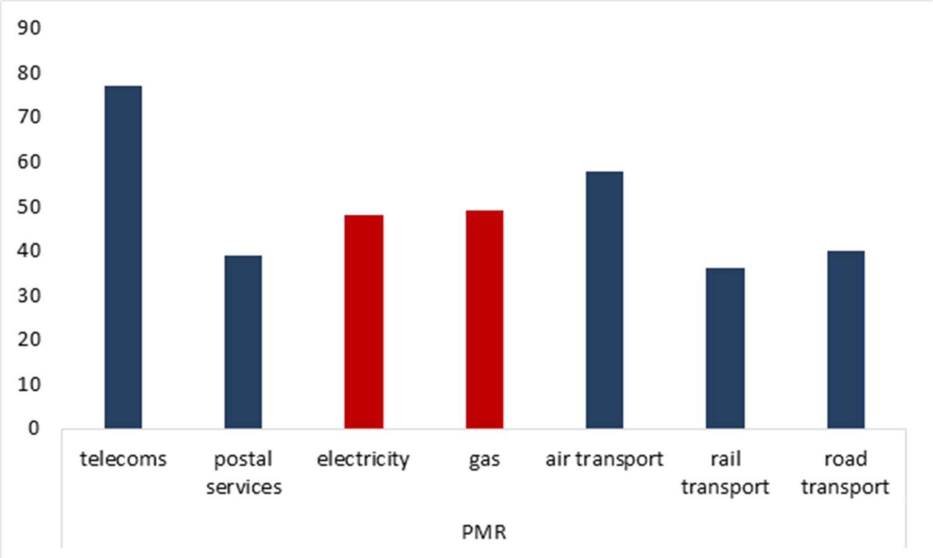
Table 1. Structural Reform Categories, 1970-2020

Reform type	Number of reforms	Number of counter-reforms	Reforms (% of total)	Counter-reforms (% of total)
Product market reforms	235	4	98.3	1.7
Of which				
Electricity sector	48	0	100.0	0.0
Gas sector	49	0	100.0	0.0

Source: Duval *et al.* (2018); Wiese et al. (2023); author's calculations.

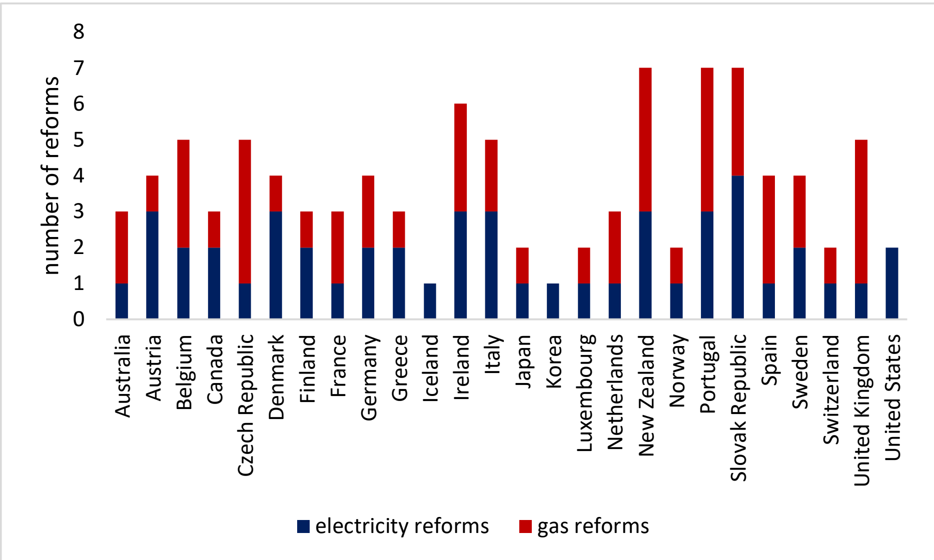
[10] Exceptions are reforms in the area of rail transport undertaken in the 1980s, which are beyond the focus of this paper. Note also that it would be very surprising if such product market reforms at that period (particularly in the 1990s) would reduce emissions At the time, renewable energy was in its infancy and reforms were likely targeted at increasing energy supply and reducing prices.

Figure 1. Number of Structural Reforms by Area, 1970-2020



Source: Duval *et al*. (2018); Wiese *et al*. (2023).

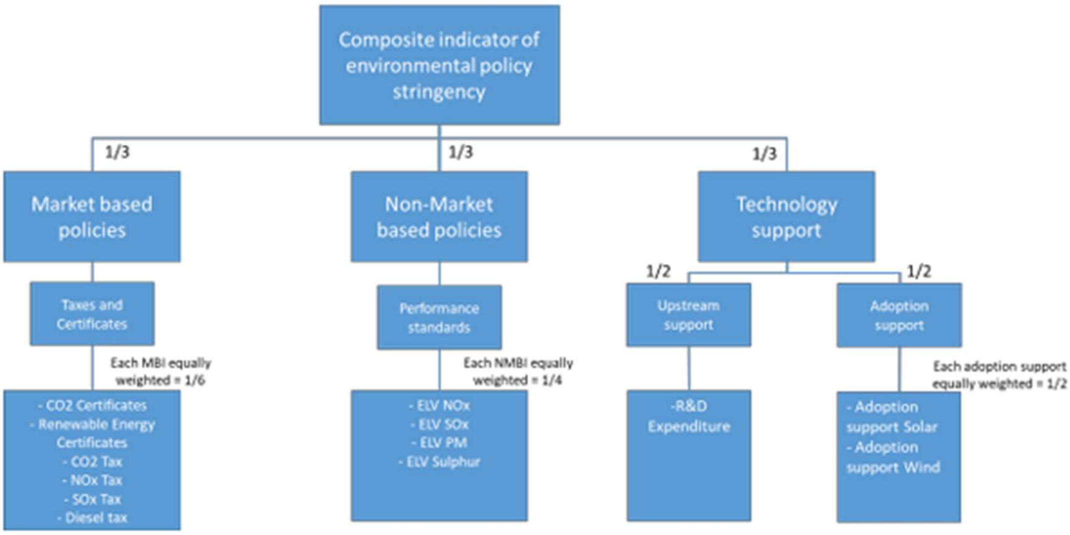
Figure 2. Number of Electricity and Gas Reforms by country, 1970-2020



Source: Duval *et al*. (2018); Wiese *et al*. (2023)

We are also interested in whether a country's environmental policies at the time of introducing product market reforms in the energy sector affects the impact of environmental outcomes. To this end, we use the country-specific Environmental Policy Stringency (EPS) Index created by the OECD and defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behavior (Botta and Kozluk, 2014). These data are the most comprehensive available source for policy measures covering 28 OECD countries and 6 emerging market economies over the period 1990–2020.[11] The EPS index allows us to investigate the impact of different policy instruments—scaled from 0 (not stringent at all) to 6 (very stringent)—relative to an overall aggregate index consisting of both market-based and non-market-based measures. In this context, market-based measures include instruments such as a carbon tax, emission trading schemes and feed-in tariffs, while non-market-based indicators capture legislation on emission limits and R&D subsidies, among others. There are also technology support policies that includes those that support innovation in clean technologies and their adoption. Figure 3 presents the breakdown of the EPS index breakdown in 2021.

Figure 3. The 2021 OECD Environmental Policy Stringency Index



Source: Kruse *et al*. (2022).

III. ECONOMETRIC METHODOLOGY

Structural reforms—in any area—tend to have evolving effects over an extended period of time. In this paper, we estimate the impulse response functions (IRFs) of environmental outcomes and measures of green growth to structural reforms in electricity and gas sectors by applying LP method. This approach has been advocated by Auerbach and Gorodnichenko (2012, 2013) and Romer and Romer (2019) as a flexible alternative to vector autoregressions (VAR) and/or

[11] One concern might be that environment legislation is adopted at the supranational level such as the European Union. This would be problematic for our empirical analysis as national governments may then not directly responsible for the stricter environmental regulation. Despite this potential concern, it is noteworthy that substantial cross-country variation exists within the EU and environmental policymaking takes place at the national level.

distributed lag models.[12] The LP method is also flexible to accommodate a panel structure and does not constrain the shape of IRFs, thereby allowing to analyze different types of policy shocks (Auerbach and Gorodnichenko, 2013; Jordà and Taylor, 2016; Ramey and Zubairy, 2018; Romer and Romer, 2019; Born et al., 2020). In this paper, given the panel setting, we adopt the LP method over commonly used VAR models for the following specific reasons. First, our estimation entails a large panel dataset with a constellation of fixed effects, which makes a direct application of standard VAR models more difficult. Second, the LP method obviates the need to estimate the equations for dependent variables other than the variable of interest, thereby significantly economizing on the number of estimated parameters. Third, the LP method is particularly suited to estimating nonlinearities (for example, how the effect of energy reform shocks differs in countries with high or low EPS), as its application is much more straightforward compared to non-linear structural VAR models, such as Markov-switching or threshold-VAR models.[13] Moreover, it allows for incorporating various time-varying features of source (recipient) economies directly and allow for their endogenous response to energy reform shocks. Lastly, the error term in the following panel estimations is likely to be correlated across countries. This correlation would be difficult to address in the context of VAR models, but it is easy to handle in the LP method by either clustering standard errors or using the Driscoll-Kraay (1998) standard errors, which allows for arbitrary correlations of the errors across countries and time.

