CARBON PRICING INITIATIVES AND GREEN BONDS: ARE THEY CONTRIBUTING TO THE TRANSITION TO A LOW-CARBON ECONOMY?

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ABSTRACT

Transitioning to a low-carbon resilient economy while promoting sustainable development require behavioral changes and the mobilization of significant investments. Key instruments used for that include carbon pricing initiatives, such as carbon taxes and cap-and-trade policies, and, more recently, green bonds. Although the existing literature has provided some evidence on emissions outcomes associated with carbon pricing initiatives, there is a lack of investigations on the environmental performance of green bonds; and only theoretical models have showed potential benefits of the combination of both instruments, carbon pricing and green bonds. Aiming to fill this gap in the literature, this study uses annual data for 148 countries between 1990 and 2016 to examine how the use of carbon pricing initiatives and green bonds relate to carbon dioxide (CO_2) emissions. This paper makes three contributions. First, it examines how two climate instruments, carbon pricing initiatives and green bonds, relate to CO_2 emissions. Previous research has focused only on individual assessments. Second, it empirically analyzes whether there are interaction effects of the two instruments on emissions. And finally, it applies Callaway and Sant'Anna (2021) recently developed econometric estimator to deal with bias in two-way fixed effects estimations that arise from heterogeneous effects of policies. The results show that both instruments might contribute to the transition to a low-carbon economy. In the preferred model, the implementation of nationwide carbon pricing initiatives is associated with a 10% reduction in CO_2 emissions, green bond issuances are associated with an 8% reduction in emissions, and no statistically significant interaction effects were observed. However, the results must be cautiously interpreted since there is evidence on heterogeneous effects of such instruments.

Keywords: carbon taxes; cap and trade schemes; green bonds; carbon emissions, climate change.
JEL Classification: Q5, H23, G3

RESUMO

Transitar para uma economia resiliente de baixo carbono e promover o desenvolvimento sustentável exigem mudanças comportamentais e a mobilização de investimentos significativos. Alguns dos principais instrumentos que vem sendo utilizados para tal incluem iniciativas de precificação de carbono, como tributação sobre carbono e sistemas de comércio de emissões e, mais recentemente, títulos verdes. Embora a literatura existente tenha fornecido algumas evidências sobre os resultados das emissões relacionadas a iniciativas de precificação de carbono, faltam investigações sobre o desempenho ambiental dos títulos verdes. Além disso, apenas modelos teóricos mostram benefícios potenciais da combinação de ambos os instrumentos, precificação de carbono e títulos verdes. Visando preencher essa lacuna na literatura, este estudo utiliza dados anuais de 148 países entre 1990 e 2016 para examinar como o uso de iniciativas de precificação de carbono e títulos verdes se relacionam com as emissões de gás carbônico. Este artigo faz três contribuições. Primeiro, examina como dois instrumentos climáticos, precificação de carbono e títulos verdes, se relacionam com as emissões de CO_2. Pesquisas anteriores se concentraram apenas em avaliações individuais. Segundo, analisa empiricamente se há efeitos da interação dos dois instrumentos sobre as emissões. E, finalmente, aplica o estimador econométrico desenvolvido recentemente por Callaway e Sant'Anna (2021) para lidar com vieses que surgem em decorrência de efeitos heterogêneos das políticas. Os resultados mostram que ambos os instrumentos podem contribuir para a transição para uma economia

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de baixo carbono. No modelo de preferência, a implementação de iniciativas nacionais de precificação de carbono está associada a uma redução de 10% nas emissões de CO2, as emissões de títulos verdes estão associadas a uma redução de 8% nas emissões e não foram observados efeitos de interação estatisticamente significativos. No entanto, os resultados devem ser interpretados com cautela, pois há evidências sobre efeitos heterogêneos no uso de tais instrumentos.

Palavras-chave: tributação sobre carbono; sistemas de comércio de emissões; títulos verdes; emissões de gás carbônico; mudança climática.
Classificação JEL: Q5, H23, G3

1. INTRODUCTION

The urgent need of transitioning to a low-carbon climate resilient economy has called agents to action. Collective global efforts to promote a sustainable development able to address climate change challenges have intensified with the adoption of the United Nations Sustainable Development Goals and the Paris Agreement, both in 2015. However, achieving such ambitious goals require behavioral changes and significant investments, with estimates around US$ 9.2 trillion per year on average to reach net-zero emissions by 2050 (McKinsey Global Institute, 2022). Some of the alternatives being used for that include carbon pricing initiatives and green bonds.

Carbon pricing initiatives have their foundations in the economic theory of public goods and externalities. Correcting the prices of negative externalities, in this case carbon emissions, makes producers and consumers consider social costs associated with their private decisions, shifting the damage burden to those that cause it. It is expected that additional payments imposed for options intensive in emissions will result in a movement towards greener products, projects, and investments, resulting in a lower level of emissions (Baranzini et al., 2017; Nordhaus, 2019).

Governments can use distinct measures to put a price on carbon emissions. The most popular of these are emissions trade systems (ETS) and carbon taxes. An ETS, also known as cap-and-trade policy, limits total emissions and allows agents with lower levels of emissions to sell their extra allowances to those with greater levels. The allowance market fluctuates freely and supply and demand set the price; the cap is on emissions. Carbon taxes work differently; a tax rate is levied directly on emissions or on the carbon content of fossil fuels. While the carbon price is set, there is uncertainty about the emission reduction outcomes.

Green bonds are fixed-income securities issued in the capital markets to raise resources to finance projects with climate or environmental sustainability components (World Bank, 2015). By stimulating this type of project, green bonds are expected contribute to climate mitigation and reduce emissions. Issuers can be a variety of agents, including supranational institutions[2], banks, corporations, state-owned companies, and national or local governments.

Distinct from carbon pricing initiatives, green bonds are not imposed as climate policies by governments. They are labeled voluntary issuances that act as signaling mechanism to the market and constitute one more option available to finance projects. Usually, green bonds follow the Green Bond Principles established by the International Capital Markets Association in a self-regulatory standardization effort, which seeks to bring guidelines and recommendations to promote transparency in the issuance of such bonds (ICMA, 2021). Voluntary second-party opinions adopted by issuers contribute to transparency in the use of the capital raised.

On the issuer side, green bonds might improve issuers' access to institutional investors whose policies mandate sustainable investments and diversify its investor base (World Bank, 2015). On the investor side, diversification, lower risk, and long-term economic sustainability might incentivize the acquisition of green bonds (Maltais & Nykvist, 2020). At the aggregate level, as green bonds are designed to finance environmentally sustainable projects, the mobilization of capital markets to this kind of product is expected to be associated with a decrease in greenhouse gas emissions if the projects would not have been done otherwise with bonds not qualified as green.

Under the denomination of Climate Awareness Bond, the European Investment Bank issued the first bond of this type and, in 2008, the World Bank issued the first labeled green bond. A market of less than US$ 1 billion in 2008 jumped to more than US$ 1.16 trillion in 2021 (Bloomberg, 2022). This growth demonstrates an increased interest and awareness among issuers and investors of the climate change problem and of the necessity of promoting sustainable investments.

While emission reduction initiatives have received extensive attention in the literature from a theoretical perspective, quantitative assessments of how such initiatives are actually performing are growing at a slow pace. Empirical investigations have studied each carbon pricing policy individually.

[2] Supranational institutions include organizations that operate in multiple countries, such as the European Investment Bank, the World Bank, and the African Development Bank.

