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Title

Cross-country heterogeneity in the impact of introducing emissions trading schemes on decarbonization

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Abstract

Although many countries have introduced emissions trading schemes (ETS) as a crucial policy tool to combat climate change, little is known about how the impact of introducing ETS varies across countries. We leverage spatial-and-temporal variations in ETS introduction across countries to investigate the impact of introducing ETS on subsequent changes in their carbon intensity, absolute carbon emissions, and renewable energy share. Our analysis reveals that, on average, ETS introduction led to a reduction in carbon intensity and emissions and an increase in the renewable energy share of total final energy consumption. Interestingly, ETS introduction has a heterogeneous impact across countries. Across 150 countries, we find that, while ETS introduction is more impactful in reducing carbon intensity in countries that depend on rents from natural resources, intriguingly, ETS introduction is less impactful in improving the renewable energy share among these countries. Moreover, for the largest emitting nations, we find that distinct climate narratives influence the impact of ETS introduction. Specifically, a decarbonization narrative amplifies the impact of introducing ETS on carbon intensity reduction. In contrast, an economic growth narrative attenuates the impact of introducing ETS on reducing carbon intensity. An energy security narrative amplifies the impact of introducing ETS on the increase in renewable energy share. Our findings highlight the potential and limits of ETS, suggesting that effective climate mitigation warrants targeted approaches across countries.

Significance Statement

Emissions trading schemes (ETS) introduction reduces carbon intensity and emissions of economies by 6.62% and 3.50%, respectively. ETS introduction also increases renewable energy share by 1.55% annually. ETS introduction is more impactful in reducing carbon intensity in countries that depend on rents from natural resources. However, it is less impactful in improving these countries' renewable energy share. Among major emitting nations, ETS introduction has a greater impact on carbon intensity reduction under the presence of a decarbonization narrative, whereas the presence of an economic growth narrative in the country attenuates its impact. The presence of an energy security narrative in the country amplifies the effect of ETS introduction on the increase in renewable energy share.

Main Text

Introduction

There is a pressing need to understand how policy actions worldwide can mitigate climate change (*1-5*). A fundamental aspect of mitigating climate change is the core challenge of reducing the carbon intensity and emissions of economies globally (*6-10*). While the need to accomplish decarbonization is well documented, how to do so consistently across countries remains unclear (*11-13*). Self-regulation by businesses to voluntarily reduce their carbon emissions is usually ineffective (*14-15*). Experts argue that decarbonization requires mandatory regulatory actions (*16-17*). To this end, several governments worldwide have introduced emissions trading schemes (ETS), one of the most common environmental regulations to incentivize carbon intensity and emissions reduction (*17-21*). As a cap-and-trade regulation, ETS sets an aggregate emissions limit for firms and creates a market for emissions permits, offering the potential to reduce emissions through a new market for pollution rights.

However, relatively less is known about how country characteristics shape the impact of ETS introduction on the subsequent carbon intensity, carbon emissions, and renewable energy share of the total energy consumption in the economy. Surprisingly, except for a few studies (*22*), extant research has largely remained silent about the role of diverging climate narratives between countries. Yet, tackling climate change warrants the participation of all countries worldwide. Our investigation addresses this research gap by asking—in which countries has ETS introduction been more impactful for decarbonization goals like reducing carbon intensity and emissions, and increasing the share of renewable energy? Research on the European Union (EU) ETS has demonstrated that introducing ETS incentivized businesses to invest in cleaner technologies and reduce the carbon intensity of their production (*23*). It has been reported that ETS introduction is associated with a reduction of 3.8% of total EU-wide emissions compared to a counterfactual without the EU ETS introduction (*11*).

A distinctive aspect of our investigation is that we examine the possibility of the heterogeneous impact of introducing ETS across the world. Improving energy efficiency across all economies worldwide is one of the most cost-effective near-term strategies for mitigating climate change (*24*). Importantly, the effectiveness of an economy's policy to mitigate climate change can be influenced by its natural resource endowments. However, it remains unclear how natural resource endowments in a country may influence the impact of ETS introduction on carbon intensity, absolute carbon emissions, and renewable energy share of the total energy consumption in the economy. Additionally, we also examine heterogeneity across major emitting nations. In doing so, our analysis complements recent research on the impact of ETS introduction on absolute carbon dioxide emissions within the EU (*11*, *21*, *23*). It is well known that national-level priorities and narratives can influence resource allocation by firms as they could influence the salience of the social cost of carbon in the economic environment (*25-26*).

Another crucial point of departure of our study from extant research is that we systematically investigate the moderating role of the country's climate narratives in the relationship between ETS introduction and subsequent decarbonization outcomes. The issue concerning the moderating role of countries' climate narratives deserves attention because these narratives offer a window into the state's main priorities (*22, 27*). The normative ideas institutionalized within the state about pursuing economic growth, decarbonization, and energy security undergird distinct climate narratives (*22*, *28-29*). For ETS introduction to accomplish the decarbonization imperative, the economy needs a supportive environment that can support the functioning of an efficient carbon market with measures such as transparent carbon accounting (*30-31*). In general, the presence of a decarbonization narrative in a country is more likely to have a well-established market economy to run an efficient carbon market that can succeed in reducing the subsequent carbon intensity and emissions. Therefore, the marginal effect of introducing ETS on carbon intensity and emissions reduction is likely more substantial in countries with a decarbonization narrative.

On the other hand, the presence of an economic growth narrative may attenuate the impact of ETS introduction on decarbonization outcomes. It is now known that low prices typically characterize most ETS across countries globally (*32*), which makes it plausible that the impact of ETS introduction arises not from the direct incentive it provides for mitigation via the efficiency of the carbon market but from the ETS's introduction serving as a credible policy signal (*11, 25-26*). When considering the signaling mechanism's perspective, one would expect that the marginal effect of introducing ETS on subsequent decarbonization outcomes is likely weaker under the presence of an economic growth narrative than under the absence of an economic growth narrative. In addition to the heterogeneity across countries in the presence of economic growth and decarbonization narratives, the differences across countries in the presence of energy security narrative may further shape the impact of ETS introduction on decarbonization outcomes such as the increase in renewable energy share of the total energy consumption in the economy. It is plausible that the presence or absence of an energy security narrative in a country may influence the impact of ETS introduction by stimulating or discouraging efforts to improve renewable energy share by improving the supply chain efficiency in the economy (*11*, *25-29*).

Therefore, a crucial empirical question is how the variation across countries' dependence on rents from natural resources and in the presence versus absence of narratives focusing on economic growth, decarbonization, and energy security may influence the relative impact of ETS introduction. We aim to investigate the conditions under which introducing ETS may be associated with a more versus less substantial reduction in carbon intensity and emissions and a more versus less substantial increase in the renewable energy share of the total energy consumption of the economies globally.

Results

We obtain country-level panel data from the publicly available World Bank database, which sources information on each country's carbon dioxide emissions from the World Resources Institute (Table S1 lists the data sources for all variables). We obtained these data on 150 countries annually from 2005-2018 (Table S2 shows the list of countries in our sample). Among these 150 countries, the largest 20 nations by carbon emissions include Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Iran, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and Vietnam (see Table S2; Korea refers to Korea, Republic, i.e., South Korea).

Our primary interest lies in estimating the effect of ETS introduction in a country on the subsequent carbon intensity, absolute carbon emissions, and renewable energy share of the total energy consumption in the economy. The main outcome variable of interest is *Carbon Intensity*, which measures the carbon dioxide emissions in kg per PPP $ of GDP at the country-year level. Specifically, we obtained these data from the World Bank database (see Table S1), which they sourced from the World Resources Institute. The mean carbon intensity is 0.24 kg per PPP $ (Table S3 shows the descriptive statistics of the key variables; Figure S1A shows the distribution of carbon intensity of economies).

The second outcome variable of interest is *Carbon Emissions*, which measures the carbon dioxide emissions in kilotons at the country-year level (we log-transform this variable to reduce the skewness). The mean carbon emissions (log) is 9.81 (Table S3 shows the descriptive statistics; Figure S1B shows the distribution of carbon emissions). The third outcome variable of interest is *Renewable Energy Share*, which measures the renewable energy consumed as a percentage of the total final energy consumed at the country-year level. We obtained panel data on renewable energy share from the Sustainable Energy for All database, which the World Bank, International Energy Agency, and the Energy Sector Management Assistance Program jointly lead. The mean renewable energy share is 33.85 percent (Table S3 shows the descriptive statistics; Figure S1C shows the distribution of renewable energy share).