Accordingly, to account for the cumulative responses of electricity and gas sector reforms over a five-year horizon, we use the following baseline specification:

$$y_{t+k,i} - y_{t-1,i} = \alpha_i + \tau_t + \beta_k SR_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \qquad (1)$$

in which y denotes a proxy of environmental performance measured as: (i) CO_2 emissions in metric tons per capita, (ii) GHG emissions in metric tons per capita, and (iii) GHG emissions per unit of GDP; and green growth measured as: (i) the share of renewable energy supply, (ii) the number of environment-related inventions per capita, and (iii) the number of patents for environment-related technologies per capita. ; the coefficients α_i and τ_t are country and time fixed effects, respectively, accounting for cross-country heterogeneity and global shocks; β_k denotes the cumulative response of environmental outcomes in each *k* year after the implementation of a product market reform; $SR_{i,t}$ denotes structural reforms in electricity and gas sectors as described in the previous section. We include treatment lags in our models. It is an empirical issue how long the effect of progressivity shocks persists in the data. $X_{i,t}$ is a vector of additional control variables. We use Akaike's information criterion to determine the lag length: we employ 2 lags of the structural reform shock, 2 lags of real GDP growth, inflation and the dependent variable. For robustness, we

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[12] Plagborg-Moller and Wolf (2021) further discuss the properties of local projections, as well as the relationship between these and VAR estimation of impulse responses.

[13] See Choi *et al*. (2018) and Miyamoto *et al*. (2019) for the recent application of local projections to the estimation of nonlinearities and interaction effects of shocks using a large panel dataset, as it is the case with our sample.

introduce additional controls for two lags of other determinants of environmental performance in some specifications of the model – see below. We estimate the equation using the Ordinary Least Squares (OLS) method.[14] We calculate Spatial Correlation Consistent (SCC) standard errors as proposed by Driscoll and Kraay (1998).[15] β_k denotes the (cumulative) response of the variable of interest h years after the energy reform shock. Impulse response functions (IRFs) are then obtained by plotting the estimated β_k for k = 0, 1, ..., 5 with 90 (and 68) percent confidence bands computed using the standard deviations associated with the estimated coefficients β_k.

To develop a more granular analysis, we also explore whether initial environmental policies, as measured by the EPS index at the time of the reform, influence the impact of structural reforms on environmental outcomes and green growth.[16] As discussed in Auerbach and Gorodnichenko (2012, 2013), the LP approach to estimating non-linear effects is equivalent to the smooth transition autoregressive (STAR) model developed by Granger and Teräsvirta (1993). The advantage of this approach is twofold. First, compared with a model in which each dependent variable would be interacted with a measure of the EPS index converted into a dummy variable for high and low values according to some ad hoc criterion, it permits a direct test of whether the effect of the energy reform shock varies across a different regimes. Second, compared with estimating structural VAR for each regime, it allows the effect of energy reforms to change smoothly between low and high levels of EPS by considering a continuum of states to compute the impulse response functions, thus making the response more stable and precise.

Accordingly, the augmented LP model to test for non-linear effects takes the following form:

$$y_{i,t+k} - y_{i,t-1} = \alpha_i + \tau_t + \beta_k^L F(z_{i,t}) SR_{i,t} + \beta_k^H (1 - F(z_{i,t})) SR_{i,t} + \theta X_{i,t} + \varepsilon_{i,t} \quad (2)$$

with $F(z_{it}) = \frac{\exp(-\gamma z_{it})}{1+\text{ex}\ (-\gamma z_{it})}, \quad \gamma > 0$

in which z_{it} is the EPS index that is normalized to have zero mean and unit variance. The weights assigned to each regime vary between 0 and 1 according to the weighting function $F(.)$, so that $F(z_{it})$ can be interpreted as the probability of being in a given state of the economy. The coefficients β_L^k and β_H^k capture the impact of structural reform shocks on environmental performance and green growth at each horizon k in cases of low EPS ($F(z_{it}) \approx 1$ when z goes to

[14] Another advantage of the local projection method compared to vector autoregression (or autoregressive distributed lag) specifications is that the computation of confidence bands does not require Monte Carlo simulations or asymptotic approximations. One limitation, however, is that confidence bands at longer horizons tend to be wider than those estimated by VARs.

[15] This is a nonparametric technique assuming the error structure to be heteroskedastic, autocorrelated up to some lag, and possibly correlated across countries.

[16] There are other studies using such a STAR function in the context of LP, such Abiad *et al*. (2016), Furceri and Li (2017), Gupta and Jalles (2022), Jalles and Karras (2022).

minus infinity) and high EPS ($1 - F(z_{it}) \approx 1$ when z goes to plus infinity), respectively. We choose $\gamma = 1.5$.[17]

IV. Empirical Results

The main variable of interest in this analysis is the cumulative change in environmental outcomes and measures of green growth in response to structural reforms in the energy sector as described in the previous section. In Figure 3, we present the results of our baseline specification including control variables. Each chart shows the cumulative effects in response to an energy-sector reform on each of our six alternative dependent variables in our sample of 25 countries over a five-year horizon, where 0 indicates the year in which the structural reform occurs. The shaded areas indicate the 90 percent and 68 percent confidence bands based on Driscoll-Kraay (1998) robust standard errors clustered at the country level.

First, we focus on measures of environmental performance and find that structural reforms in electricity and gas markets lead to higher CO_2 and GHG emissions per capita, but these unconditional results are statistically insignificant and surrounded by great uncertainty. GHG emissions per unit of GDP, on the other hand, responds to structural reforms in the opposite direction, declining below the initial level over the five-year period and showing some signs of decoupling between economic growth and emissions. Second, we focus on indicators of green growth—defined as environmentally sustainable economic growth—and find that structural reforms lower the supply of renewable energy as a share of total energy supply, but this negative effect is not persistent over the long run. Furthermore, structural reforms in the energy sector stimulates a sustained increase in the number of environmental inventions and patents per capita beyond the initial level. Although this result seems contradictory to previous studies that find a negative relationship between product market reforms (i.e., liberalization) in the energy sector and R&D spending (Sirin, 2011; Jamasb and Pollitt, 2011), we think that our analysis based on the latest data and a larger set of countries captures the surge of renewable energy technologies over the past decade.

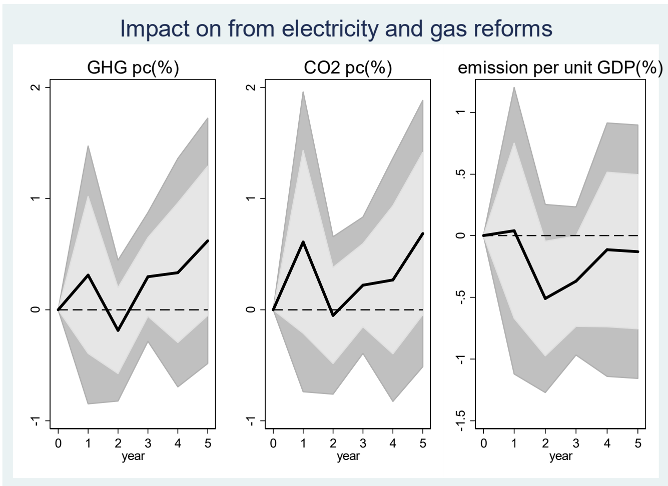
We develop a more granular analysis by focusing on types of structural reforms in electricity and gas sectors and obtain similar response patterns for “market access and structure” reforms (Figure 4) and “public ownership” reforms (Figure 5). In the case of energy-sector privatization, it should be noted that reforms lead to higher emissions across all measures, including GHG emissions per unit of GDP. In Appendix Figures A2-A3, we present the IRFs for structural reforms in electricity and gas markets separately, which are consistent with the baseline results.

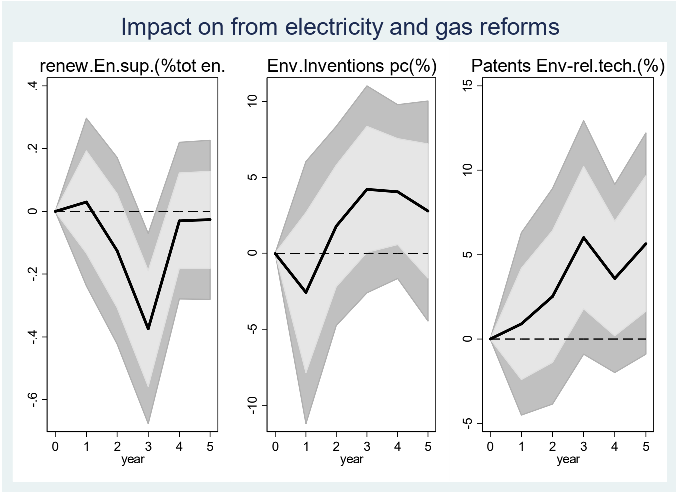
We are also interested in whether the strength of initial environmental policies at the time of an energy reform influences its impact on environmental performance and green growth by estimating a state-dependent version of the model that allows dynamic responses to vary with the

[17] Our results hardly change when using alternative values of the parameter γ, between 1 and 4.