With a few exceptions (Gloaguen & Alberola, 2013), evaluations of ETS schemes performed for European Union (EU) members show a reduction of up to 1.5 percent per year in greenhouse gas emissions (Anderson & Di Maria, 2011; Bayer & Aklin, 2020), which is nearly half of the 2.6 percent annual decrease in emissions required to stabilize temperature increase around 2ºC in a 100-year average period. When studies examine individual countries in the EU, conclusions are mixed. For Lithuania (Jaraite-Kažukauske & Di Maria, 2016) and the United Kingdom (McGuinness & Ellerman, 2008) the EU ETS reduced emissions, while in France (Wagner et al., 2014) and Germany (Petrick & Wagner, 2014) there were no statistically significant effect. Findings for ETSs outside the EU are also mixed. In Tokyo, for example, Arimura and Abe (2021) find a reduction in emissions over the time period in which the ETS was implemented, but Wakabayashi and Kimura (2018) find that other drivers caused reductions in emissions and not the ETS.

Findings in the literature on carbon taxes are similarly ambiguous. Analyses focused on European countries and the Canadian province of British Columbia indicate a consistent emission reduction of up to 2 percent annually (Abrell et al., 2019; Andersson, 2019; Aydin & Esen, 2018; Larsen & Nesbakken, 1997; Metcalf, 2019; Rivers & Schaufele, 2015). Nonetheless, some studies present contradictory evidence for the same countries. For instance, Fernando (2017) and Lin and Li (2011) found no relationship in Denmark, Sweden, Netherlands, and Finland. Pretis (2019) found no relationship in British Columbia.

Factors influencing distinct results even when studies examine the same countries or localities might include the different periods of analysis and/or econometric approaches used. The heterogeneity of such policies around the globe also plays a role in cross-countries comparisons. Distinct rules, rates, prices, enforcement mechanisms, and varying degrees of compliance associated with cap-and-trade policies and carbon taxes constitute a challenge for capturing quantitative effects of these instruments.

One explanation for the small or statistically insignificant effects of carbon pricing initiatives on emissions in the literature may be the political challenges associated with the implementation of such policies. The mitigation effects of these instruments are weakened by concessions and exemptions for certain industries (Lin & Li, 2011), and by the adoption of tax rates and prices that are lower than the optimal ones prescribed by economic models to achieve emissions goals (Shmelev & Speck, 2018). Researchers also point out that, at current levels, such policies have insufficient capacity to curb emissions at rates required to contain global warming (Pretis, 2019), and need to be combined with other environmental policies (Shmelev & Speck, 2018).

The literature on green bonds is still nascent. The emerging research has focused mainly on the asset pricing properties of green bonds and there is intense debate on whether such bonds offer issuers the opportunity to raise funds at lower rates, the so-called greenium (Hachenberg & Schiereck, 2018). Few studies examine the effects of such bonds on environmental indicators, and evidence on emissions in particular is even more scarce. Using firm-level data from Bloomberg, Flammer (2019) finds that companies have decreased their carbon emissions after issuing certified green bonds. According to Fatica and Panzica (2021), stronger reductions in companies' emissions were observed in connection with green bond issuances after the 2015 Paris Agreement. To date, only one study has investigated the effect of green bonds on emissions at the country level. Using a bivariate approach applied to data from 2008 to 2019, Saeed Meo & Karim (2021) analyze the ten most relevant economies in terms of the use of green finance. They find, in general, a negative correlation between green bond issuance and carbon dioxide (CO_2) emissions. Nonetheless, this relationship varies depending on the quantiles of the two variables and on the country. For Canada, for instance, the relationship is negative on the high quantiles of the green finance distribution and positive on the low quantiles of green finance, independently of the quantile of CO_2 emissions.

Recently, Flaherty et al. (2017) and Heine et al. (2019) developed economic intergenerational models and predict that the combination of carbon pricing initiatives and green bonds can provide additional benefits. First, it would deliver better results on emissions than the separate use of these measures. Second, it would improve the political feasibility of climate policies. The authors argue that a carbon price initiative promotes a transition to a low-carbon economy in the future by imposing costs on the current generation. Conversely, green bond financed projects might reduce emissions in the short term, but the responsibility to repay the debt is passed forward to future generations. Therefore, the combination of both enables generations to share the financial burden of addressing climate change. Moreover, combining the instruments diminishes the political difficulty of only levying taxes, and the debt risk of only relying on green bonds to finance the battle against global warming (Heine et al., 2019).

The purpose of this study is to investigate how the adoption of carbon pricing initiatives and issuance of green bonds relate to CO_2 emissions in 148 countries between 1990 and 2016. This paper contributes to the literature in four ways. First, it examines how two climate instruments, carbon pricing initiatives and green bonds, relate to CO_2 emissions. Previous research has focused on one instrument at a time. Second, it empirically analyzes whether there are interaction effects between carbon pricing and green bonds on emissions, providing empirical evidence to the theoretical models above mentioned. Third, it uses a panel dataset with 148 countries for 27 years, a more comprehensive database than previous research. And finally, it applies recently developed econometric diagnostic tests and the Callaway and Sant'Anna (2021) estimator to deal with bias in two-way fixed effects (TWFE) estimations that arise from heterogeneous effects of policies.

2. DATA AND METHODS

Data for the dependent variable, CO_2 emissions, come from the Our World in Data website. Data for the first instrument of interest, carbon pricing initiatives implemented as taxes or ETS schemes, come from the Carbon Pricing Dashboard[3] maintained by the World Bank. For the purpose of this study, a country is considered as having implemented a carbon pricing initiative in the first year of the national adoption of any policy, carbon tax or ETS. Data on the second climate instrument, green bonds, come from Bloomberg[4]. Similar to carbon pricing, a country is considered as making use of green bonds as climate instrument if any issuance is associated with that country in a given year.

Countries use such climate instruments in a wide range of formats. For carbon pricing initiatives, factors such as tax rates, incidence, frequency of payments, emissions coverage, caps, and compliance vary from place to place. Green bonds are also heterogeneous in terms of amount issued, currency, type of project financed, and size of the country's capital market. In order to allow comparability among countries, key independent variables are defined in a binary form. The disadvantage of not capturing policies' intensities is discussed at the end.

Control variables include population, urbanization level, GDP per capita, energy intensity, and share of renewable energy consumption, with all data extracted from the World Bank and Our World in Data.

The Kaya identity, used by the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) to study future emissions scenarios, identifies human population, Gross Domestic Product (GDP) per capita, energy intensity, and carbon intensity as the four key variables that drive carbon emissions (Rosa & Dietz, 2012). There is relative agreement in the literature about the direct positive effect of population size and GDP on CO_2 emissions (Andersson, 2019; Martin & Saikawa, 2017; Shi, 2003). The logic here is that larger populations and higher GDP imply higher levels of consumption and, therefore, higher levels of emissions.

Urbanization, on the other hand, might affect CO_2 emissions in two different ways (Liddle & Lung, 2010). On one hand, an increase in the proportion of the population that lives in urban areas might lead to an increase in energy consumption, leading to higher emissions. On the other, the concentration of people may decrease transport demand and the use of fossil fuels. The bulk of

[3] https://carbonpricingdashboard.worldbank.org/

[4] This study excludes green bonds issued by supranational institutions, or with missing information for amount or issuance date. Green bonds issued in 2008 and 2009, associated with the United States in the Bloomberg database, were excluded due to been issued by supranational institutions, according to the World Bank (2014).

evidence points to a positive relation between urbanization and CO_2 emissions (Cole & Neumayer, 2004; York et al., 2003), although some studies find the opposite (Fan et al., 2006).