The main independent variable of interest is *Post ETS*, a time-varying indicator equal to one if the focal country has introduced an emissions trading scheme by the focal year and zero otherwise. To test the moderating role of a country's natural resource rents, we use its *Natural Resource Rents*, which measures total natural resources' rents (in % of GDP) as the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents (see Table S1). To test the moderating role of the climate narratives in the impact of ETS introduction on decarbonization outcomes, we follow recent research and classify the largest 20 emitting nations by the presence versus absence of economic growth, decarbonization, and energy security narratives in the focal country (*22*). We construct three country-specific indicators, *Economic Growth Narrative*, *Decarbonization Narrative*, and *Energy Security Narrative*, which are set to one if the country has an economic growth narrative, a decarbonization narrative, and an energy security narrative, respectively, and zero otherwise.

Panel data allows our analysis to control for unobserved time-invariant country-specific effects that can affect both the ETS introduction and the outcome variables. Our analysis benefits from the insights of recent climate change research (*9-12, 33-34*) and controls for the effects of relevant characteristics such as population, foreign domestic investment (FDI), the presence of carbon tax scheme (CTS), and climatological disasters (the Materials and Methods section document the details).

Descriptive trends in the carbon intensity of countries

The average carbon intensity of countries decreased by one-third, from 0.3 kg per PPP $ of GDP in 2005 to 0.2 kg per PPP $ of GDP in 2018. Beyond the average decrease in carbon intensity, we observe considerable heterogeneity across countries: 80% of 150 countries reduced their carbon intensity during 2005-2018 (Figure S2A shows the heterogeneity in annual trends for countries where carbon intensity has reduced, e.g., Uzbekistan, Ukraine, Russia, Estonia, China, Bulgaria, Poland; Figure S2B shows the annual trends for countries where carbon intensity has increased, e.g., Lao, Oman, Iraq, Kuwait, Iran, Algeria, Saudi Arabia). Although these descriptive patterns are striking, they cannot reveal whether carbon intensity reduction can be attributed to the introduction of ETS or the changes in other macroeconomic variables (e.g., FDI, access to electricity, forest area). To test this question systematically, we investigate whether introducing ETS is associated with a subsequent reduction in the country's carbon intensity in a regression analysis framework. Specifically, we employ the fixed-effects research design by leveraging the staggered introduction of ETS across countries (see the Materials and Methods section for detailed documentation of the empirical approach). In our regression models, the unit of analysis is country-year, and the standard errors are clustered at the country level for appropriate statistical inference (*35*).

Impact of ETS introduction on carbon intensity, emissions, and renewable energy

Columns 1-3 of Table 1 estimate the effect of introducing ETS on carbon intensity, carbon emissions, and renewable energy share, respectively, while including country-fixed and year-fixed effects but without control variables. Columns 4 and 5 estimate the effect of introducing ETS on carbon intensity while including country-fixed and year-fixed effects along with other control variables but without and with the inclusion of GDP as a covariate. Columns 6 and 7 estimate the effect of introducing ETS on carbon emissions and renewable energy share while including country-fixed and year-fixed effects and all other control variables.

[Insert Table 1 here]

We interpret the results of the fully saturated models, i.e., Columns 5-7 of Table 1. The coefficient of -0.037 ($p = 0.011$) in Column 5 suggests that the carbon intensity reduces by 0.037 kg (per PPP $ of GDP) post- relative to pre-ETS. It implies that ETS introduction is associated with a carbon intensity reduction of 15.9%, which is economically material, as the average carbon intensity in our sample is 0.23 kg (per PPP $ of GDP). This interpretation remains qualitatively similar in Column 4 when we exclude GDP as a covariate. Thus, these results suggest that ETS introduction in an economy is associated with a subsequent reduction in the economy's carbon intensity. One can rule out the potential concern that the inclusion or exclusion of GDP as a covariate could be driving the observed effects of ETS introduction on subsequent reduction in carbon intensity. One can also rule out the potential concern that outliers may be driving these results because the inference remains similar when we use the median regression model instead of the ordinary least squares (OLS) regression model (*36*). In addition, we observe that the association between CTS and carbon intensity is statistically indistinguishable from zero ($p = 0.306$ in Column 4; $p = 0.317$ in Column 5). Thus, these findings suggest that, unlike the introduction of ETS, the introduction of CTS in an economy is not associated with a subsequent reduction in the carbon intensity of the economy.

The coefficient of -0.184 ($p = 0.000$) in Column 6 of Table 1 suggests that the absolute carbon emissions show a reduction of 16.7% post- relative to pre-ETS. The coefficient of 3.464 ($p = 0.000$) in Column 7 suggests that the renewable energy share shows an increase of 3.464 percentage points post- relative to pre-ETS. It implies that introducing ETS is associated with a renewable energy share increase of 10.2%, which is economically material, as the mean value of renewable energy share in our sample is 33.75% of the total energy consumption. Thus, these results suggest that ETS introduction in an economy is associated with a subsequent reduction in not only the economy's carbon intensity but also its absolute carbon emissions. ETS introduction is also associated with an increase in the renewable energy share of the total energy consumption in the economy.

Heterogeneity across countries in the impact of ETS introduction

We next explore the heterogeneity across countries in the impact of ETS introduction. To examine how the heterogeneity across the 150 countries in natural resource rents may influence the relative impact of ETS introduction, we interact the variable *Post ETS* with a focal country's natural resource rents. Column 1 of Table 2 shows a large and negative coefficient of *Post ETS* × *Natural Resource Rents* that is statistically distinguishable from zero (β = -0.007, p = 0.003), implying that ETS introduction is more impactful in reducing carbon intensity among countries that are more dependent on natural resource rents. In contrast, the large and negative coefficient of *Post ETS* × *Natural Resource Rents* that is statistically distinguishable from zero (β = -0.401, p = 0.001) in Column 3 implies that that ETS introduction is less impactful in increasing the share of renewable energy share among countries that are more dependent on natural resource rents. Figure 1 shows the average marginal effects of introducing ETS on carbon intensity, emissions, and renewable energy share from the fully flexible kernel-smoothing estimator, as recommended by recent research to guard against any misspecification bias (*37*). The kernel-smoothing estimator does not require the linear interaction effect assumption. It estimates a series of local effects with a kernel-reweighting scheme by selecting bandwidths using a standard 5-fold cross-validation procedure. The results in Figure 1A show that the marginal effects of introducing ETS on the carbon intensity reduction are stronger for countries with greater dependence on natural resource rents. In contrast, Figure 1C reveals that the marginal effects of introducing ETS on the renewable energy share increase are weaker for countries with greater dependence on natural resource rents.

[Insert Figure 1 and Table 2 here]

We also explore the effect of ETS introduction on the subsample of 20 major emitting nations. Figure S3 shows a comparison of the effect sizes of ETS introduction observed for 20 major emitting nations compared to all 150 countries. More importantly, we examine how the heterogeneity across the largest 20 emitters in the absence versus presence of economic growth, decarbonization, and energy security narratives may influence the relative impact of ETS introduction. To do so, we interact the variable *Post ETS* with the presence of economic growth, decarbonization, and energy security narratives, respectively, in the focal country. Column 1 of Table S4 show a large and positive coefficient of *Post ETS* × *Economic Growth Narrative* that is statistically distinguishable from zero (β = 0.132, p = 0.000), implying that the effect of introducing ETS on subsequent carbon intensity reduction weakens substantially under the presence of economic growth narrative in the country (also see Figure S4A for average marginal effect). In contrast, the large and negative coefficient of *Post ETS* × *Decarbonization Narrative* that is statistically distinguishable from zero (β = -0.034, p = 0.006) in Column 1 implies that the effect of introducing ETS on subsequent carbon intensity reduction amplifies under the presence of decarbonization narrative in the country. Column 2 of Table S4 suggests that there is no moderating influence of the three narratives in the impact of ETS introduction on the change in absolute carbon emissions in the country (this could be because we these regression analyses are estimated on the largest emitters of carbon dioxide). Column 3 shows a large and positive coefficient of *Post ETS* × *Energy Security Narrative* that is statistically distinguishable from zero (β = 3.750, p = 0.044), implying that the effect of introducing ETS on the subsequent increase in the renewable energy share strengthens substantially under the presence of energy security narrative in the country (also see Figure S4C for average marginal effect).