EPS index. These results, presented in Figure 6, show striking differences in the impact of structural reforms on measures of emissions and green growth. First, in countries with stronger environmental regulations and pro-climate policies, structural reforms in the energy sector delivers a significant and persistent decline in CO_2 and GHG emissions per capita and GHG emissions per unit of GDP in the first year and over the long run, whereas emissions continue to increase in countries with low environmental standards. Second, electricity and gas sector reforms make a greater contribution to increasing the share of renewable energy and the development of environmental technologies in countries with higher EPS index, while the impact is opposite in low-EPS countries. This is in line with the work by Eugster (2021) who finds that the estimated effect of climate change mitigating policies on innovation in clean energy technologies is positive on net, meaning that increased innovation in clean and grey technologies is not offset by a decrease in innovation in dirty technologies. We obtain similar results when we estimate the state-dependent model for "market access and structure" reforms (Figure 7) and "public ownership" reforms (Figure 8). In particular, we observe that energy-sector privatization results in significantly better environmental outcomes and green growth in countries with stronger environmental regulations.

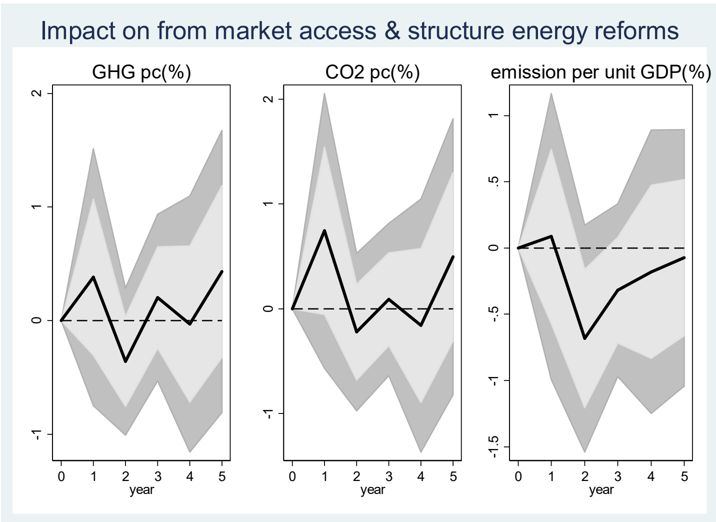
Figure 3. Impact of Energy Sector Reforms: Baseline Model

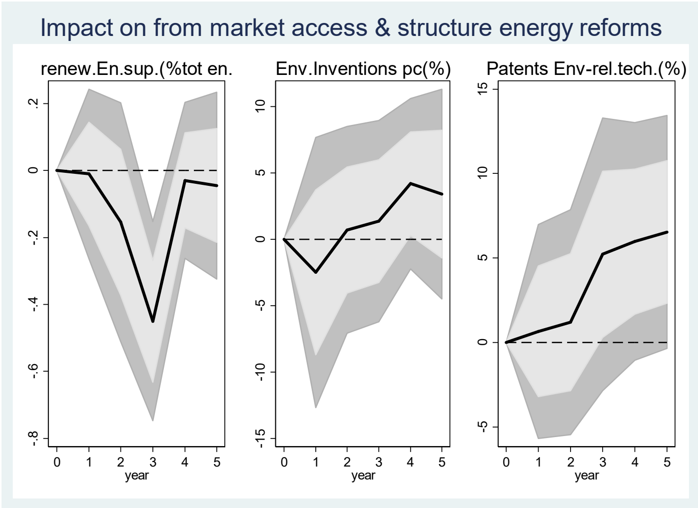




Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level.

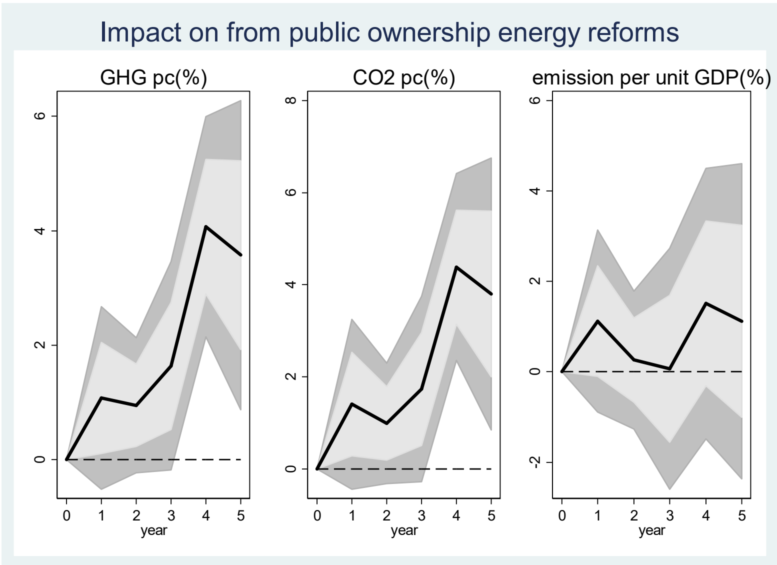
Figure 4. Impact of Energy Market Access and Structure Reforms: Baseline Model

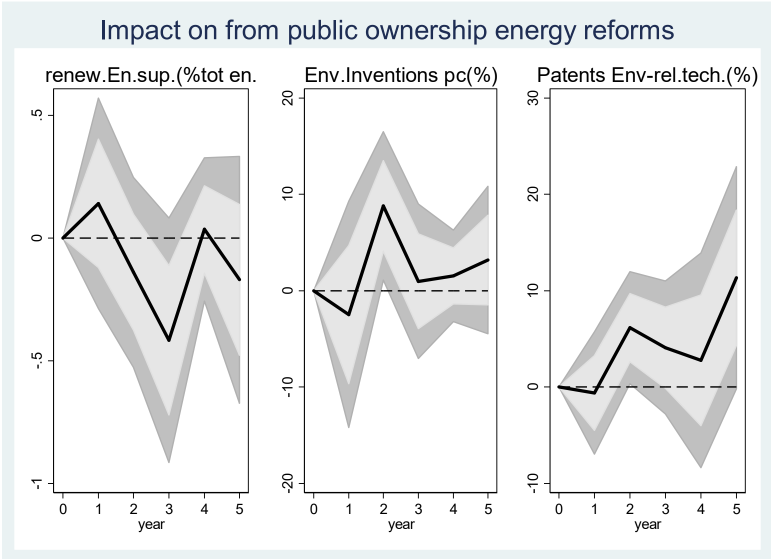




Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level.

Figure 5. Impact of Energy Privatization: Baseline Model





Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level.

We conduct several robustness exercises. For reasons of parsimony, we focus solely on two dependent variables, which we find to be the most representative of green growth—GHG emissions per capita and the number of patents for environment-related technologies per capita.

- First, we know that a possible bias from estimating equation (1) using country-fixed effects is that the error term may have a non-zero expected value, due to the interaction of fixed effects and country-specific developments (Teulings and Zubanov, 2014). This would lead to a bias of the estimates that is a function of k. To address this issue, equation (1) was re-estimated by excluding country fixed effects from the analysis. These results, shown in Appendix Figure A4, suggest that this bias is negligible.
- Second, to estimate the causal impact of energy reform shocks on environmental and green growth outcomes, it is important to control for previous trends in reform dynamics. In the baseline specification, we attempt to do this by controlling for up to two lags in the dependent variable.[18] To further mitigate this concern, we re-estimate equation (1) by including country-specific time trends as additional control variables. These results, presented in Appendix Figure A4, remain qualitatively unchanged.
- Third, since electricity and gas sector reforms may be implemented as part of broader packages, we also re-estimate our main regression controlling for reforms in additional areas (such as road and railway, unemployment benefits replacement rate, and EPL for

[18] Similar results are obtained when using alternative lag parametrizations. Results for zero, one and three lags (not shown) confirm that previous findings are not sensitive to the choice of the number of lags.

regular contracts), which are drawn from the same structural reform dataset. These results also remain consistent with our baseline findings.