Energy intensity is an indicator of how much energy is used to produce each unit of economic output. It is calculated by dividing energy supply by GDP measured in terms of purchasing power parity (PPP). The greater the ratio, the more energy is used in the production of each unit of GDP. In the Kaya identity, emissions and energy intensity are positively correlated, meaning that the lower the energy intensity, the more efficient the economic activity and the lower the level of emissions that are generated (Fan et al., 2006). This is consistent with the literature findings (Cole & Neumayer, 2004; Liddle & Lung, 2010).

Theoretically, renewable energy consumption[5], the share of renewable energy in total final energy consumption, is associated with substituting environmentally sustainable sources for carbon fuels and, thus, with lower levels of emissions (Gloaguen & Alberola, 2013; Hájek et al., 2019). Some studies support the theory, finding a positive relationship between carbon taxes and the development of renewable energy (Lin & Li, 2011).

Technology factors, here defined as energy intensity and renewable energy consumption, might also have some relationship with the climate policies here studied. The more energy intensity and the less renewable energy consumption in a country, the more emissions and the greater the need for the implementation of carbon taxes or ETSs. Moreover, green bonds might be issued to finance renewable power plants that can increase renewable energy consumption.

After merging all the data sources, the final sample include a balanced panel of 148 countries with non-missing information for the period 1990 to 2016.

Empirical strategy

In analyzing the relationship between CO_2 emissions and the climate instruments, to exploit exogenous variation in the timing of enforcement of carbon pricing initiatives and in the timing of green bonds issuances, the empirical approach consists of estimating TWFE regressions. The general model, with country-year as the unit of analysis, is specified as follows:

$$ln\_co2_{it} = \beta_0 + \beta_1 carbon\_pricing_{it} + \beta_2 green\_bond_{it} + \beta_3 carbon\_pricing_{it} * green\_bond_{it} + \boldsymbol{\gamma X_{it}} + \alpha_i + \delta_t + u_{it} \quad (1)$$

where the dependent variable is the natural logarithm of CO_2 emissions in country i in year t, $\boldsymbol{X_{it}}$ is the vector of control variables, and u_{it} is the error term. α_i represents the country fixed effects and controls for unobserved country-specific characteristics that do not vary over time, such as, unobserved societal willingness to support climate change policies. δ_t denotes the year fixed effects and controls characteristics, such as aggregate shocks, that change over time but influence all the countries at the same time.

β_1 is the first coefficient of interest. It is associated with the variable $carbon\_pricing_{it}$, is an indicator equals to 1 if country i has a carbon pricing initiative in force in year t. Carbon pricing initiatives in the sample are an absorbing treatment, meaning that once the country has implemented it, it remains in force for the whole period. β_2 is the second coefficient of interest. It is associated with the variable $green\_bond_{it}$, which is also an indicator variable equals to 1 if there is any green bond issued in year t associated with country i. Differently from carbon pricing initiatives, green bonds are a discretionary instrument that may or may not be issued in a given year, so that the indicator switches on and off in distinct periods. β_3 is the last coefficient of interest. It is associated with the interaction between $carbon\_pricing_{it}$ and $green\_bond_{it}$, an indicator equals 1 if country i has both a carbon pricing initiative in force and any green bond issued in year t.

The TWFE estimators are a weighted average of all possible two-countries and two-years difference-in-differences (DID) estimators in the data (Goodman-Bacon, 2021). As such, they rely

[5] Renewable resources comprehend: hydro, solid and liquid biofuels, wind, solar, biogas, geothermal, marine, and waste.

on the parallel trends assumption to estimate average treatment effects and have a causal interpretation: distinct groups of countries would have had the same emissions evolution in the absence of any of the climate instruments studied here. Nonetheless, a growing body of literature has pointed out that with more complex designs, such as many groups, variation in the treatment timing, and treatments that switch on and off and/or are non-binary, an additional assumption of homogeneous treatment effects across groups and periods needs to hold for TWFE estimators to be unbiased (de Chaisemartin & D'Haultfœuille, 2021).

In TWFE models, treated units may receive negative weights in the calculation of the average treatment effect (Jakiela, 2021). In the case of heterogeneous treatment effects, these negative weights of treated units may result in bias and coefficients may even have the opposite sign of the individual treatment effects (Roth et al., 2022). Considering that it is unlikely that the assumption that treatments have homogeneous effects across groups and periods holds in reality, recent papers have developed diagnostic tools and alternative estimators to address the drawbacks of the TWFE in diverse research designs. In the econometric literature about the topic, de Chaisemartin and D'Haultfœuille (2021) and Roth et al. (2022) offer comprehensive overviews of the recent advances.

Callaway and Sant'Anna (2021) develop an alternative estimator that uses not treated or not yet treated units as a comparison group to obtain average treatment effects in treatments that present variation in the timing of adoption across units and that have a staggered design, meaning, units remain treated once treatment is adopted. Relying on a conditional parallel trends assumption, the approach enables accounting for heterogeneous and dynamic treatment effects and avoids the related TWFE bias.

In this study, it is also unlikely that the use of any of the climate instruments – carbon pricing initiatives, green bonds, or their combination – have homogenous effects across countries and years. In one attempt to evaluate the TWFE estimators obtained and perform a robustness check, this study also implements Callaway and Sant'Anna's (2021) approach. The Stata package called CSDID contemplate these authors' method and serves this purpose.

3. DESCRIPTIVE STATISTICS

At some point over the period 1990 to 2016, 15 countries used both carbon pricing initiatives and green bonds, 13 countries implemented only carbon pricing initiatives, eight had only green bonds issued, and 112 did not use either instrument. In general, carbon pricing policies remain in force once adopted. Green bonds, on the other hand, are a more volatile instrument and only nine countries in the sample used them two or more consecutive years after the first issuance. As a consequence, countries can be classified in distinct groups of the climate initiatives each year depending whether green bonds were issued that year.

Table 1 presents basic descriptive statistics for the key independent variables and the controls for the first and last years of the panel, 1990 and 2016. Countries are classified in a certain group if they used the instruments under study at any point in the period. The table is divided into five columns. Values in each cell correspond to the mean with standard deviations in parentheses. The first column presents information for all the countries included in the sample. Columns (2) - (5) contain data for countries grouped according to the climate instruments used in the respective periods. Column (2) contains data for countries with no climate policy implemented in any year of the sample. Columns (3), (4), and (5) contain data for countries that implemented a carbon pricing initiative in any year, countries that issued green bonds in any year, and countries that made use of both instruments in any year, respectively.