Dynamic treatment effects of ETS introduction

To address potential concerns about the validity of estimated coefficients in settings with staggered treatments, we also present our results from analyses incorporating new methodological advances that avoid the problem that cohorts can be negatively weighted in the pooled cohort two-way fixed-effect estimators (*38*-*41*). Figures 2-4 show the results for the three outcomes of interest (carbon intensity, carbon emissions, renewable energy share) from this new method that identifies average treatment effects on treated units in staggered treatment designs by comparing treated units to never treated units (*38*). We employ the doubly robust DID estimator (*42*), which is based on the inverse probability of tilting and weighted least squares. We cluster standard errors at the country level for correct statistical inference using the wild bootstrapped procedure (100 replications).

[Insert Figures 2-4 here]

Figure 2A presents the event study estimates showing dynamic treatment effects of introducing ETS in a narrow time window of a few years *before* and *after* the introduction of ETS. A narrow time window around the event of interest facilitates causal identification because of a greater likelihood of meeting the assumption that unobserved conditions would likely have remained similar in the absence of the event under investigation (*43*-*44*). These event study estimates provide two valuable insights. First, there is no evidence of diverging pre-trends prior to the introduction of ETS. Second, there is clear evidence of a carbon intensity reduction following ETS's introduction. Specifically, carbon intensity shows a reduction of 0.069 kg per PPP dollar of GDP ($p = 0.000$, 95CI [-0.103, -0.033]) within five years of the introduction of ETS, which implies a carbon intensity reduction of 29 percent, i.e., an annual reduction rate of 6.62%. When we compute event study estimates based on the entire observation period (see Figure 2B), we find that the introduction of ETS is associated with a carbon intensity reduction of 0.115 kg per PPP dollar of GDP ($p = 0.000$, 95CI [-0.171, -0.060]). We also conducted an additional analysis to estimate the dynamic treatment effects of carbon tax introduction on carbon intensity. In contrast to introducing ETS, we find no evidence of a substantial reduction in the economy's carbon intensity after introducing a carbon tax.

Relatedly, Figure 3A presents the event study estimates showing the dynamic treatment effects of introducing ETS on carbon emissions in a narrow time window. The results show carbon emissions reduction following ETS's introduction. Specifically, carbon emissions reduce by 16.36 percent ($p = 0.000$, 95CI [-0.214, -0.143]) within five years of ETS's introduction, implying an annual reduction rate of 3.5%. When we compute event study estimates based on the entire observation period (see Figure 3B), we find that ETS introduction is associated with carbon emissions reduction of 32.7 percent, which implies an annual reduction rate of 3%.

Finally, Figure 4A presents the event study estimates showing the dynamic treatment effects of introducing ETS on renewable energy share in a narrow time window. The results reveal an increase in renewable energy share following ETS's introduction. Specifically, renewable energy share shows an increase of 2.73 percentage points (p =

0.000, 95CI [1.729, 3.724]) within five years of ETS' introduction, implying an increase of 8 percent, i.e., an annual rate of increase of 1.55%. When we compute event study estimates based on the entire observation period (see Figure 4B), we find that the introduction of ETS is associated with a renewable energy share increase of 17.8 percent, which implies an annual rate of increase of 1.27%.

Introducing ETS did not have a discernable impact on economic productivity

In an additional analysis, we also investigate whether the introduction of ETS may have led to any changes in the economy's productivity. The relationship between environmental regulations and economic productivity has been a topic of intense debate with competing arguments. The idea that climate change affects economic productivity is not new (*45-46*). However, whether introducing ETS can influence economic productivity remains debatable. On the one hand, introducing ETS may increase the economy's productivity because environmental regulations can spur innovation and boost technological progress (*47-48*). On the other hand, ETS introduction may decrease the economy's productivity because the compliance and opportunity costs associated with such an environmental regulation may create distortions in the economy (*49*). For example, introducing ETS may encourage low-carbon innovation that can crowd out the subsequent development of other technologies in the economy (*50*).

The regression analysis (see Table S5) reveals that introducing ETS is not associated with any substantial change in the real total factor productivity ($\beta = 0.007$, $p = 0.726$, 95CI [-0.031, 0.044]). We also compute the event study estimates of introducing ETS on real TFP in a narrow time window. These event study estimates provide two useful insights (see Figure S5A). First, there is no evidence of diverging pre-trends in real TFP prior to the introduction of ETS. Second, there is no evidence of any material change in real TFP following ETS's introduction ($\beta = 0.003$, $p = 0.796$, 95CI [-0.022, 0.029]). When we compute event study estimates based on the entire observation period (see Figure S5B), we again find that the change in real TFP following the introduction of ETS is statistically indistinguishable from zero ($\beta = 0.007$, $p = 0.766$, 95CI [-0.044, 0.061]).

Discussion

How much did the introduction of ETS reduce the carbon intensity and emissions of economies globally? In which countries was introducing ETS more impactful? These pressing questions are of fundamental importance for policymakers and scholars seeking to understand the benefits and limitations of introducing climate mitigation tools like ETS. Our analysis sheds light on these questions by leveraging the spatial-and-temporal variation in introducing ETS across countries. We find a significant reduction in average carbon intensity and emissions and a material increase in renewable energy share following the introduction of ETS. Intriguingly, while ETS introduction is more impactful in reducing carbon intensity in countries that depend on rents from natural resources, it is less impactful in improving the share of renewable energy in these countries. Moreover, for the 20 major emitting nations, the impact of introducing ETS on carbon intensity reduction is more substantial when there is a decarbonization narrative in the country. In contrast, the relationship disappears under the presence of an economic growth narrative. We further find that the presence of the energy security narrative amplifies the impact of ETS introduction on the subsequent increase in renewable energy share among these countries. Thus, our study advances the understanding of the heterogeneity across countries in the relative impact of introducing ETS on subsequent decarbonization efforts.

Our study makes three noteworthy contributions to understanding the varied impact of introducing ETS, which is emerging as one of the most crucial policy instruments for climate mitigation (*14-20*). First, our findings show that ETS introduction, on average, can facilitate countries' transition to accomplish their decarbonization imperatives. Our investigation brings forward evidence supporting the idea that, rather than taxation, introducing emissions trading schemes may lead to a more significant reduction in the carbon intensity and carbon emissions of economies because it can better deal with environmental externalities by spurring innovation toward greater renewable energy adoption.

Importantly, by investigating how the heterogeneity in natural resource rents across the world and the presence versus absence of economic growth, decarbonization, and energy security narratives in the major emitting nations influences the effectiveness of introducing ETS, our study underscores the importance of the moderating role of natural resource endowments and distinct climate narratives. While natural resource rents have a socially desirable effect by amplifying the impact of introducing ETS on carbon intensity reduction, they also seem to have an undesirable effect by attenuating the impact of ETS on renewable energy share increase. Moreover, the marginal effect of introducing ETS on carbon intensity reduction is stronger under the presence of a decarbonization narrative but weaker under the presence of an economic growth narrative. The marginal effect of introducing ETS on renewable energy share increase is stronger under the presence of an energy security narrative. Our study thus shows that ETS introduction can be a credible policy signal to accomplish the decarbonization imperative on average, but its impact across countries is heterogeneous as it is shaped by a country's economic dependence on natural resources and the presence of distinct climate narratives across countries. The broader implication is that climate mitigation needs tailored approaches across the world.

Finally, our findings inform the contemporary debates about the impact of climate-change mitigating regulations. A popular view is that climate-change-mitigating regulations may not only reduce the economy's carbon intensity and emissions but also increase the economy's productivity. For example, industry reports often conclude that energy efficiency investments offer a win-win opportunity; that is, by reducing the energy consumption required to achieve a given level of energy services, businesses can contribute to decreasing the emissions causing climate change and the energy savings in the process can increase economic productivity by reducing costs. Surprisingly this popular narrative is backed by little empirical evidence (*1-5*, *14*, *25-26*). Strikingly, our investigation reveals that ETS introduction may not change countries' economic productivity.

There are limitations to our study, which offer meaningful opportunities for future research. Given the lack of availability of fine-grained cross-country data at the level of business sectors, our analysis cannot tell how much of the effect of introducing ETS on subsequent carbon intensity and emissions reduction can be attributed to the direct impact on the regulated sectors and the indirect impact on the non-regulated sectors. Admittedly, the analysis presented in this study represents an important first step. More research on specific business sectors and heterogeneity across countries in their emissions trading schemes are needed for definitive answers. When such cross-country sector-level data become available, it will be fruitful to pin down the effect of direct and indirect channels. While examining the impact of ETS introduction, one may wonder why renewable energy share would be an outcome variable, whereas natural resource rents would be a moderator variable. Figure S6 sheds light on this question. The event study estimates reveal that ETS introduction increases the subsequent renewable energy share (Figure S6A), but neither increases nor decreases the natural resource rents (Figure S6B).