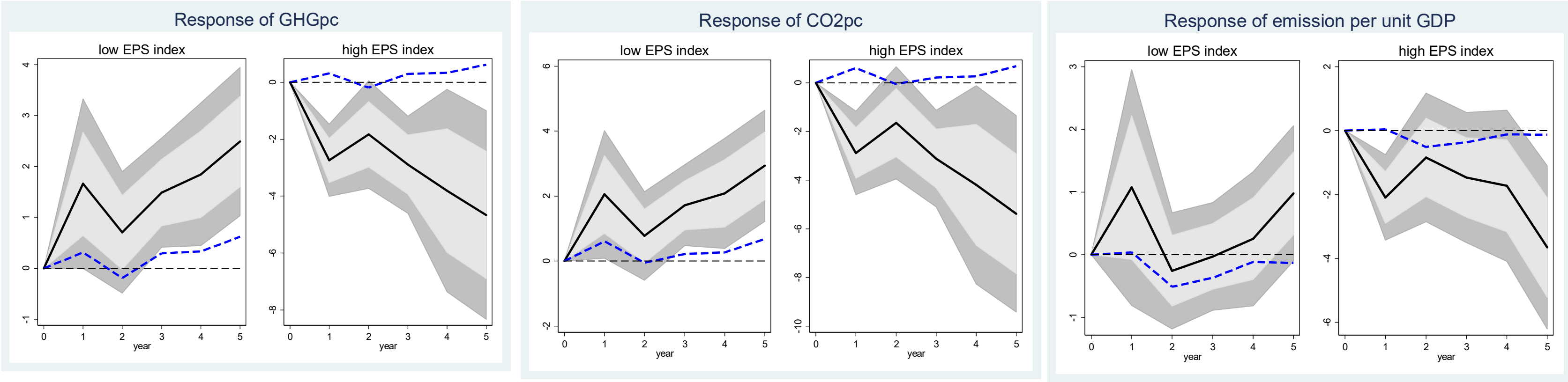
- Fourth, while the previous robustness checks go a long way toward mitigating endogeneity concerns, we also estimate the model by using additional control variables and the instrumental variable (IV) approach. The literature has put forward several theories to rationalize why and when reforms (do not) happen. We focus on one broad factor examined in the literature: political institutions.[19] Specifically, we use the following set of political economy variables as external instruments, which we divide in four categories: (i) ideology of the governing party/ies, using a discrete variable to distinguish between left, center and right (3, 2 and 1, respectively) (Parties); (ii) political system, using a discrete variable for parliamentary, assembly-elected and presidential forms of governments (2, 1 and 0, respectively) (System); (iii) party fragmentation, using a continuous variable bounded between 0 (no fragmentation) and 1 (maximum fragmentation) to capture the number of political parties in the lower house of the legislative assembly (Fragmentation); (iv) the strength of democratic institutions as measured by the Polity IV index, which is normalized between 0 and 1 (Democ). We obtain these from the World Bank Database of Political Institutions database. By means of a two-stage least squares estimator, we re-estimate equation (1) using up to two lags of the four political economy exogenous instruments described above.[20] These results, reported in Appendix Figure A4, are broadly similar to our baseline findings, confirming that endogeneity is not a serious concern in our case.

[19] Duval, Furceri and Miethe (2018) provides a recent contribution in this area.

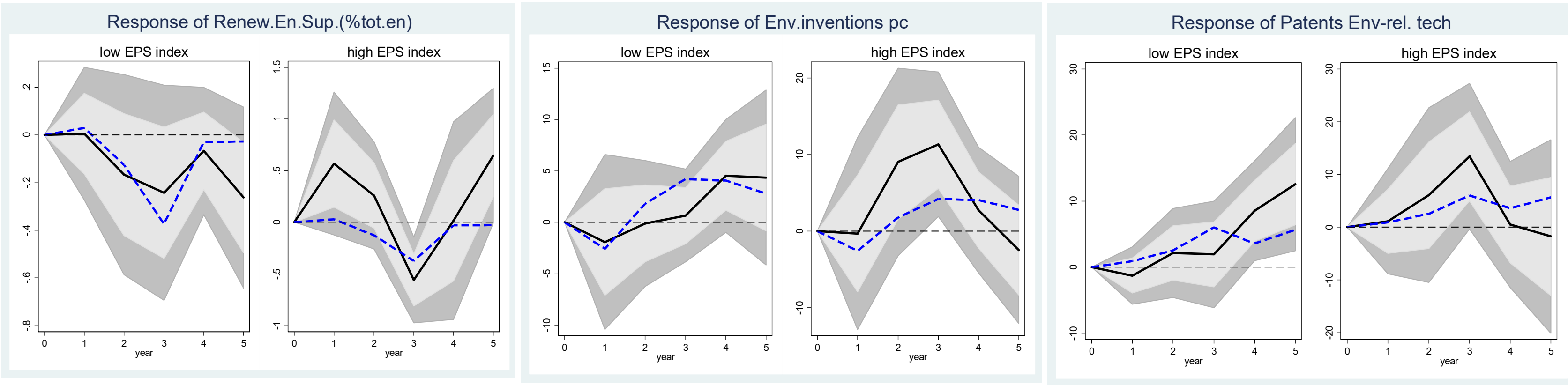
[20] To check the validity of our instruments and assess the strength of our identification, we rely on the Kleibergen-Paap and Hansen statistics. The underidentification test tests that the excluded instruments are "relevant" (meaning correlated with the endogenous regressors). Our obtained statistics generally reject the null hypothesis that the different equations are unidentified according to the Stock-Yogo critical values. Then, the Hansen test statistics reveal that the instrument sets contain valid instruments (i.e., uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated equation) is not rejected.

Figure 6. Impact of Energy Sector Reforms: State-Dependent Model

Emissions



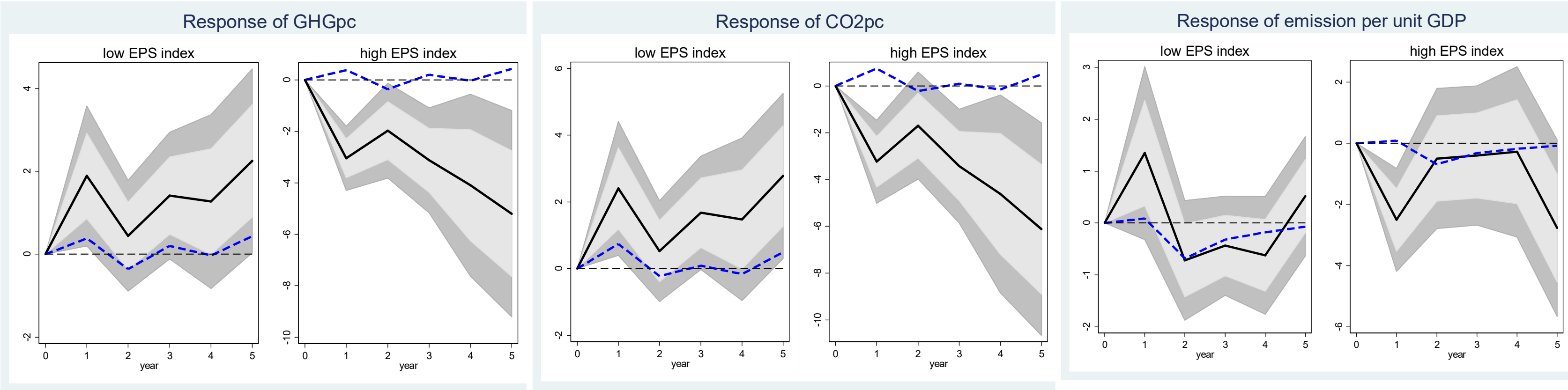
Green Growth



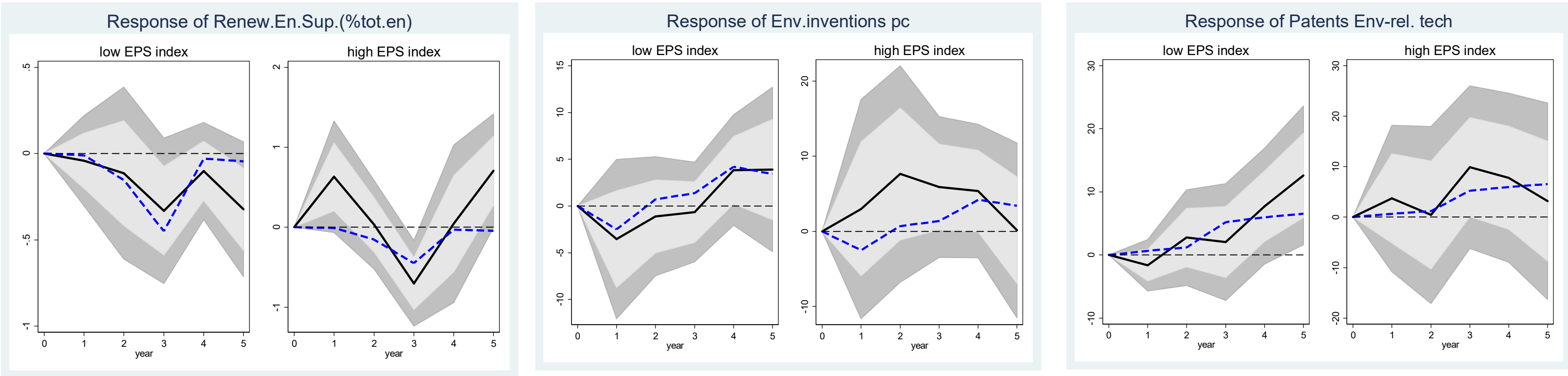
Note: estimation of equation 2 using EPS as z in F(z). x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level. The blue dotted line denotes the unconditional baseline result from estimating equation (1).