Table 1 – Descriptive statistics, 1990 and 2016

	(1) All countries		(2) Countries with no climate policy		(3) Countries using only carbon pricing initiatives		(4) Countries issuing green bonds		(5) Countries with carbon pricing initiatives and green bonds	
	1990	**2016**	**1990**	**2016**	**1990**	**2016**	**1990**	**2016**	**1990**	**2016**
CO_2 emissions (million tonnes)	139.89 (526.8)	219.75 (937.3)	41.91 (241.2)	66.61 (189.0)	135.71 (187.5)	117.26 (172.2)	1,129.55 (1,799)	2,352.53 (3,465)	341.05 (354.9)	311.17 (326.4)
Population (ln)	15.51 (2.10)	15.92 (2.10)	15.10 (2.04)	15.59 (2.11)	15.59 (1.59)	15.72 (1.44)	18.27 (1.93)	18.59 (1.92)	16.95 (1.18)	17.07 (1.18)
Urbanization (% population)	0.49 (0.23)	0.58 (0.23)	0.42 (0.21)	0.52 (0.22)	0.69 (0.12)	0.73 (0.12)	0.63 (0.27)	0.73 (0.21)	0.75 (0.09)	0.81 (0.11)
GDP per capita ($ thousand 2017 PPP)	13.5 (16.7)	20.1 (20.7)	9.2 (15.2)	13.3 (15.5)	25.6 (16.6)	42.3 (26.4)	16.2 (15.0)	28.0 (22.8)	32.1 (8.4)	45.3 (10.9)
Energy intensity (kWh / $2017 PPP GDP)	1.34 (1.19)	1.09 (0.73)	1.18 (1.22)	1.07 (0.80)	1.99 (1.01)	1.18 (0.50)	2.00 (1.37)	1.31 (0.47)	1.58 (0.61)	1.00 (0.26)
Renewable energy consumption (% total energy consumption)	0.38 (0.34)	0.33 (0.29)	0.47 (0.35)	0.37 (0.31)	0.07 (0.10)	0.15 (0.09)	0.26 (0.22)	0.19 (0.15)	0.13 (0.16)	0.22 (0.17)
Countries	148		111		14		8		15	
Average years using the instrument					9.85 (3.43)		1.75 (1.03)		1.93 (1.16)	

Notes: mean values with standard deviations in parenthesis.

Table 1, Colum (1) shows that, in recent decades and in most countries, average carbon dioxide emissions have increased steadily. Nonetheless, the groups of countries that implemented carbon pricing initiatives [Column (3)] or used a combination of these initiatives with green bonds [Column (5)] have decreased their average emissions. For countries that only implemented carbon pricing initiatives, the mean emission level decreased from 136 million tonnes of CO_2 in 1990 to 117 million tonnes in 2016. For those that adopted any form of carbon pricing and issued green bonds, reduction over the same period was from 341 to 311 million tonnes of CO_2. Compared to the other groups, average CO_2 emission levels and variations are much higher for the group of countries that only used green bonds as a climate instrument. The explanation is the participation of China and the United States in this group, first and second highest emitters, respectively.

Table 1 also shows that, compared to groups of countries that use any climate policy, countries with no climate policies have lower urbanization levels and GDPs per capita. Most countries that have used climate policies are developed. For my sample overall, energy intensity, a measure of how much energy is used to produce one unit of GDP, declined between 1990 and 2016, and, in 2016, is lower for countries that combine carbon pricing with green bonds, followed by those with no climate policies. The general decrease in the average energy intensity shows that countries are generating their economic outputs more efficiently, which might be due to technological improvements. Interestingly, the share of renewable energy in total final energy consumption is high for the groups of countries with no climate policies and that only used green bonds, though it decreases between 1990 and 2016. On the other hand, in countries that implement only carbon pricing or that combine carbon pricing with green bond issuance, the energy consumed coming from renewable sources increases.

The last row of Table 1 denotes the average number of years that countries in each group have used the instruments. Countries that only implemented carbon pricing initiatives have an average of

11 years with the policies in force. Countries with only green bond issuances have used the instrument for an average of 2.6 years. Countries that have combined carbon pricing initiatives and green bonds at any point in the period 1990-2016 have done so for an average of 3 years.

4. RESULTS

Table 2 presents the estimation results. Models (1) – (3) cover all 148 countries and models (4) – (7) cover a subsample of 138 countries. This subsample includes, for those countries with green bond issuances, only the ones that continued to issue every year once they started. That is, for these countries, green bond issuance is a staggered condition[6]. This staggered condition subsample allows the estimation of the doubly-robust difference-in-difference method outlined by Callaway and Sant'Anna (2021), here referred to as CSDID.

Model (1) estimates the relationship between the climate policies and CO_2 emissions using no controls other than carbon pricing, green bonds, their interaction, and year and country fixed effects. Model (2) adds time-varying country-specific control variables to Model (1) to eliminate variation in the policies' coefficients that might be due to the influence of these variables. Revenues from carbon taxes and funding from green bonds might be used to finance renewable energy projects (Semmler et al., 2021), which might imply a degree of mediation caused by the variable share of renewable energy consumption. Table A.1 in the Appendix presents regression results that suggest some degree of mediation, at least in relation to carbon pricing initiatives. In this case, revenues from carbon taxes, for instance, could have been used by governments to finance the construction of renewable power plants capable of reducing emissions. Considering this possibility, Model (3) repeats Model (2) but excludes the share of renewables as a control.

Models (4) – (6) replicate Models (1) – (3), respectively, but consider only countries that have green bond issuance as a staggered condition – i.e., countries for which green bond issuance never stopped once it started. In studies with multiple periods and units treated at a different point in time, such as the case here, TWFE regressions might result in biased estimates if treatments have heterogeneous effects across time and units of analysis (Roth et al., 2022). Considering the recent evolution in the econometric literature that attempts to address this concern, Model (7) uses the CSDID method with no controls besides the climate instruments under study[7] and serves as a direct comparison to the results of Model (4).

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[6] 10 countries have green bonds issuances switching on and off between 1990 and 2016 and, thus, are not considered as having a staggered treatment.

[7] When including other controls, a considerable portion of 2x2 difference-in-difference estimation fails, and some groups of countries that either implemented carbon pricing initiatives or issued green bonds are not considered even with a balanced panel. Futher research is needed to allow the inclusion of additional covariates.

Table 2 – Estimation results, sample 1990 – 2016

Dependent variable: log of CO_2 emissions	All countries			Only countries with green bonds as a staggered condition			
	(1) TWFE no controls	(2) TWFE all controls	(3) TWFE all controls, except renewables	(4) TWFE no controls	(5) TWFE all controls	(6) TWFE all controls, except renewables	(7) CSDID no controls
Key independent variables							
Carbon pricing	-0.48***	-0.10**	-0.15***	-0.50***	-0.12***	-0.18***	-0.33***
	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)	(0.03)
Green bonds	-0.17	-0.08**	-0.08*	0.11	-0.04	-0.02	0.014
	(0.13)	(0.04)	(0.04)	(0.11)	(0.08)	(0.07)	(0.02)
Carbon pricing * Green bonds	-0.19	0.01	-0.02	-0.48***	-0.04	-0.08	0.032
	(0.13)	(0.04)	(0.05)	(0.12)	(0.08)	(0.09)	(0.02)
Controls							
Population		1.16***	1.32***		1.15***	1.30***	
		(0.10)	(0.12)		(0.10)	(0.12)	
Urbanization		0.74*	1.05**		0.75*	1.04**	
		(0.43)	(0.44)		(0.44)	(0.45)	
GDP per capita		0.79***	0.97***		0.79***	0.97***	
		(0.08)	(0.10)		(0.08)	(0.10)	
Energy intensity		0.23***	0.27***		0.23***	0.27***	
		(0.04)	(0.04)		(0.04)	(0.04)	
Renewable energy share		-1.25***			-1.23***		
		(0.27)			(0.28)		
Constant	2.02***	-23.17***	-27.99***	1.80***	-22.98***	-27.54***	
	(0.04)	(2.05)	(2.43)	(0.04)	(2.06)	(2.48)	
Observations (country-years)	3,996	3,996	3,996	3,726	3,726	3,726	
Countries	148	148	148	138	138	138	138
R^2	0.46	0.82	0.79	0.47	0.82	0.79	
F	12.79	65.74	46.60	12.83	61.91	44.64	

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

The results in Table 2 confirm the hypothesis that carbon pricing initiatives are negatively related to CO_2 emissions. In all specifications, coefficients for this variable are negative and statistically significant at least at the 5% level. The implementation of a carbon pricing initiative by the countries here sampled is associated with at least an average decrease of at least 10% in CO_2 emissions over the period 1990 to 2016 [Model (2)].