Although we leverage spatial-and-temporal variation in the introduction of ETS, one may wonder about the extent to which such policies are plausibly exogenous. Regulations are typically an outcome of intense deliberations among several constituents of the economy. One may conjecture that countries that are already going to succeed in reducing carbon intensity are the ones that come up with ETS. However, the lack of diverging pre-trends in carbon intensity between the treatment and control units reasonably rules out this possibility. Another potential alternative explanation is that more productive economies can afford to introduce ETS. Therefore, it may not be the specific policy signal per se but the ex-ante productivity of such economies that drives carbon intensity and emissions reduction. However, one can rule out this alternative explanation because we do not observe any diverging pre-trends in the real total factor productivity of economies that introduced ETS versus those that did not. Nonetheless, it will be fruitful for future research to randomly assign firms to such regulations and then examine firm behavior. We hope our findings will encourage more studies to advance knowledge of the conditions under which regulations such as ETS can more versus less substantially help mitigate the challenges climate change poses to society.

Materials and Methods

Data and variables

To analyze the effect of introducing ETS on the subsequent change in economies' carbon intensity, carbon emissions, and renewable energy share of the total energy consumption, we merge several databases for our analyses. The primary data set of this study comprises country-level panel data obtained from the publicly available World Bank database, which sources information on each country's carbon dioxide emissions from the World Resources Institute (Table S1 lists the specific data sources for all variables along with the respective URLs). We were able to obtain these data on 150 countries from 2005-2018 (Table S2 shows the list of countries). These countries include the largest 20 countries (in alphabetical order) by carbon dioxide emissions: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Iran, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and Vietnam.

Our primary interest lies in estimating the effect of ETS's introduction on the carbon intensity of economies. The main outcome variable of interest is *Carbon Intensity*, which measures the carbon dioxide emissions in kg per PPP $ of GDP at the country-year level. Carbon dioxide emissions stem from burning fossil fuels, including carbon dioxide produced during the consumption of solid, liquid, and gas fuels. The mean carbon intensity is 0.24 kg per PPP $ (Table S3 shows the descriptive statistics; Figure S1A shows the distribution of carbon intensity). Another outcome variable of interest is *Carbon Emissions*, which measures the carbon dioxide emissions in kilotons at the country-year level (we log-transform this variable to reduce the skewness; Figure S1B shows the distribution). The third outcome variable of interest is *Renewable Energy Share*, which measures the renewable energy consumed as a percentage of the total final energy consumed at the country-year level.

We obtained information on the introduction of ETS from the publicly available World Bank Carbon Pricing database (see Table S1). The main independent variable is *Post ETS*, a time-varying indicator equal to one if the country has introduced an emissions trading scheme by the given year and zero otherwise. To test the moderating role of a country's natural resource rents, we use its *Natural Resource Rents*, which measures total natural resources' rents (in % of GDP) as the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents (see Table S1). To test the moderating role of the climate narratives in the impact of ETS introduction on decarbonization outcomes, we classify the largest 20 emitting nations by the presence versus absence of economic growth, decarbonization, and energy security narratives in the focal country (*22*). We construct three country-specific indicators, *Economic Growth*

Narrative, *Decarbonization Narrative*, and *Energy Security Narrative*, which are set to one if the country has an economic growth narrative, a decarbonization narrative, and an energy security narrative, respectively, and zero otherwise.

The advantage of panel data enables our analysis to control for unobserved time-invariant country-specific effects that can affect both the independent and the dependent variables. To this end, we construct *Country* as a categorical variable with 150 levels, each referring to a particular country. Our analysis is also able to control for unobserved time-varying common shocks (e.g., the global financial crisis). We construct *Year* as a categorical variable with 14 levels for each year from 2005 to 2018. Given that country-and-year varying characteristics can influence both the independent and dependent variables under investigation, we benefit from the insights of climate change research (*9-12, 33-34*) and control for the effects of relevant country-and-year varying characteristics, including population, climatological disasters, FDI, access to electricity, forest area, land area, agricultural land, and GDP. Following prior research (*11*), we also control for *CTS*, a binary indicator equal to one if the focal country had introduced a carbon tax scheme by the given year and zero otherwise.

Statistical analysis

We used Stata v.17 to conduct the empirical analyses reported in this paper. All statistics employed two-tailed tests to enable conservative statistical inference.

To examine the effect of introducing ETS on the subsequent change in the three outcomes of interest, we estimate the following fixed-effects regressions using the ordinary least squares (OLS) model, where the outcome variables are *Carbon Intensity*, *Carbon Emissions,* and *Renewable Energy Share*, respectively, and the key independent variable is *Post ETS*:

$$Outcome_{i,t+1} = \alpha + \beta_1 Post\ ETS_{i,t} + \beta_x X_{i,t} + \sigma_i + \tau_t + \varepsilon_{i,t}\ , \qquad (1)$$

In this equation, the unit of analysis is country-year. We control for country-and-year varying characteristics that may confound the effect of introducing ETS. For example, technological change unrelated to the ETS introduction may reduce the carbon intensity of economies. Controlling for the effect of FDI reduces this concern because technological change can be imported via FDI. Following recent research on climate change (*12, 46*), we also include country-fixed effects and year-fixed effects in estimation equation (1) to account for unobserved country characteristics and time-varying common shocks. The inclusion of country-fixed effects is helpful because it accounts for the time-invariant country-specific heterogeneity, such as regional culture, while year-fixed effects account for the effect of shocks, such as the global financial crisis (*10*). As the ETS introduction varies at the country level, we adjust for serial correlation within each country by clustering standard errors at the country level for correct statistical inference (*35*).

The main coefficient of interest is β_1. It estimates whether the introduction of ETS led to a reduction in the subsequent carbon intensity of the country. If introducing ETS did not reduce carbon intensity, then β_1 should be statistically indistinguishable from zero. In contrast, if introducing ETS reduced carbon intensity, then we should expect to find $\beta_1 < 0$. To rule out the potential concern that the inclusion or exclusion of GDP as a covariate may drive the results, we test whether the observed association between ETS introduction and subsequent carbon intensity reduction is robust to the estimation equation including or excluding the GDP covariate. Following recent research (*11*), we also ensure that the observed effect of ETS introduction on subsequent carbon intensity remains robust to including GDP and GDP^2 or log(GDP) and $\log(GDP)^2$. We can also rule out the concern that outliers may drive the results because the results remain qualitatively similar when we use the median regression model instead of the OLS regression model (*36*).

To investigate the possibility of a moderating role of the natural resource rents among 150 countries, we subsequently interact the variable *Post ETS* with the economy's natural resource rents. To examine the possibility of a moderating role of the climate narratives among the major emitters, we subsequently interact the variable *Post ETS* with the presence versus absence of economic growth, decarbonization, and energy security narratives in the focal country.

To examine the dynamic treatment effects of introducing ETS on subsequent carbon intensity, carbon emissions, and renewable energy share of the total energy consumption in the economy, we also present the results using a new method to address potential concerns about the validity of coefficients in settings with staggered treatments (*38*). This new methodological advancement avoids the problem that cohorts can be negatively weighted in the pooled cohort two-way fixed-effect estimators (*39-41*). Specifically, this method identifies average treatment effects on treated units in staggered treatment designs by comparing the change in the carbon intensity of treated units to never treated ones (i.e., by comparing countries that introduced ETS to countries that never introduced ETS in our setting). The "already treated" units that can cause problems in the two-way fixed effect estimations are not used as controls in this method. We employ the doubly robust DID estimator based on the inverse probability of tilting and weighted least squares (*42*), and we cluster standard errors at the country level using the wild bootstrapped procedure (using 100 replications) for correct statistical inference (*35-36*).

We also investigated whether introducing ETS may have led to any changes in the economy's productivity. This analysis uses the same estimation equation (1) with the only difference that the outcome variable of interest now is the real total factor productivity of the economy in place of the carbon intensity of the economy. We obtain the data on the real total factor productivity of economies from the Penn World Table 10.0, which provides a cross-country dataset that includes a measure of real total factor productivity.