Figure 7. Impact of Market Access and Structure Reforms: State-Dependent Model

Emissions: Market Access & Structure Reforms



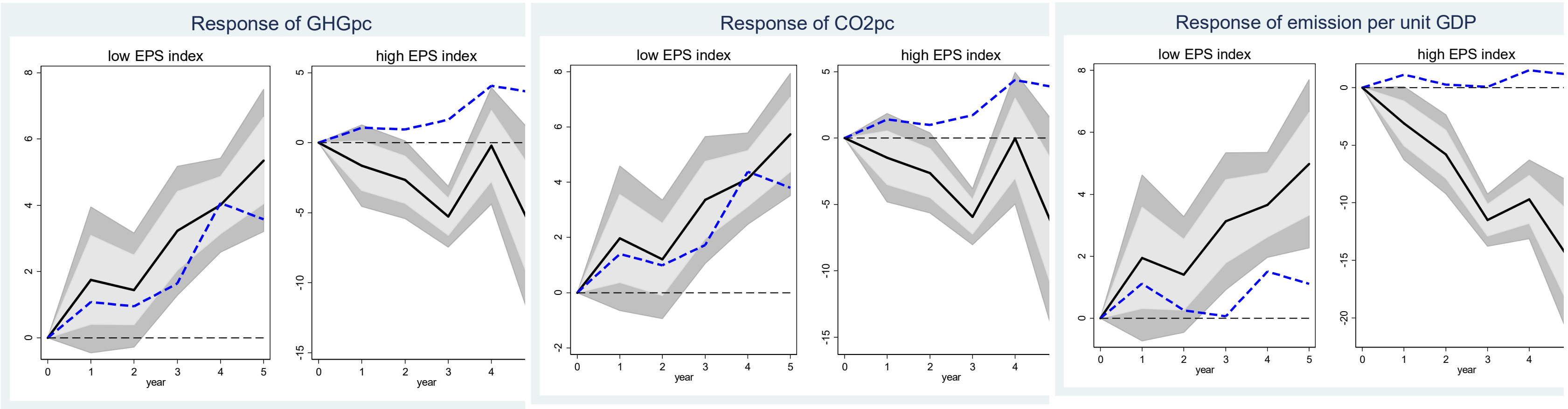
Green Growth: Market Access & Structure Reforms



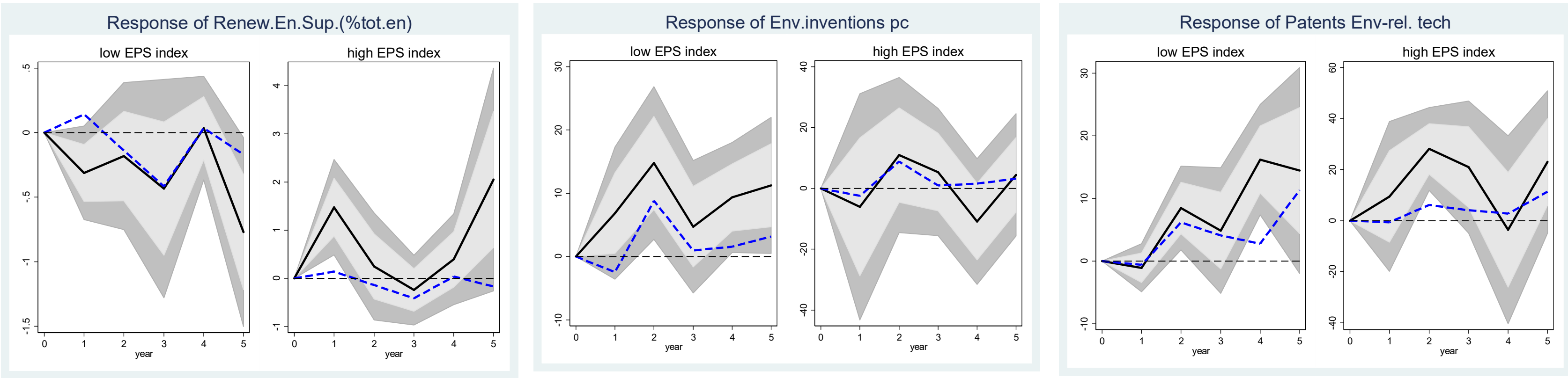
Note: estimation of equation 2 using EPS as z in F(z). x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level. The blue dotted line denotes the unconditional baseline result from estimating equation (1).

Figure 8. Impact of Public Ownership Reforms: State-Dependent Model

Emissions: Public Ownership Reforms



Green Growth: Public Ownership Reforms



Note: estimation of equation 2 using EPS as z in F(z). x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level. The blue dotted line denotes the unconditional baseline result from estimating equation (1).

V. CONCLUSION

Addressing climate change—the defining challenge of our time—requires global efforts to reduce GHG emissions, which are projected to increase by only 7.5 percent by 2030 compared to the required reduction of 55 percent just to keep global warming below 1.5°C. Therefore, what the world needs is a new development model that better balances income growth and environmental priorities by modernizing the energy matrix away from fossil fuels and increasing efficiency in the distribution and use of energy. In turn, these objectives require structural reforms and policies designed to alter behavior throughout the economy. To this end, this paper closes an important gap in the literature by investigating how structural reforms in electricity and gas sectors can contribute to climate change mitigation, help guard against threats associated with climate change, and thereby promote green growth defined as environmentally sustainable economic growth.

We use the LP method to estimate the cumulative impact of structural reforms in the energy sector—based on a narrative database of product market reforms—on alternative measures of environmental performance and green growth in a panel of 25 countries during the period 1970–2020. We also explore the possibility of nonlinear effects of structural reforms by taking into account initial environmental policies at the time of an energy reform. We obtain somewhat mixed, but striking results. First, while electricity and has sector reforms so far failed in bringing about a reduction in CO_2 and GHG emissions per capita, there is some evidence for greater effectiveness in lowering GHG emissions per unit of GDP. Second, although electricity and gas sector reforms are not associated with higher supply of renewable energy as a share of total energy supply, they appear to stimulate a sustained increase in the number of environmental inventions and patents per capita over the medium term. Furthermore, we find strong evidence of nonlinear effects, with market-oriented electricity and gas sector reforms leading to better environmental outcomes and green growth in countries with stronger environmental regulations.

These results have several important implications for the design of structural reforms and policies, which should aim not just for market efficiency but also for green growth. First, decoupling economic growth from GHG emissions is possible through comprehensive reforms and policies aimed at shifting the energy matrix away from fossil fuels. Second, while transitioning energy supply to low-carbon sources is critical, achieving environmentally sustainable growth is also dependent on greater efficiency in the distribution and use of energy.

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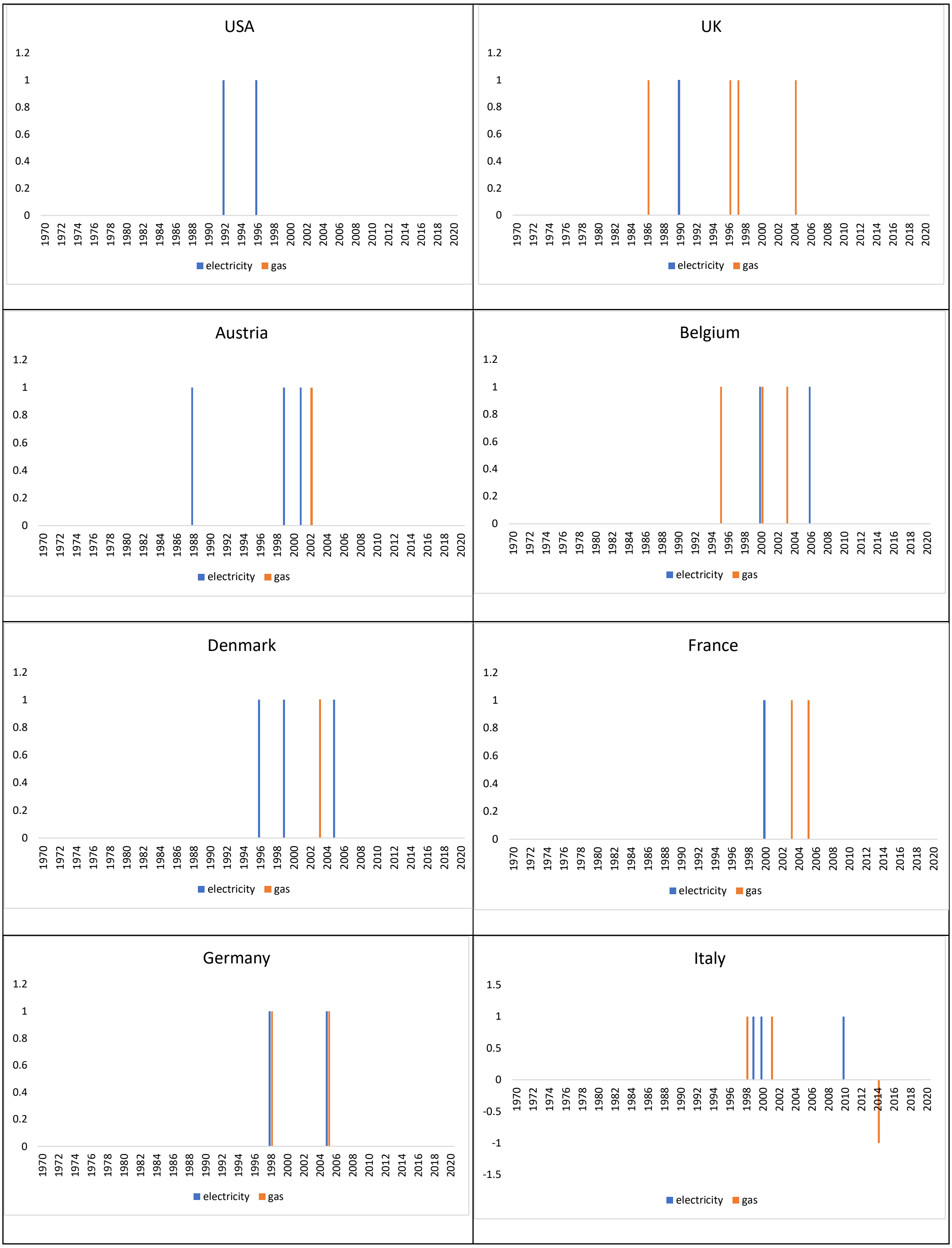
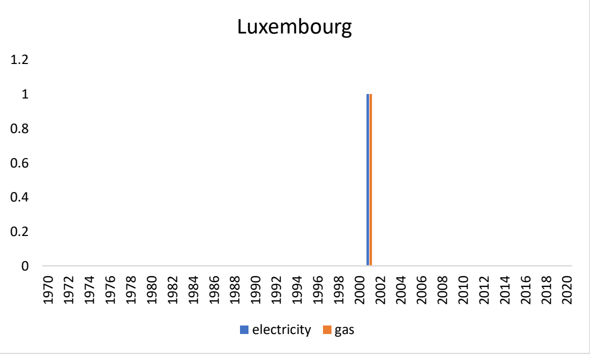
Appendix Table A1. Examples of Identified Structural Reforms in Electricity and Gas