Comparisons of this result with findings in the existing literature are not straightforward due to the study design, sample selection, and types of carbon pricing initiatives analyzed. Associated with the adoption of the EU ETS, for instance, Bayer & Aklin (2020) found a 3.8% reduction in emissions for the period 2008-2016 while Dechezleprêtre et al. (2018) found a 10% reduction between 2005 and 2012.

Given that the CSDID method accounts for heterogeneous and dynamic treatment effects, comparison of the TWFE estimations in Model (4) with the CSDID estimations in Model (7) allows us to see whether heterogeneity might play a role in biasing the other TWFE models. When heterogeneous effects are considered in Model (7), coefficients for the CSDID estimations [Model (7)] are lower than in the TWFE Model (4) and the interaction coefficient of carbon pricing and green bonds is no longer significant, which suggests that heterogeneous effects of the instruments among countries and/or years are indeed biasing the TWFE estimates. Awareness of this problem suggest that the remaining models should be interpreted cautiously.

Figure 1 presents the average dynamic effects of carbon pricing adoption according to the period of exposure obtained from the CSDID estimates. For years prior to the adoption of the policy, this average dynamic effect fluctuates around zero, which is a positive indication of internal validity. After policy implementation, emissions decrease across time. The break in the post-treatment effects around periods 11 to 12 is one additional indication of heterogeneity. In this sample, countries exposed to the policy for more than 11 years are those who adopted it before 2005 (the result of the last year of the sample, 2016, minus 11). It might be the case that early adopters (those who implemented a carbon pricing initiative prior to 2005) are systematically different from those who adopted initiatives later. In fact, 2005 is the year of the implementation of the ETS in the European Union. This policy almost surely has had higher compliance, stronger incentives to change behavior, or even complementary effects with the carbon taxes already in force in some countries and, thus, can be influencing the deeper effects of period 11 when compared to period 12.

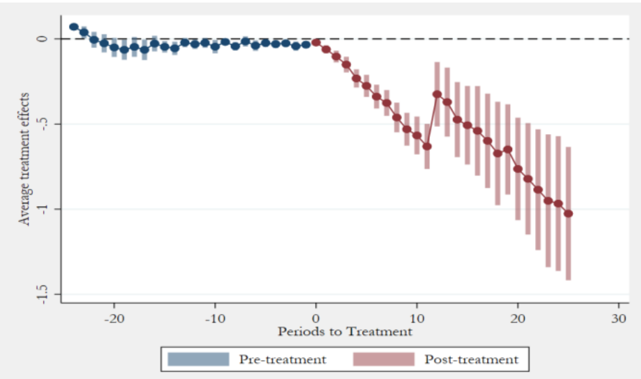

Figure 1 – CSDID dynamic effects of a carbon pricing initiative, sample 1990-2016

Figure 2 depicts the average dynamic effects of carbon pricing adoption obtained from the CSDID estimates, grouping countries according to the year of implementation. Comparing groups of countries that implemented such policies in 1991 and 2005, there is a sharp decrease in emissions from the first year onwards after 2005, while for the 1991 adopters' group reductions in emissions took some years to begin.

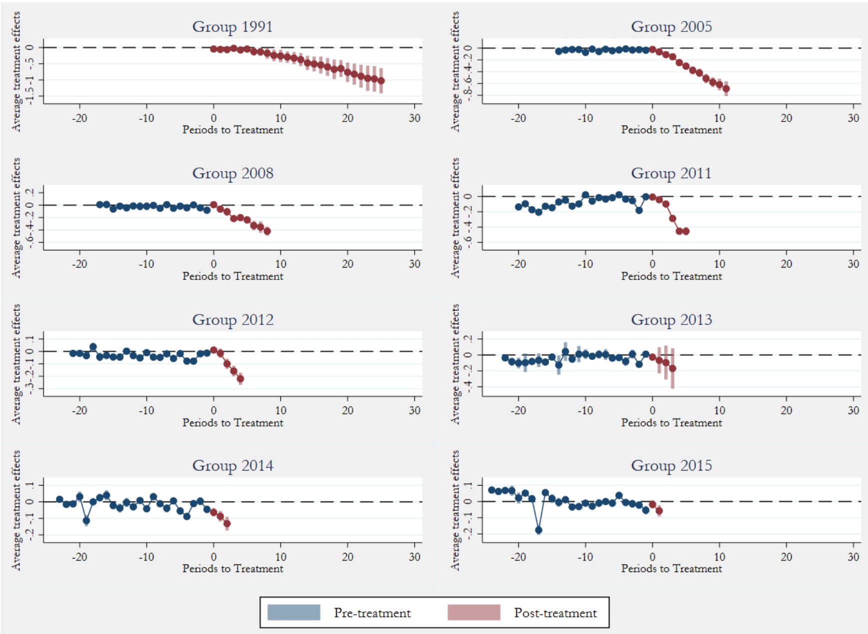

Figure 2 – CSDID dynamic effects of a carbon pricing initiative, per year of implementation, sample 1990 – 2016

In contrast to the unambiguous results of carbon pricing initiatives, the analyses of green bonds shown in Table 2 produce mixed results. Coefficients for this climate instrument are statistically significant at least at the 10% level only in specifications (2) and (3). In each model, green bonds issuance is associated with an 8% decrease in emissions. The green bonds' coefficient does not vary between Models (2) and (3) and there is no significant relationship between green bonds and share of renewables, as shown in Table A.1 of the Appendix [Column (2)]. In light of that, there seems to be no mediation of the renewable energy variable in the relationship between green bonds and emissions.

Interaction effects of carbon pricing initiatives and green bonds are statistically significant only in Model (4), which might be due to limited statistical power. In the subsample analyzed in Models (4) - (7), only 13 countries present green bonds issuances. Of those, eight had green bonds issued for two or more periods, and 10 also adopted carbon pricing initiatives. In total, 27 observations vary for green bonds and the interaction of climate instruments. This might not be enough variation to be exploited by the regressions and the observed significance for the interaction in Model (4) might be driven by the carbon pricing variable.

In almost all models, the control variables have the expected sign and are statistically significant at the 5% level, with exception of the urbanization level, which is significant at the 10% level in Models (2) and (5). Population, urbanization level, GDP per capita, and energy intensity all have a positive association with emissions, while share of renewable energy in final energy consumption has a negative association with emissions.

For 14 countries in the sample, first issuances of green bonds occurred in 2017 and 2018, denoting the recent growing popularity of the instrument. Including these years in the analysis would introduces more variation in the green bonds and interaction variables to be exploited by the regression models. It also serves as a robustness check for the previous results. In order to capture more variation and check on whether results vary, a subsample of 65 countries that have data for all variables from 1990 to 2018[8] was used to estimate the same seven regression models presented in Table 2.

[8] The energy intensity variable is available for 148 countries prior to 2017 but only 65 countries in years 2017 and 2018.

With the subsample 1990-2018, the majority of the results continue to show a statistically significant relationship between carbon pricing initiatives and CO_2 emissions. Nonetheless, magnitudes are lower than before. Furthermore, in Model (2) specification, the coefficient for this variable is no longer significant, which suggests a complete mediation by variable renewable energy share. As with the sample 1990-2016, green bonds continue to have a statistically significant and negative association with emissions only in Models (2) and (3). However, magnitudes in this case are slightly higher.