Competing Interest Statement: Authors declare that they have no competing interests.

Author Contributions:

Conceptualization: AA, SA, SN
Methodology: AA, SA
Investigation: AA, SA, SN
Visualization: AA
Supervision: AA, SA, SN
Writing—original draft: AA
Writing—review & editing: AA, SA, SN

References

1. Anderegg, W.R., Prall, J.W., Harold, J., & Schneider, S.H. Expert credibility in climate change. *Proceedings of the National Academy of Sciences*, **107**(27), 12107-12109 (2010).
2. Diffenbaugh, N.S., & Burke, M. Global warming has increased global economic inequality. *Proceedings of the National Academy of Sciences* **116**(20), 9808-9813 (2019).
3. Perrault, A.M., & Giraud, G. Trickle-down climate risk regulation. *Science* **377**(6610), 1021-1021 (2022).
4. Meckling, J., Kelsey, N., Biber, E. & Zysman, J. Winning coalitions for climate policy. *Science* **349**(6253), 1170-1171 (2015).
5. Chancel, L. Global carbon inequality over 1990–2019. *Nature Sustainability* **5**(11), 931-938 (2022).
6. Masnadi, M.S., El-Houjeiri, H.M., Schunack, D., Li, Y., Englander, J.G., Badahdah, A., Monfort, J.C., Anderson, J.E., Wallington, T.J., Bergerson, J.A., & Gordon, D. Global carbon intensity of crude oil production. *Science* **361**(6405), 851-853 (2018).
7. Chakravarty, S., Chikkatur, A., De Coninck, H., Pacala, S., Socolow, R., & Tavoni, M. Sharing global CO2 emission reductions among one billion high emitters. *Proceedings of the National Academy of Sciences* **106**(29), 11884-11888 (2009).
8. Eskander, S.M., & Fankhauser, S. Reduction in greenhouse gas emissions from national climate legislation. *Nature Climate Change* **10**(8), 750-756 (2020).
9. Bruckner, B., Hubacek, K., Shan, Y., Zhong, H., & Feng, K. Impacts of poverty alleviation on national and global carbon emissions. *Nature Sustainability* **5**(4), 311-320 (2022).

10. Peters, G.P., Marland, G., Le Quéré, C., Boden, T., Canadell, J.G., & Raupach, M.R. Rapid growth in CO2 emissions after the 2008–2009 global financial crisis. *Nature Climate Change* **2**(1), 2-4 (2012).
11. Bayer, P., & Aklin, M. The European Union emissions trading system reduced CO2 emissions despite low prices. *Proceedings of the National Academy of Sciences* **117**(16), 8804-8812 (2020).
12. Jorgenson, A.K. Economic development and the carbon intensity of human well-being. *Nature Climate Change* **4**(3), 186-189 (2014).
13. Jing, L., El-Houjeiri, H.M., Monfort, J.C., Brandt, A.R., Masnadi, M.S., Gordon, D., & Bergerson, J.A. Carbon intensity of global crude oil refining and mitigation potential. *Nature Climate Change* **10**(6), 526-532 (2020).
14. Lenox, M., & Duff, R. *The decarbonization imperative: transforming the global economy by 2050*. Stanford Business Books: Stanford, CA (2021).
15. Farrell, J. Corporate funding and ideological polarization about climate change. *Proceedings of the National Academy of Sciences* **113**(1), 92-97 (2016).
16. Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, H.J. A roadmap for rapid decarbonization. *Science* **355**(6331), 1269-1271 (2017).
17. Linsenmeier, M., Mohommad, A. & Schwerhoff, G. Policy sequencing towards carbon pricing among the world's largest emitters. *Nature Climate Change* **12**, 1107-1110 (2022).
18. Dargusch, P. China must lead on emissions trading. *Science* **357**(6356), 1106-1107 (2017).
19. Rabe, B.G. *Can we price carbon?* MIT Press: Cambridge, MA (2018).
20. World Bank. *State and trends of carbon pricing*. Washington, DC (2022).
21. Dechezleprêtre, A., Nachtigall, D., & Venmans, F.. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *Journal of Environmental Economics and Management*, **118,** p.102758 (2023).
22. Guy, J., Shears, E., & Meckling, J. National models of climate governance among major emitters. *Nature Climate Change* **13**, 189-195 (2023).
23. Martin, R., Muuls, M., & Wagner, U.J. The impact of the European Union emissions trading scheme on regulated firms: What is the evidence after ten years? *Review of Environmental Economics and Policy* **10**, 129-148 (2016).
24. Patrinos, A.A., & Bradley, R.A. Energy and technology policies for managing carbon risk. *Science* **325**(5943), 949-950 (2009).
25. Nordhaus, W. Revisiting the social cost of carbon. Projections and uncertainties about climate change in an era of minimal climate policies. *Proceedings of the National Academy of Sciences* **114**, 1518-1523 (2017).
26. Aldy, J.E., Kotchen, M.J., Stavins, R.N., & Stock, J.H. Keep climate policy focused on the social cost of carbon. *Science* **373**(6557), 850-852 (2021).
27. Jones, M. D., & McBeth, M. K. A narrative policy framework: Clear enough to be wrong? *Policy Studies Journal* **38**, 329–353 (2010).
28. Dubash, N. K. The politics of climate change in India: narratives of equity and cobenefits. *WIREs Climate Change* **4**, 191–201 (2013).
29. Hall, P. The role of interests, institutions, and ideas in the comparative political economy of the industrialized nations. In *Comparative Politics: Rationality, Culture, and Structure* (eds. Lichbach, M. I. & Zuckerman, A. S.) Cambridge University Press (1997).
30. Friedland, A.J., & Gillingham, K.T. Carbon accounting a tricky business. *Science* **327**(5964), 411-412 (2010).
31. Stechemesser, K., & Guenther, E. Carbon accounting: a systematic literature review. *Journal of Cleaner Production* **36**, 17-38 (2012).
32. Newell, R.G., Pizer, W.A., & Raimi, D. Carbon market lessons and global policy outlook. *Science* **343**(6177), 1316-1317 (2014).

33. Le Quéré, C., Korsbakken, J.I., Wilson, C., Tosun, J., Andrew, R., Andres, R.J., Canadell, J.G., Jordan, A., Peters, G.P., & van Vuuren, D.P. Drivers of declining CO2 emissions in 18 developed economies. *Nature Climate Change* **9**(3), 213-217 (2019).
34. Fankhauser, S. Adaptation to climate change. *Annual Review of Resource Economics* **9**(1), 209-230 (2017).
35. Cameron, A.C., & Miller, D.L. A practitioner's guide to cluster-robust inference. *Journal of Human Resources* **50**(2), 317-372 (2015).
36. Cameron, A.C., & Trivedi, P.K. *Microeconometrics using Stata*. Second Edition. College Station, TX: Stata Press (2022).
37. Hainmueller, J., Mummolo, J., & Xu, Y. How much should we trust estimates from multiplicative interaction models? Simple tools to improve empirical practice. *Political Analysis* **27**(2), 163-192 (2019).
38. Callaway, B., & Sant'Anna P.H. Difference-in-differences with multiple time periods. *Journal of Econometrics* **225**(2), 200-230 (2021).
39. De Chaisemartin, C., & d'Haultfoeuille, X. Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review* **110**(9), 2964-2996 (2020).
40. Goodman-Bacon, A. Difference-in-differences with variation in treatment timing. *Journal of Econometrics* **225**(2), 254-277 (2021).
41. Sun, L., & Abraham, S. Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics* **225**(2), 175-199 (2021).
42. Sant'Anna PH, Zhao J. Doubly robust difference-in-differences estimators. *Journal of Econometrics* **219**(1):101-122 (2020).
43. Angrist, J.D., & Pischke J.S. *Mostly harmless econometrics: An empiricist's companion*. NJ: Princeton University Press (2009).
44. Dunning, T. *Natural experiments in the social sciences: a design-based approach*. UK: Cambridge University Press (2012).
45. Dell, M., Jones, B.F., & Olken, B.A. What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature* **52**(3), 740–98 (2014).
46. Dell, M., Jones, B.F., & Olken, B.A. Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics* **4**(3), 66-95 (2012).
47. Calel, R., & Dechezleprêtre, A. Environmental policy and directed technological change: evidence from the European carbon market. *Review of Economics and Statistics* **98**(1), 173-191 (2016).
48. Porter, M., & Van der Linde, C. Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives* **9**(4), 97-118 (1995).
49. Fowlie, M., Reguant, M., & Ryan, S.P. Market-based emissions regulation and industry dynamics. *Journal of Political Economy* **124**(1), 249-302 (2016).
50. Dechezleprêtre, A., & Sato, M. The impacts of environmental policies on competitiveness. *Review of Environmental Economics and Policy* **11**(2), 183–206 (2017).