	Year	Area	Content	Normative language	Mention in other reports	Large change in OECD indicator	reform /counter-reform
Electricity							
Australia	1996	Market access and structure	The Council of Australian Governments agreed to have the necessary structural changes in place to create a competitive market for bulk electricity in southern and eastern Australia from 1 July 1995. (pg. 126, 1994) In its report of 30 June 1997, the National Competition Council attested on the basis of the States and Territories 1996-97 annual reports that: good progress has been made towards implementing the National Electricity Market in eastern and southern Australia, including commitments for interconnection by both Queensland and Tasmania… (pg. 76, 1998)	… this will offer new scope for greater competition in the electricity market with the commencement of cross-border trading. (pg. 76, 1998)	pg. 68, 1995 pg. 76, 1998	Yes	1
Finland	2000	Public ownership	Privatization mandates are broadened by Parliament. The government now has authorization to reduce the government ownership to 50.1 per cent in Altia Group and Vapo, to 20 per cent in Rautaruukki, to 15 per cent in Kemira Group, 10 per cent in Outokumpu and zero in Inspecta. (pg. 151, 2002)	Product markets have been rapidly liberalized…and the telecommunication and electricity markets are now fully liberalized. (pg. 64, 2002)		Yes	1
Gas							
Belgium	1996	Public ownership	Among the transactions that occurred that year [1996], the initial public offer (16.60 percent of capital) of the Belgian gas treatment, transmission and storage monopoly Distrigaz is to be mentioned. The Belgian government later sold its remaining share in the company, but retains one golden share… [see http://www.privatizationbarometer.com/atlas.php?id=6&mn=PM]			Yes in 1995	1
Slovak Republic	2007	Market access and structure	The Slovak Republic implemented wide-ranging reforms to introduce competition in energy markets… Managerial separation has been put in place in both the gas and electricity transport networks. Legal unbundling of companies operating gas and electricity network is virtually complete. (pg. 105, 2007)	… wide-ranging reforms to introduce competition in energy markets… (pg. 105, 2007)		Yes	1

Source: Duval *et al.* (2018); Wiese *et al.* (2023).