Incorporating more countries using green bonds indeed affects estimations results. To examine whether this result comes from adding more years or from sample composition, regressions were also run for the subsample of 65 countries but for the period 1990-2016 instead of 1990-2018. Comparing such results, the coefficients for carbon pricing do not alter much and the magnitude and statistical significance remain the same, which is an indication that selection of fewer years for these countries is not influencing the overall results. The green bond coefficients, on the other hand, are not significant if the same countries are considered only until 2016, which is an indication that the driving influences for the results of period 1990-2018 are the addition of more years and more variation in the use of green bonds and not sample composition.

Diagnostics for the TWFE estimates

The CSDID estimations presented in Table 2 already indicate that the TWFE results might be biased due to heterogeneous effects across countries and/or years of the adoption of climate instruments. To further assess whether this is the case, it was employed the diagnostics proposed by Jakiela (2021) using the sample 1990-2016 with countries with green bonds as a staggered condition. According to the author, two questions need to be answered for this assessment. The first is whether treated units receive negative weights. The second involves directly testing the homogeneous effect hypothesis.

Weights for each independent variable of interest were estimated using the residuals of regressions of each one on country and year fixed effects, using the other key independent variables as controls. Figure 3 displays the distribution of weights for each climate instrument and their interaction. The histograms show that some countries that implemented carbon pricing initiatives in fact receive negative weights, while those with green bonds or a combination of carbon pricing and green bonds do not.

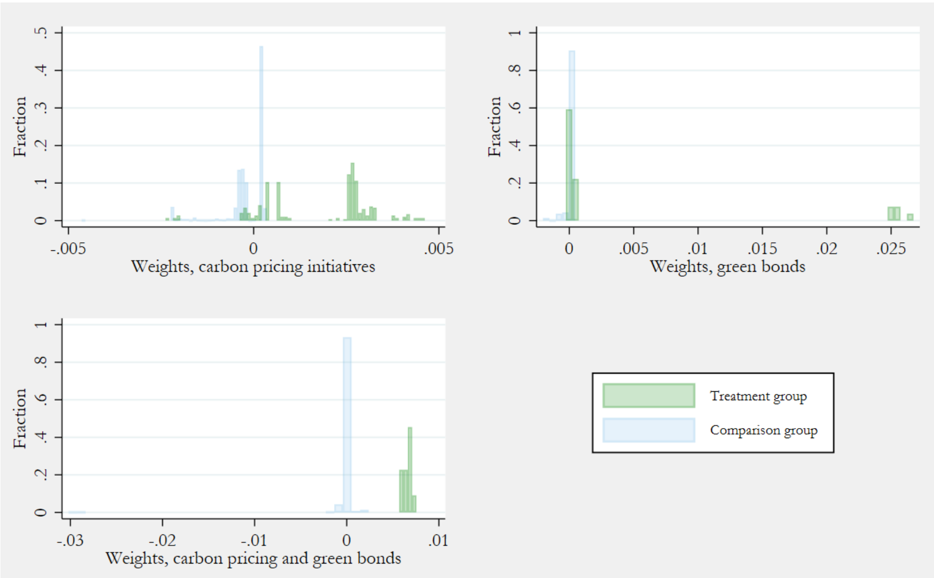

Figure 3 – TWFE weights by climate instrument, sample 1990 – 2016, staggered green bonds

Under the homogeneous effects hypothesis, the relationship between the residualized emissions and the residualized instruments is linear and the slope would not differ between the group of countries that adopted such instruments and the group that did not (Jakiela, 2021). The interaction coefficient of the instrument with its residualized values shows whether the relationship between residualized emissions and residualized instrument differs between the group of country that adopted the instrument and the group that did not. The residuals of emissions come from the regression of emissions on the climate instruments and their interaction, and country and year fixed effects. As before, the residuals for each instrument are obtained from regressions of each instrument on country and year fixed effects, using the other key independent variables as controls. The results of such regressions show that slopes differ between groups for countries that adopted carbon pricing and that use a combination of carbon pricing and green bonds. In this case, the homogeneous hypothesis can be rejected, meaning that the relationship between carbon pricing and the combination of carbon pricing with green bonds and emissions are not consistent with the needed TWFE assumptions.

5. DISCUSSION

Expecting to reduce emissions and promote the transition to a low-carbon economy, governments around the globe have made use of carbon pricing initiatives, such as carbon taxes and cap-and-trade schemes, to change agents' consumption and production decisions through markets mechanisms. In addition, green bonds have been issued by a variety of agents to finance environmentally sustainable projects which are also expected to contribute to climate mitigation and emission reduction. While some studies have examined the role of carbon pricing initiatives and found a negative relationship with emissions, evidence on the association between green bonds and emissions is still scarce, especially at the country-level. A few theoretical economic models also point out interaction effects between carbon pricing initiatives and green bonds on emissions (Flaherty et al., 2017; Heine et al., 2019).

This study extends this current body of research, contributing on four fronts. First, it examines how two climate instruments, carbon pricing initiatives and green bonds, relate to CO_2 emissions. The existing literature has focused on one instrument at a time. Second, it empirically analyzes the question of whether there are interaction effects of the two instruments on emissions. Third, it uses panel data from 1990 to 2016 for 148 countries, a more comprehensive database than used by previous research. And finally, it tests TWFE assumptions and applies a recently developed econometric estimator, CSDID, that address bias that might arise from heterogeneous effects of the use of the instruments across countries and years.

The results of the regressions suggest that the adoption of a carbon pricing initiative is negatively associated with carbon dioxide emissions. Specifically, controlling for country and year fixed effects and for time-varying, country-specific variables in my preferred regression model[9], the implementation of a carbon pricing initiative is associated with an average 10% decrease in CO_2 emissions in the period 1990 to 2016. As a reference, Bayer and Aklin (2020) found a 3.8% reduction in emissions for the period 2008-2016 while Dechezleprêtre et al. (2018) found a 10% reduction between 2005 and 2012, both associated with the adoption of the EU ETS in 2005.

Estimates from the preferred model also suggest that green bond issuance is associated with an average 8% reduction in country emissions between 2012[10] and 2016. The literature lacks similar investigation using country-level data. Nonetheless, Flammer (2019), analyzing firm-level data between 2007 and 2018, finds that companies that issued green bonds had a decrease of 27.7% in their CO_2 emissions.

The results do not show statistically significant interaction effects on emissions of the simultaneous use of carbon pricing initiatives and green bonds. However, taking together coefficients of carbon pricing initiatives, green bonds, and their interaction suggest that countries that made use of both instruments had an associated average 17% lower emissions between 1990 and 2016.

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[9] Model (2) in Table 2, which uses the largest number of countries and controls for the largest number of variables.

[10] First year in which a green bond issuance was observed in the sample.

Overall, the results show that both instruments have a negative association with CO_2 emissions and, thus, might contribute to the transition to a low-carbon economy. Nonetheless, although my analysis with the preferred TWFE model controls for factors that are time-varying but fixed across countries, country-varying but fixed across time, as well as broader observable time- and country-varying conditions, my results might be subject to bias for a variety of reasons.

Several time- and country-varying factors correlated with CO_2 emissions and the adoption of climate instruments are not easily measured or even unobservable and, the fact that they are no included in my analysis could result in omitted variable bias. For instance, cultural attitudes towards the environment and the climate change discussion might change over time and influence countries' emissions levels as well as their use of climate instruments. Over time, some societies may have become more aware of the climate change problem and more prone to care about the environment and the future. As a consequence, they might have changed their production and consumption behaviors, and, thus, may have reduced emissions. They also might have become more willing to accept the implementation of carbon pricing initiatives or to make use of green bonds as an instrument to finance sustainable projects and signal their commitment to the low-carbon transition.