Data and materials availability: All data are publicly available from the sources documented in the Supplementary Material (see Table S1). The code used to generate all the results in this paper are available as Stata do files, which can be obtained from the corresponding author on reasonable request.

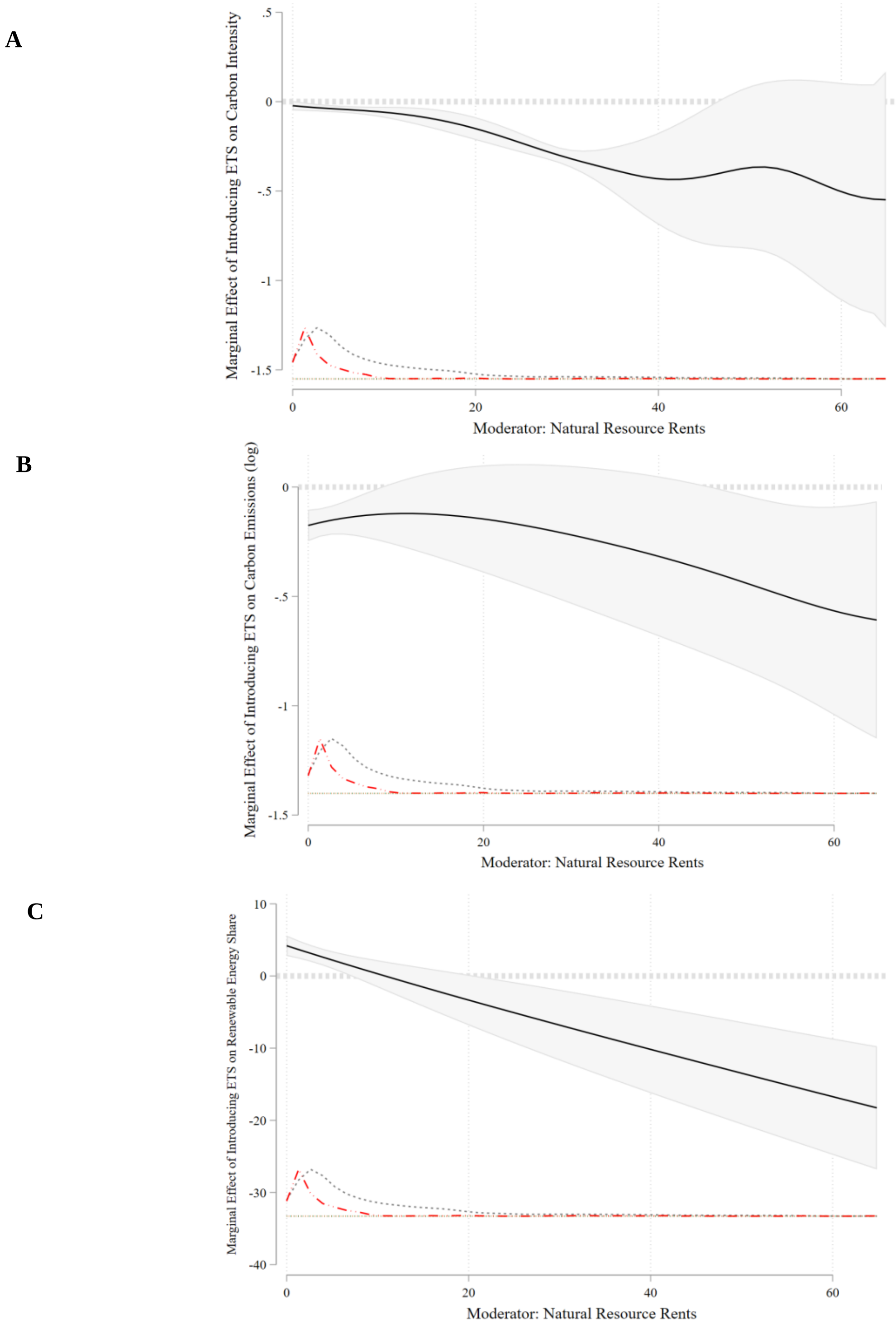

Figure 1. Average marginal effects of introducing ETS with varying natural resource rents. Figures 1A-1C reveal the average marginal effects of introducing ETS with countries' varying natural resource rents on carbon intensity, emissions, and renewable energy share, respectively. We use the kernel-smoothing estimator of the marginal effect that allows a fully flexible estimation of the functional form of the marginal effect of introducing ETS across the values of the moderator variable by estimating a series of local effects with a kernel-reweighting scheme. The shaded area in grey denotes 95 percent confidence intervals.

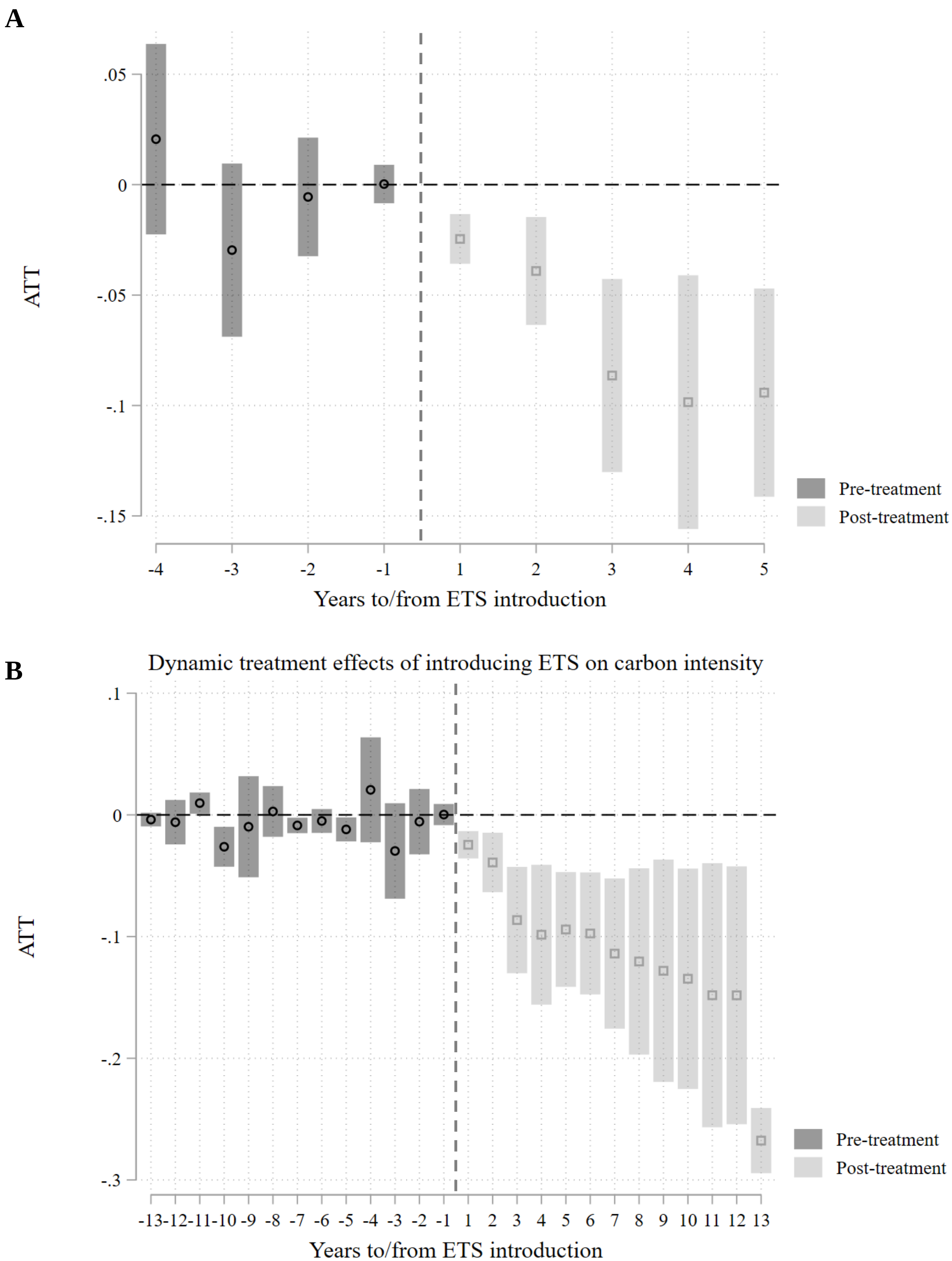

Figure 2. Dynamic treatment effects of introducing ETS on carbon intensity. The figure shows the event-study estimates for the dynamic effects of ETS introduction on carbon intensity in a narrow time window (Panel A) and across the entire observation period (Panel B). Bars denote 95 percent confidence intervals (wild bootstrapped standard errors with 100 replications) around each estimated coefficient, which measures the change in carbon intensity relative to the year before the introduction of ETS. The graphs indicate no pre-trend, which alleviates potential concerns about the ETS introduction's plausible exogeneity.