Appendix Figure A1

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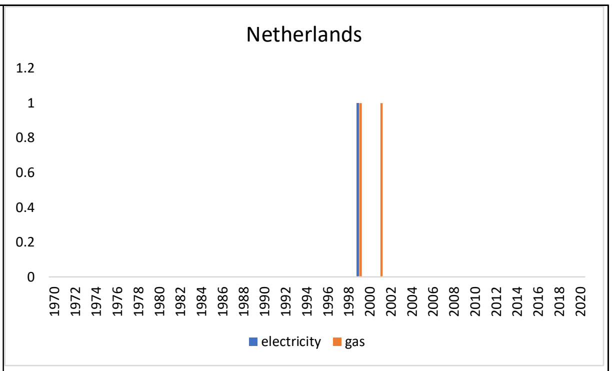
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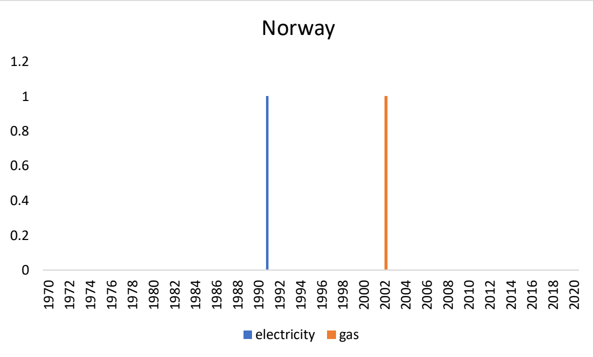
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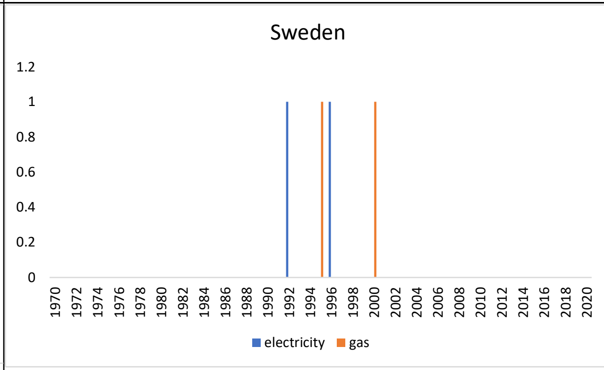
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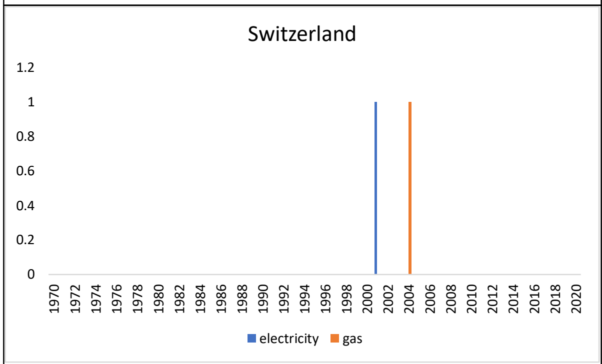
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electricity
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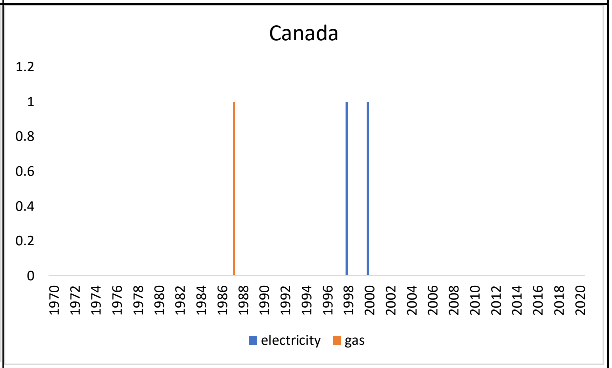
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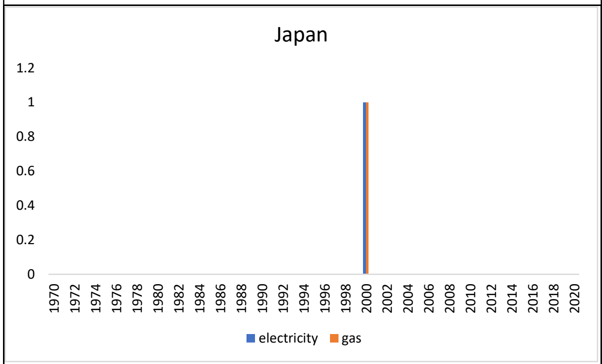
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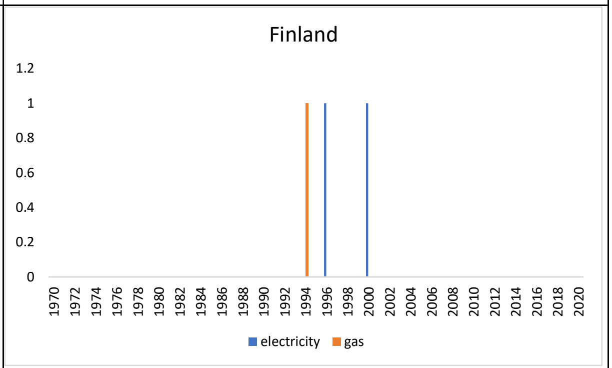
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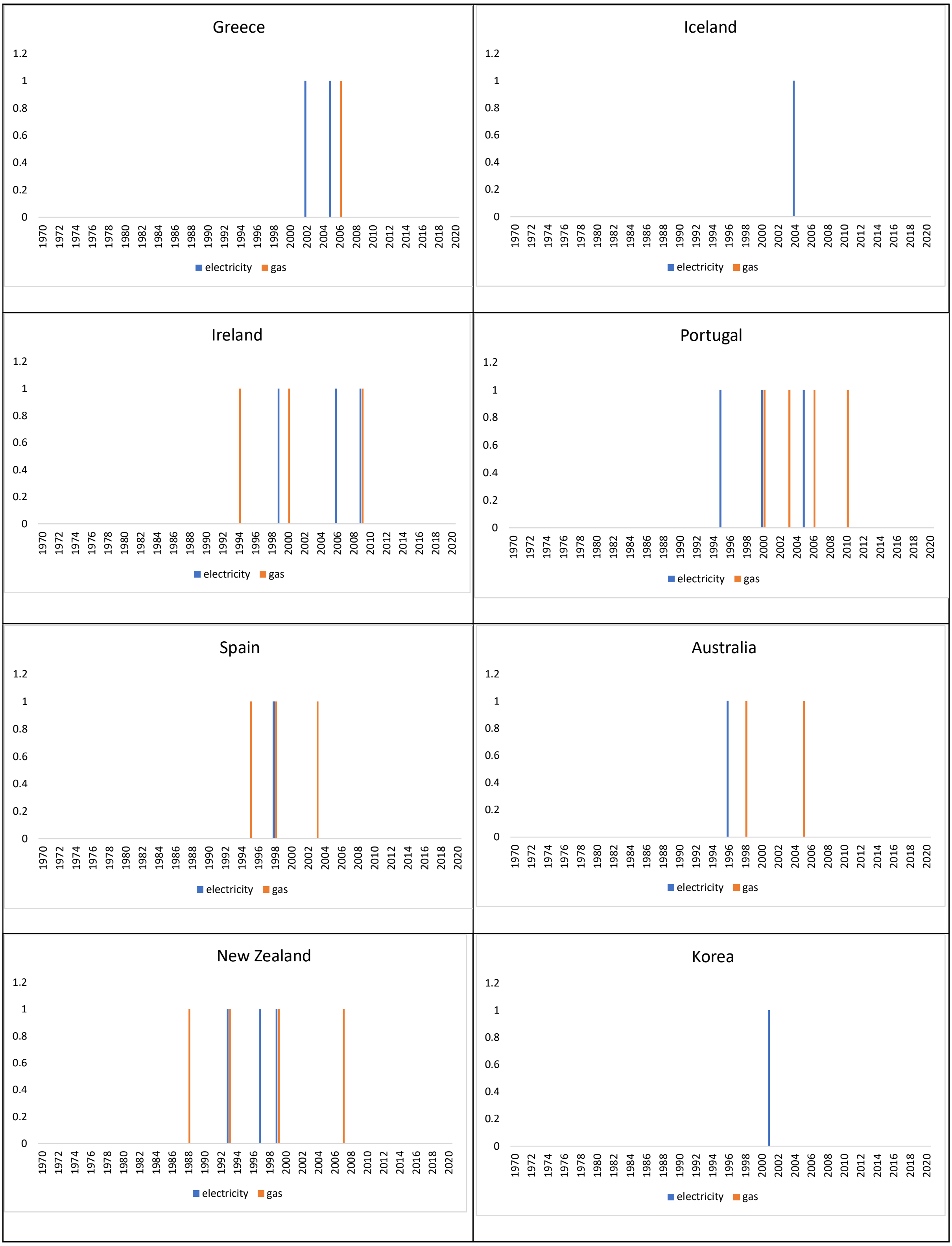
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Iceland
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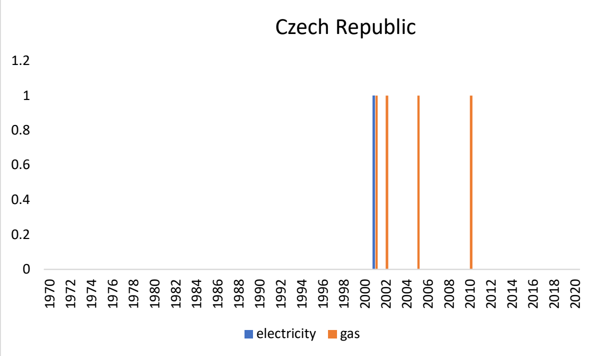
Australia
New Zealand
Korea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electricity
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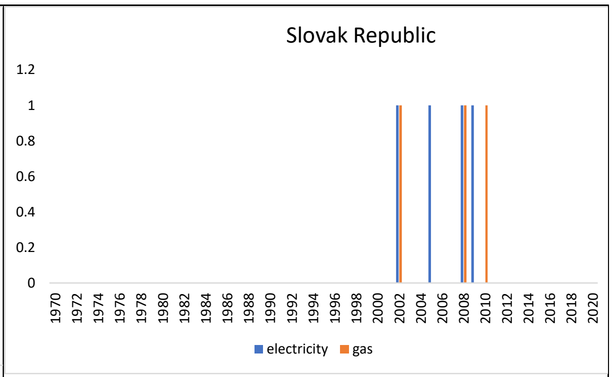
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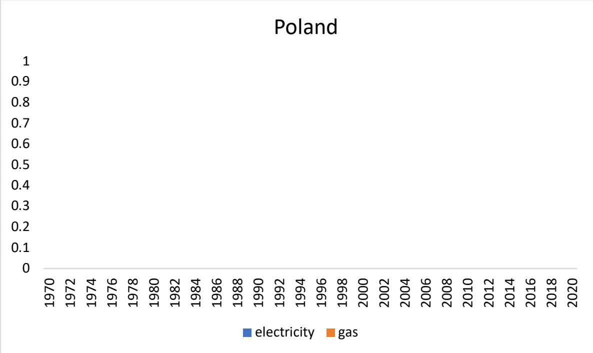
electricity
gas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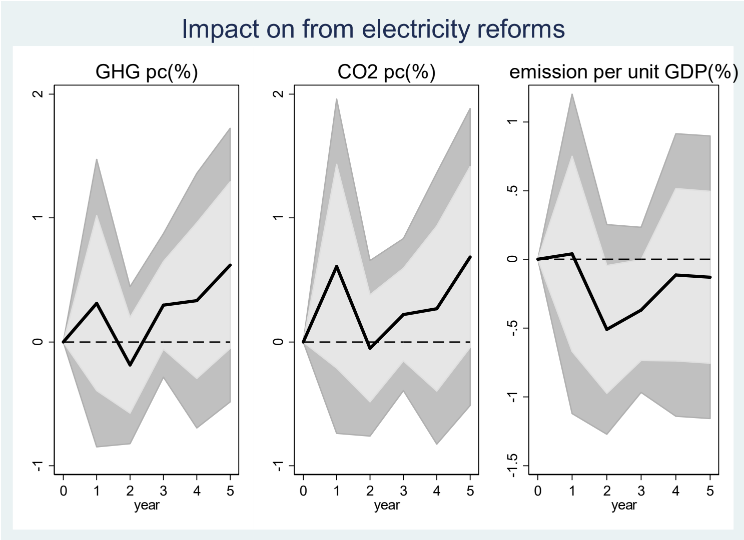
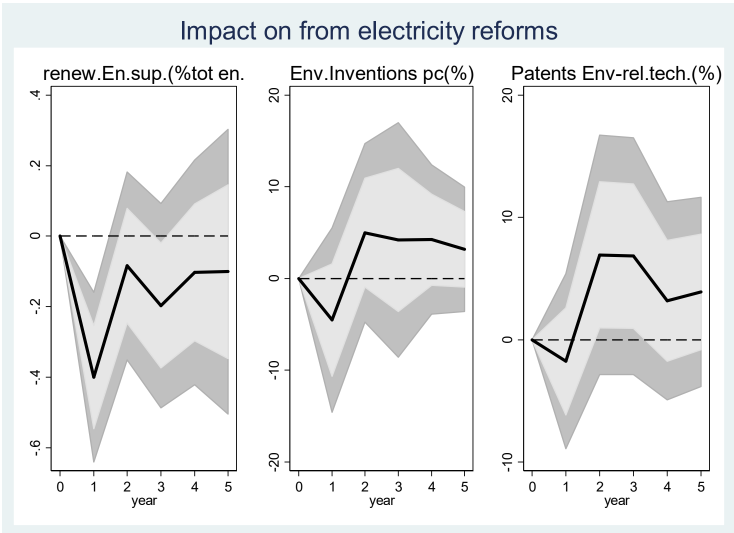
electricity
gas