The approach also raises reverse causality concerns. It might be the case that emissions levels are the reason why carbon pricing initiatives are adopted or green bonds are issued. The use of these instruments is not random and further research is needed to investigate their determinants. CO_2 emissions can be one of those determinants and, hence, this analysis can be subject to bias due to this simultaneity. The use of the instrumental variables quasi-experimental approach would overcome the aforementioned endogeneity problems. But this would require instrumental variables for the implementation of carbon pricing initiatives and for green bond issuances that are correlated with the climate instruments and uncorrelated with the error term. The challenging proposition of such instrumental variables is an area for further research.

Another possible limitation of the approach here adopted is that the climate instruments examined are very heterogeneous across countries. Carbon pricing characteristics such as tax rates, prices, coverage, and compliance vary from one jurisdiction to another. And green bond characteristics such as amounts issued, projects being financed, and the size of capital markets are subject to extensive variation. The use of an indicator variable for these instruments in the regression models makes it possible to compare them; however, it does not allow capturing intensity in the use of such instruments.

In addition, subnational climate-related initiatives, such as carbon taxes implemented in Chinese provinces or American States like California, sometimes overlap with the national initiatives here analyzed and might influence emissions as well. Other non-financial policies such as building standards and transportation regulations might also be part of subnational decisions and contribute to emission reductions.

A further problem is that data on green bonds are usually compiled by institutions linked to the capital markets, such as Bloomberg, the source used for this study. As a result, the focus of the data is more on financial aspects and performance, such as yields, prices, and transactions, which might not be ideal for policy analysis. Detailed information about the projects being financed by green bonds would make it possible to determine whether resources are indeed being used to finance a climate sustainable project or even if the projects have mitigation potential.

Some initiatives, such as the Green Bond Transparency Platform[11] kept by the Inter-American Development Bank, are being developed to provide more comprehensive data on green bonds. However, as of today, there is no publicly available database on world-wide green bond issuances and their projects. Moreover, green bonds issued by supranational institutions, such as the World Bank and the European Union, were not considered in the present analysis. These bonds are used to finance projects in countries around the globe and there is no unique source of information about which country is receiving the funds raised and which projects are being stimulated. Future research would benefit from more complete data on green bonds.

[11] https://www.greenbondtransparency.com/

Another challenge to the analysis of green bonds is whether projects being financed through them would have been financed otherwise by other means. If so, the fact that they have been financed by green bonds would make little difference in regard to emissions. An additional investigation would need to explore this possibility making use of more comprehensive data.

There is an ongoing debate in the econometric literature about TWFE estimation and potential biases arising from heterogeneous treatment effects across time or units. Using the CSDID method, one of the recently developed approaches that handle bias related to heterogeneous effects, reveals that countries that adopted carbon pricing initiatives in 1990 had a smoother reduction in emissions than countries that adopted such initiatives in 2005. It seems plausible, therefore, to assume that the climate instruments have heterogenous effects across countries and across years, which may bias the TWFE models estimated. Nonetheless, research about methods is evolving; the debate is not settled, and there is still no general agreement on a gold standard approach to deal with the identified source of bias in TWFE models when effects are heterogeneous. Future research on carbon pricing initiatives and green bonds can benefit from the upcoming advances in the econometric literature.

6. APPENDIX

Table A.1 – Regression results, test paths of mediation

	(1) Regression of CO_2 on instruments (test path C)	(2) Regression of renewables on instruments (test path A)	(3) Regression of CO_2 on renewables (test path B)	(4) Regression of CO_2 on instruments and renewables (test paths B and C)
Carbon pricing	-0.484**	0.081**		-0.256**
	(0.044)	(0.010)		(0.058)
Green bonds	-0.172	0.009		-0.145**
	(0.125)	(0.027)		(0.061)
Carbon pricing * Green bonds	-0.191	0.053*		-0.041
	(0.132)	(0.031)		(0.071)
Renewable energy share			-3.046**	-2.835**
			(0.613)	(0.659)
Constant	2.025**	0.383**	3.188**	3.110**
	(0.036)	(0.007)	(0.233)	(0.249)
Country and year fixed effects	yes	yes	yes	yes
Observations	3,996	3,996	3,996	3,996
R^2	0.457	0.146	0.631	0.647
F	12.787	5.729	20.990	21.208

* Significant at 10%; ** Significant at 5%; *** Significant at 1%

7. REFERENCES

Abrell, J., Kosch, M., & Rausch, S. (2019). How Effective Was the UK Carbon Tax?—A Machine Learning Approach to Policy Evaluation. *Center of Economic Research at ETH Zurich*, 51.

Anderson, B., & Di Maria, C. (2011). Abatement and Allocation in the Pilot Phase of the EU ETS. *Environmental and Resource Economics*, *48*(1), 83–103. https://doi.org/10.1007/s10640-010-9399-9

Andersson, J. J. (2019). Carbon Taxes and CO2 Emissions: Sweden as a Case Study. *American Economic Journal: Economic Policy*, *11*(4), 1–30. https://doi.org/10.1257/pol.20170144

Arimura, T. H., & Abe, T. (2021). The impact of the Tokyo emissions trading scheme on office buildings: What factor contributed to the emission reduction? *Environmental Economics and Policy Studies*, *23*(3), 517–533. https://doi.org/10.1007/s10018-020-00271-w

Aydin, C., & Esen, Ö. (2018). Reducing CO2 emissions in the EU member states: Do environmental taxes work? *Journal of Environmental Planning & Management*, *61*(13), 2396–2420. https://doi.org/10.1080/09640568.2017.1395731

Baranzini, A., van den Bergh, J. C. J. M., Carattini, S., Howarth, R. B., Padilla, E., & Roca, J. (2017). Carbon pricing in climate policy: Seven reasons, complementary instruments, and political economy considerations. *WIREs Climate Change*, *8*(4), e462. https://doi.org/10.1002/wcc.462

Bayer, P., & Aklin, M. (2020). The European Union Emissions Trading System reduced CO_2 emissions despite low prices. *Proceedings of the National Academy of Sciences*, *117*(16), 8804–8812. https://doi.org/10.1073/pnas.1918128117

Bloomberg. (2022). *Bloomberg terminal and BloombergNEF*. Subscription service

Callaway, B., & Sant'Anna, P. H. C. (2021). Difference-in-Differences with multiple time periods. *Journal of Econometrics*, *225*(2), 200–230. https://doi.org/10.1016/j.jeconom.2020.12.001

Cole, M. A., & Neumayer, E. (2004). Examining the Impact of Demographic Factors on Air Pollution. *Population and Environment*, *26*(1), 5–21. https://doi.org/10.1023/B:POEN.0000039950.85422.eb

de Chaisemartin, C., & D'Haultfœuille, X. (2021). *Two-Way Fixed Effects and Differences-in-Differences with Heterogeneous Treatment Effects: A Survey* (SSRN Scholarly Paper ID 3980758). Social Science Research Network. https://doi.org/10.2139/ssrn.3980758

Dechezleprêtre, A., Nachtigall, D., & Venmans, F. (2018). *THE JOINT IMPACT OF THE EUROPEAN UNION EMISSIONS TRADING SYSTEM ON CARBON EMISSIONS AND ECONOMIC PERFORMANCE ECONOMICS DEPARTMENT WORKING PAPERS No. 1515*. 57.