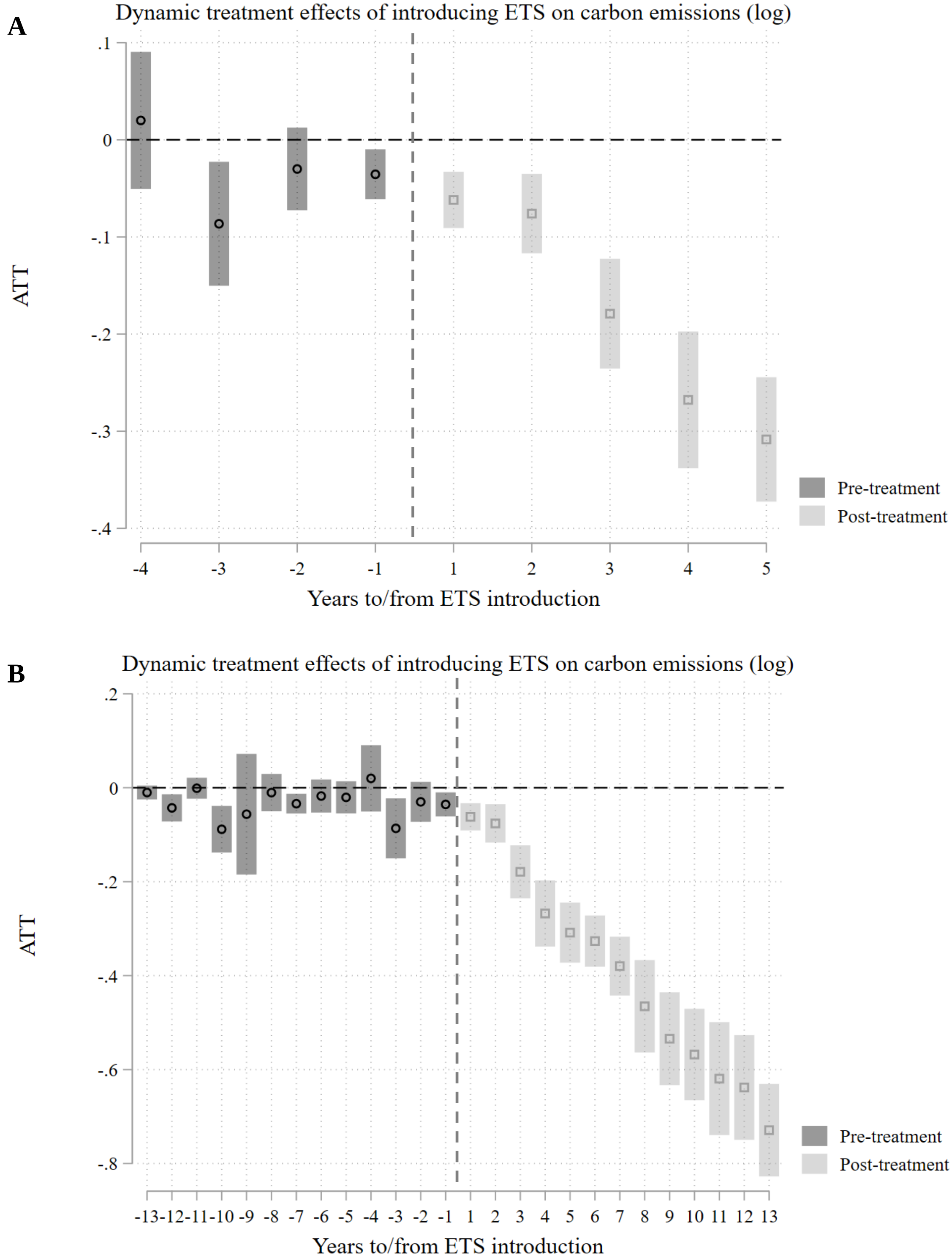

Figure 3. Dynamic treatment effects of introducing ETS on carbon emissions. The figure shows the event-study estimates for the dynamic effects of ETS introduction on carbon emissions in a narrow time window (Panel A) and across the entire observation period (Panel B). Bars denote 95 percent confidence intervals (wild bootstrapped standard errors with 100 replications) around each estimated coefficient, which measures the change in carbon emissions (log) relative to the year before the introduction of ETS.

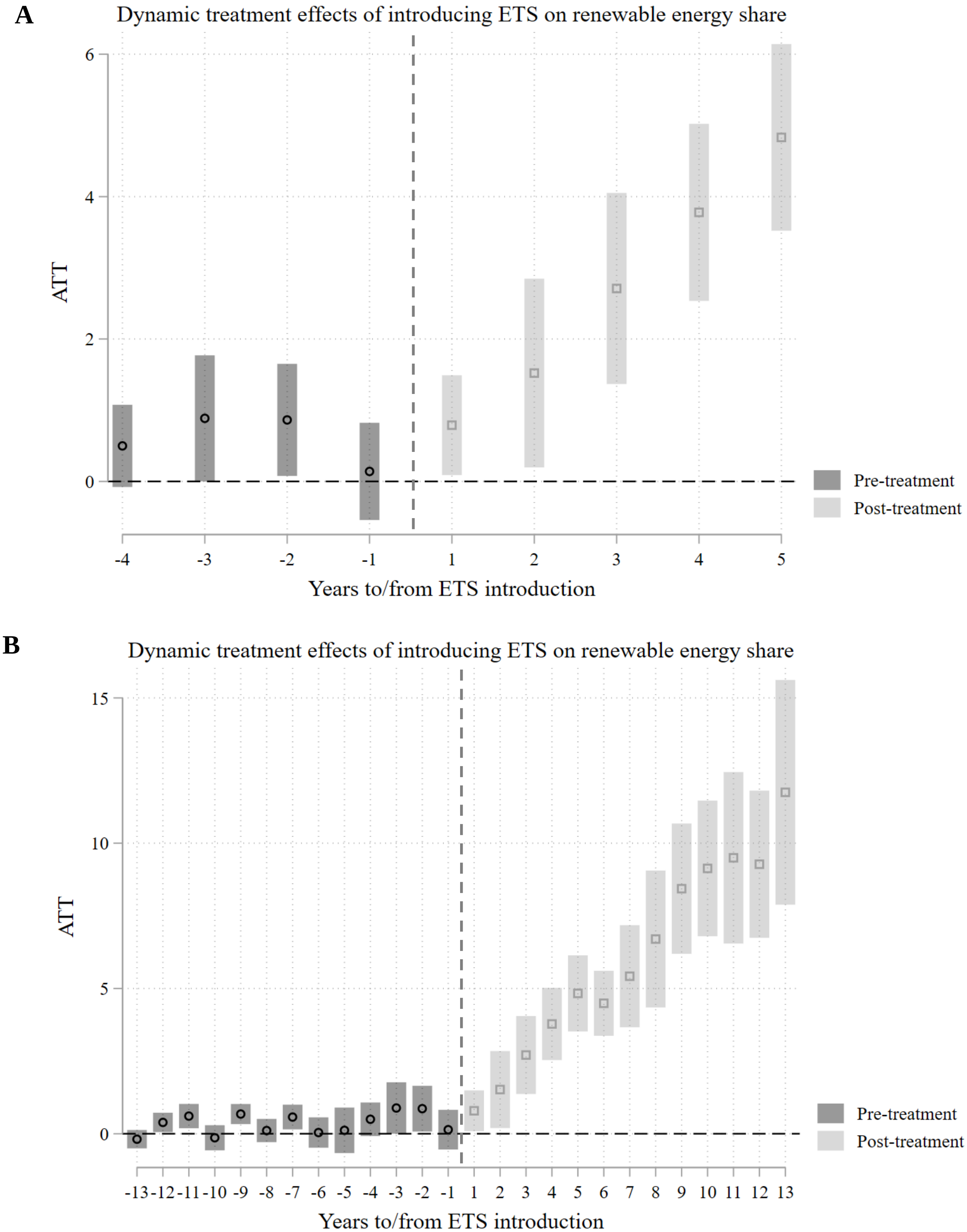

Figure 4. Dynamic treatment effects of introducing ETS on renewable energy share. The figure shows the event-study estimates for the dynamic effects of ETS introduction on renewable energy share in a narrow time window (Panel A) and across the entire observation period (Panel B). Bars denote 95 percent confidence intervals (wild bootstrapped standard errors with 100 replications) around each estimated coefficient, which measures the change in renewable energy share relative to the year before the introduction of ETS.