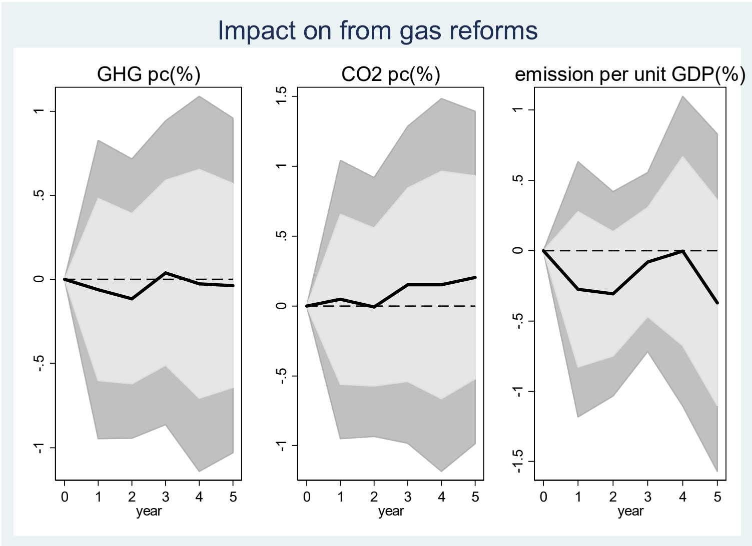
Figure A2. Impact of Electricity Reforms: Baseline Model

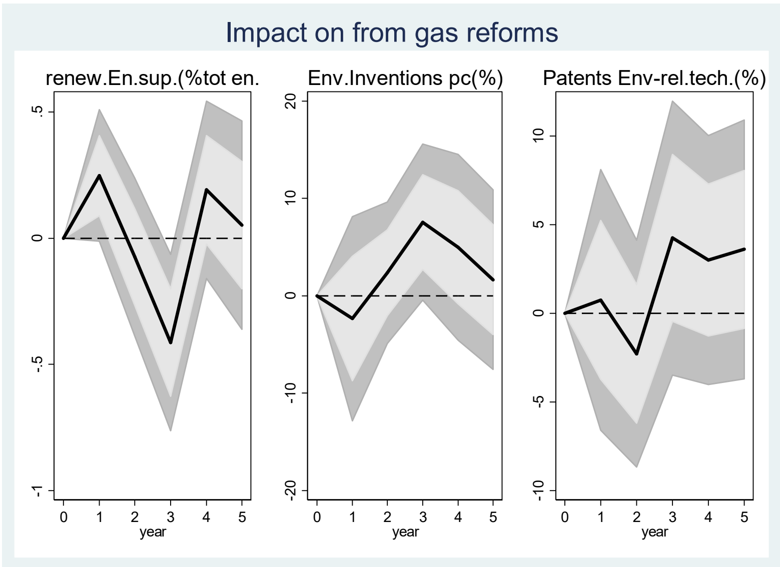




Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level.

Figure A3. Impact of Electricity Reforms: Baseline Model

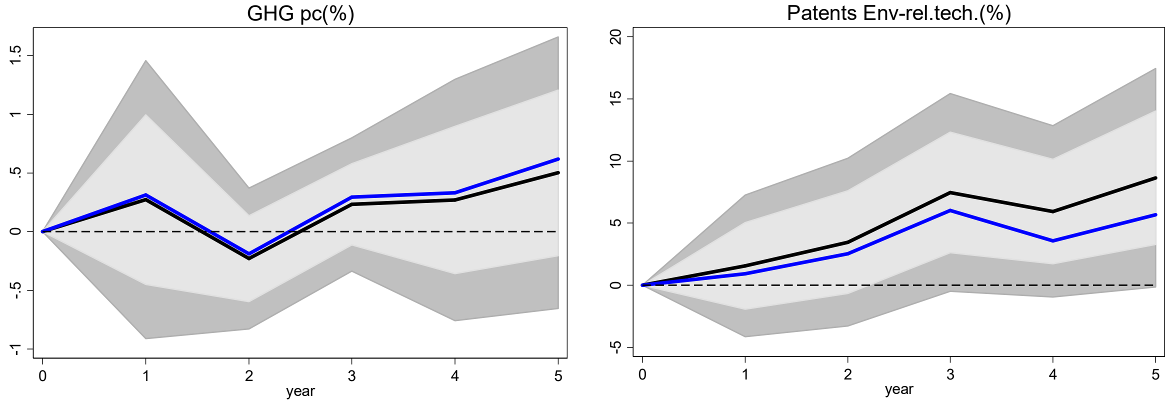




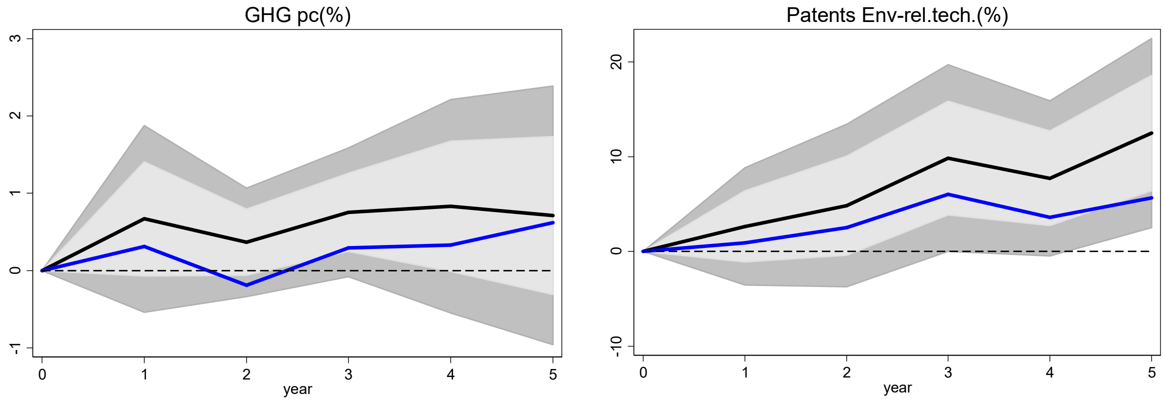
Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform, dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level.

Figure A4. Impact of Energy Reforms: Robustness Exercises

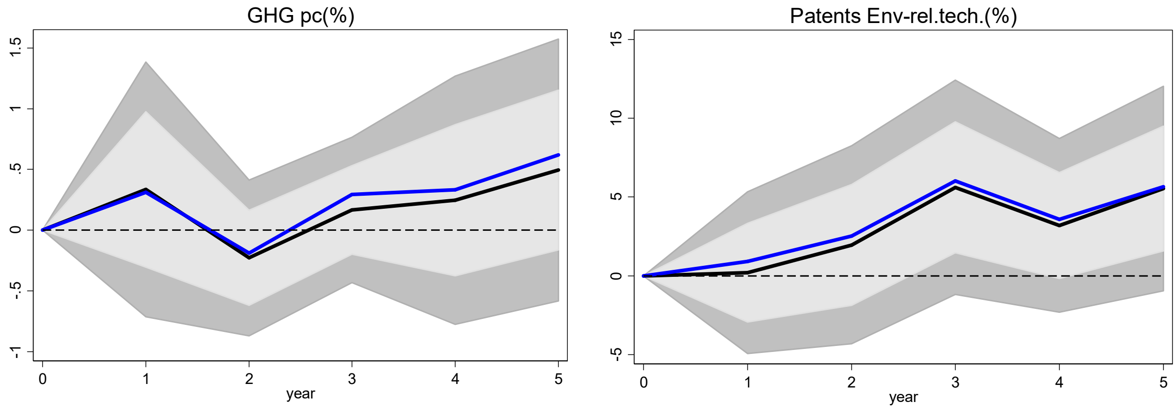
Excluding country fixed effects



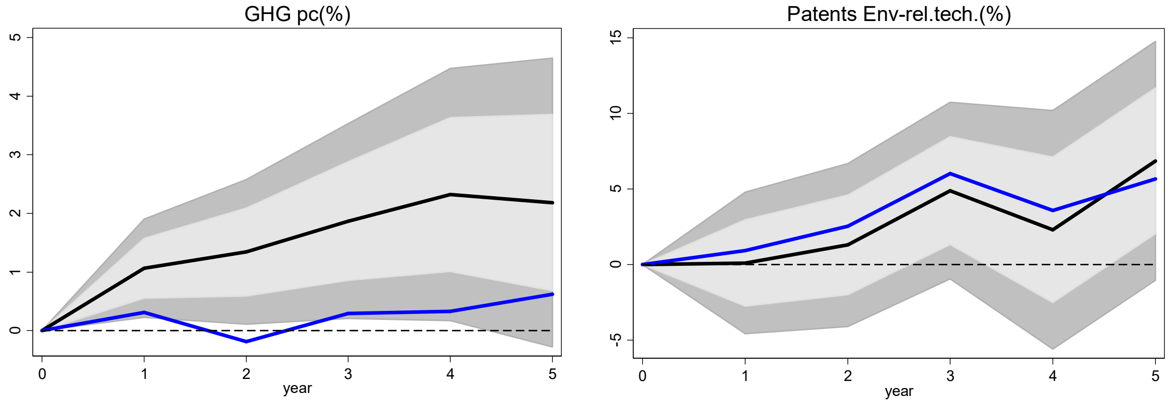
Including country-specific time trends



Controlling for additional reform areas



Instrumental Variable Approach



Note: x-axis in years; t=0 is the year of the structural reform; t=1 is the first year of impact. Solid black lines denote the response to a structural reform under different robustness or sensitivity exercises as described; dark grey area denotes 90 percent confidence bands while light gray area denotes 68 percent confidence bands, based on standard errors clustered at country level. Solid blue lines denote the baseline response.