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. https://doi.org/10.1016/j.eiar.2005.11.007

Fatica, S., & Panzica, R. (2021). Green bonds as a tool against climate change? *Business Strategy and the Environment*, *30*(5), 2688–2701. https://doi.org/10.1002/bse.2771

Fernando, S. (2017). *The Environmental Effectiveness of Carbon Taxes: A Comparative Case Study of the Nordic Experience*. http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-326435

Flaherty, M., Gevorkyan, A., Radpour, S., & Semmler, W. (2017). Financing climate policies through climate bonds – A three stage model and empirics. *Research in International Business and Finance*, *42*, 468–479. https://doi.org/10.1016/j.ribaf.2016.06.001

Flammer, C. (2019). *Green Bonds: Effectiveness and Implications for Public Policy* (Working Paper No. 25950; Working Paper Series). National Bureau of Economic Research. https://doi.org/10.3386/w25950

Gloaguen, O., & Alberola, E. (2013). *Assessing the factors behind CO2 emissions changes over the phases 1 and 2 of the EU ETS: an econometric analysis*. 38.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, *225*(2), 254–277. https://doi.org/10.1016/j.jeconom.2021.03.014

Hachenberg, B., & Schiereck, D. (2018). Are green bonds priced differently from conventional bonds? *Journal of Asset Management*, *19*(6), 371–383. https://doi.org/10.1057/s41260-018-0088-5

Hájek, M., Zimmermannová, J., Helman, K., & Rozenský, L. (2019). Analysis of carbon tax efficiency in energy industries of selected EU countries. *Energy Policy*, *134*, 110955. https://doi.org/10.1016/j.enpol.2019.110955

Heine, D., Semmler, W., Mazzucato, M., Braga, J. P., Flaherty, M., Gevorkyan, A., Hayde, E., & Radpour, S. (2019). Financing Low-Carbon Transitions through Carbon Pricing and Green Bonds. *Vierteljahrshefte Zur Wirtschaftsforschung*, *88*(2), 29–49. https://doi.org/10.3790/vjh.88.2.29

ICMA. (2021). *Green Bond Principles*. https://www.icmagroup.org/assets/documents/Sustainable-finance/2021-updates/Green-Bond-Principles-June-2021-140621.pdf

Jakiela, P. (2021). Simple Diagnostics for Two-Way Fixed Effects. *ArXiv:2103.13229 [Econ, q-Fin]*. http://arxiv.org/abs/2103.13229

Jaraite-Kažukauske, J., & Di Maria, C. (2016). Did the EU ETS Make a Difference? An Empirical Assessment Using Lithuanian Firm-Level Data. *The Energy Journal*, *37*(1). https://doi.org/10.5547/01956574.37.2.jjar

Larsen, B. M., & Nesbakken, R. (1997). Norwegian emissions of CO2 1987–1994: A study of some effects of the CO2 tax. *Environmental & Resource Economics*, *9*(3), 275–290. https://doi.org/10.1007/BF02441400

Liddle, B., & Lung, S. (2010). Age-structure, urbanization, and climate change in developed countries: Revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Population and Environment*, *31*(5), 317–343. https://doi.org/10.1007/s11111-010-0101-5

Lin, B., & Li, X. (2011). The effect of carbon tax on per capita CO2 emissions. *Energy Policy*, *39*(9), 5137–5146. https://doi.org/10.1016/j.enpol.2011.05.050

Maltais, A., & Nykvist, B. (2020). Understanding the role of green bonds in advancing sustainability. *Journal of Sustainable Finance & Investment*, *0*(0), 1–20. https://doi.org/10.1080/20430795.2020.1724864

Martin, G., & Saikawa, E. (2017). Effectiveness of state climate and energy policies in reducing power-sector CO2 emissions. *Nature Climate Change*, *7*(12), 912–919. https://doi.org/10.1038/s41558-017-0001-0

McGuinness, M., & Ellerman, A. D. (2008). *CO2 Abatement in the UK Power Sector: Evidence from the EU ETS Trial Period*. 18.

McKinsey Global Institute. (2022). *The net-zero transition: What it would cost, what it could bring*. https://www.mckinsey.com/business-functions/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring#

Metcalf, G. (2019). *On the economics of a carbon tax for the United States*. https://www.brookings.edu/wp-content/uploads/2019/03/On-the-Economics-of-a-Carbon-Tax-for-the-United-States.pdf

Nordhaus, W. (2019). Climate Change: The Ultimate Challenge for Economics. *American Economic Review*, *109*(6), 1991–2014. https://doi.org/10.1257/aer.109.6.1991

Petrick, S., & Wagner, U. J. (2014). *The Impact of Carbon Trading on Industry: Evidence from German Manufacturing Firms* (SSRN Scholarly Paper ID 2389800). Social Science Research Network. https://doi.org/10.2139/ssrn.2389800

Pretis, F. (2019). *Does a Carbon Tax Reduce CO2 Emissions? Evidence From British Columbia* (SSRN Scholarly Paper ID 3329512). Social Science Research Network. https://doi.org/10.2139/ssrn.3329512

Rivers, N., & Schaufele, B. (2015). Salience of carbon taxes in the gasoline market. *Journal of Environmental Economics and Management*, *74*, 23–36. https://doi.org/10.1016/j.jeem.2015.07.002

Rosa, E. A., & Dietz, T. (2012). Human drivers of national greenhouse-gas emissions. *Nature Climate Change*, *2*(8), 581–586. https://doi.org/10.1038/nclimate1506

Roth, J., Sant'Anna, P. H. C., Bilinski, A., & Poe, J. (2022). What's Trending in Difference-in-Differences? A Synthesis of the Recent Econometrics Literature. *ArXiv:2201.01194 [Econ, Stat]*. http://arxiv.org/abs/2201.01194

Saeed Meo, M., & Karim, M. Z. A. (2021). The role of green finance in reducing CO2 emissions: An empirical analysis. *Borsa Istanbul Review*. https://doi.org/10.1016/j.bir.2021.03.002

Semmler, W., Braga, J. P., Lichtenberger, A., Toure, M., & Hayde, E. (2021). *Fiscal Policies for a Low-Carbon Economy*. World Bank. https://doi.org/10.1596/35795

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975–1996: Evidence from pooled cross-country data. *Ecological Economics*, *44*(1), 29–42. https://doi.org/10.1016/S0921-8009(02)00223-9

Shmelev, S. E., & Speck, S. U. (2018). Green fiscal reform in Sweden: Econometric assessment of the carbon and energy taxation scheme. *Renewable and Sustainable Energy Reviews*, *90*, 969–981. https://doi.org/10.1016/j.rser.2018.03.032

Wagner, U., Muûls, M., Martin, R., & Colmer. (2014). *The Causal Effects of the European Union Emissions Trading Scheme: Evidence from French Manufacturing Plants*. https://conference.iza.org/conference_files/EnvEmpl2014/martin_r7617.pdf

Wakabayashi, M., & Kimura, O. (2018). The impact of the Tokyo Metropolitan Emissions Trading Scheme on reducing greenhouse gas emissions: Findings from a facility-based study. *Climate Policy*, *18*, 1–16. https://doi.org/10.1080/14693062.2018.1437018

World Bank. (2014). *Green Bonds Market Tops $20 Billion, Expands to New Issuers, Currencies & Structures, by Heike Reichelt and Alexandra Klopfer*. https://blogs.worldbank.org/climatechange/green-bonds-market-tops-20-billion-expands-new-issuers-currencies-structures

World Bank. (2015). *What are Green Bonds?* World Bank. https://doi.org/10/green-bonds

York, R., Rosa, E. A., & Dietz, T. (2003). A rift in modernity? Assessing the anthropogenic sources of global climate change with the STIRPAT model. *International Journal of Sociology and Social Policy*, *23*(10), 31–51. https://doi.org/10.1108/01443330310790291