Table 1. Effect of introducing ETS. The unit of analysis is country-year. Standard errors are clustered at the country level; exact p-values from two-sided tests are reported in brackets. Sample includes all 150 countries. OLS regression models are employed. The number of observations in Columns 4-7 is 1,927 (i.e., 23 fewer than 1,950) due to missing values of some control variables.

Variables	(1) Carbon Intensity	(2) Carbon Emissions (log)	(3) Renewable Energy Share	(4) Carbon Intensity	(5) Carbon Intensity	(6) Carbon Emissions (log)	(7) Renewable Energy Share
Post ETS	-0.0619	-0.3388	5.6745	-0.0363	-0.0373	-0.1836	3.4544
	[0.000]	[0.000]	[0.000]	[0.013]	[0.011]	[0.000]	[0.000]
CTS				-0.0383	-0.0379	-0.2003	1.7677
				[0.306]	[0.317]	[0.000]	[0.020]
Population				0.0001	0.0008	0.0018	-0.0759
				[0.589]	[0.033]	[0.366]	[0.015]
Climatological Disasters				-0.0010	-0.0007	-0.0027	-0.2145
				[0.528]	[0.630]	[0.772]	[0.128]
FDI				0.0003	0.0003	0.0020	-0.0317
				[0.071]	[0.066]	[0.064]	[0.060]
Access to Electricity				0.0024	0.0023	0.0198	-0.2915
				[0.000]	[0.000]	[0.000]	[0.000]
Forest Area				-0.0007	-0.0004	-0.0008	0.0214
				[0.010]	[0.004]	[0.214]	[0.158]
Land Area				-0.0011	-0.0010	-0.0002	-0.1045
				[0.335]	[0.392]	[0.900]	[0.000]
Agricultural Land				0.0043	0.0043	0.0218	-0.2255
				[0.003]	[0.002]	[0.001]	[0.059]
GDP					-0.0000	0.0000	-0.0000
					[0.000]	[0.838]	[0.950]
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,950	1,950	1,950	1,927	1,927	1,927	1,927
Adjusted R-squared	0.870	0.993	0.987	0.882	0.882	0.994	0.990
Mean (DV)	0.231	9.822	33.774	0.231	0.231	9.813	33.748

Table 2. Examining the moderating role of natural resources rents in the effect of introducing ETS. The unit of analysis is country-year. Standard errors are clustered at the country level; exact p-values from two-sided tests are reported in brackets. OLS regression models are employed.

Variables	(1) Carbon Intensity	(2) Carbon Emissions (log)	(3) Renewable Energy Share
Post ETS × Natural Resource Rents	-0.0068	0.0050	-0.4005
	[0.003]	[0.532]	[0.001]
Post ETS	-0.0221	-0.1917	4.3201
	[0.112]	[0.000]	[0.000]
Natural Resource Rents	-0.0012	-0.0042	-0.0250
	[0.211]	[0.139]	[0.513]
Controls Included	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Observations	1,927	1,927	1,927
Adjusted R-squared	0.884	0.994	0.990
Mean (DV)	0.231	9.813	33.748

Supplementary Materials

The supplementary material file includes:
Figures S1 to S6
Tables S1 to S5

Supplementary Materials for

Cross-country heterogeneity in the impact of introducing emissions trading schemes on decarbonization

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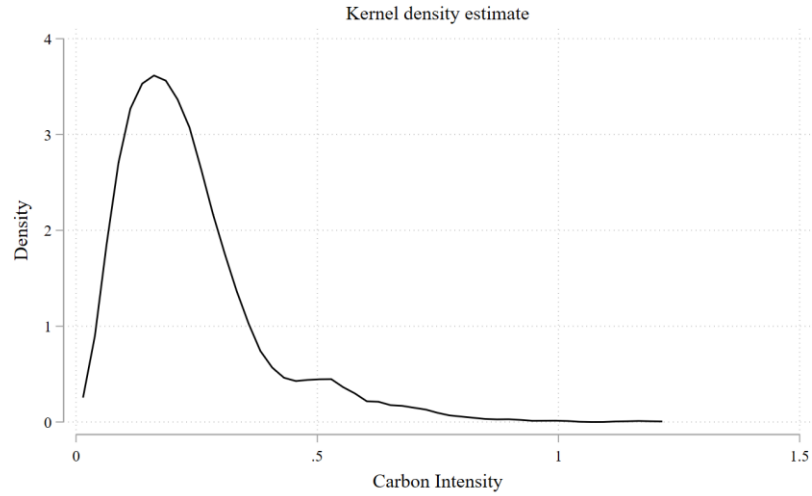
This PDF file includes:

Figures S1 to S6
Tables S1 to S5

A



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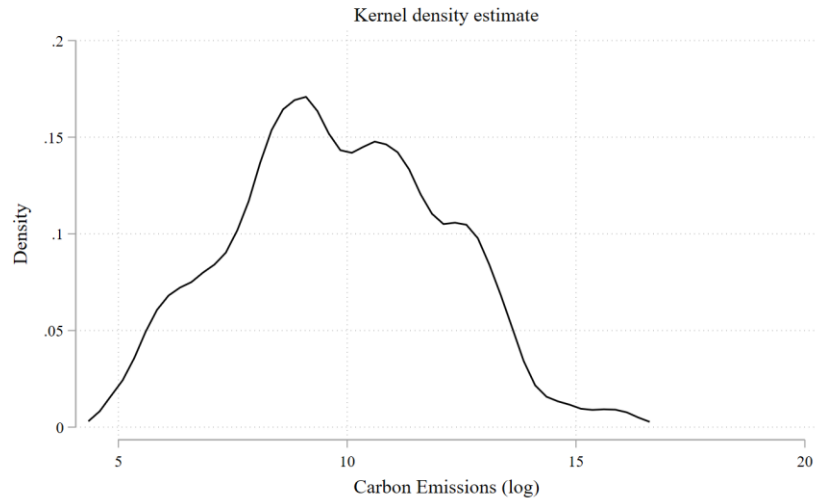

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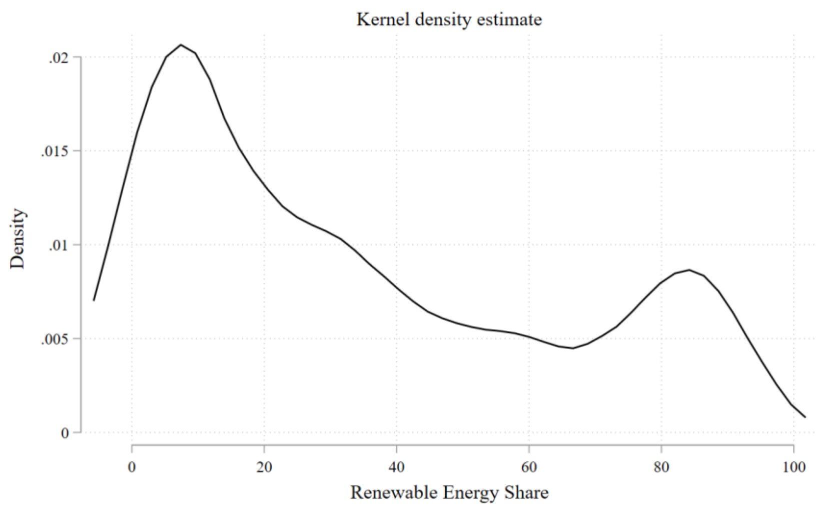

Figure S1. Distribution of carbon intensity, carbon emissions, and renewable energy share. Panels A, B, and C show the distribution of economies' carbon intensity, carbon emissions (log), and renewable energy share, respectively.

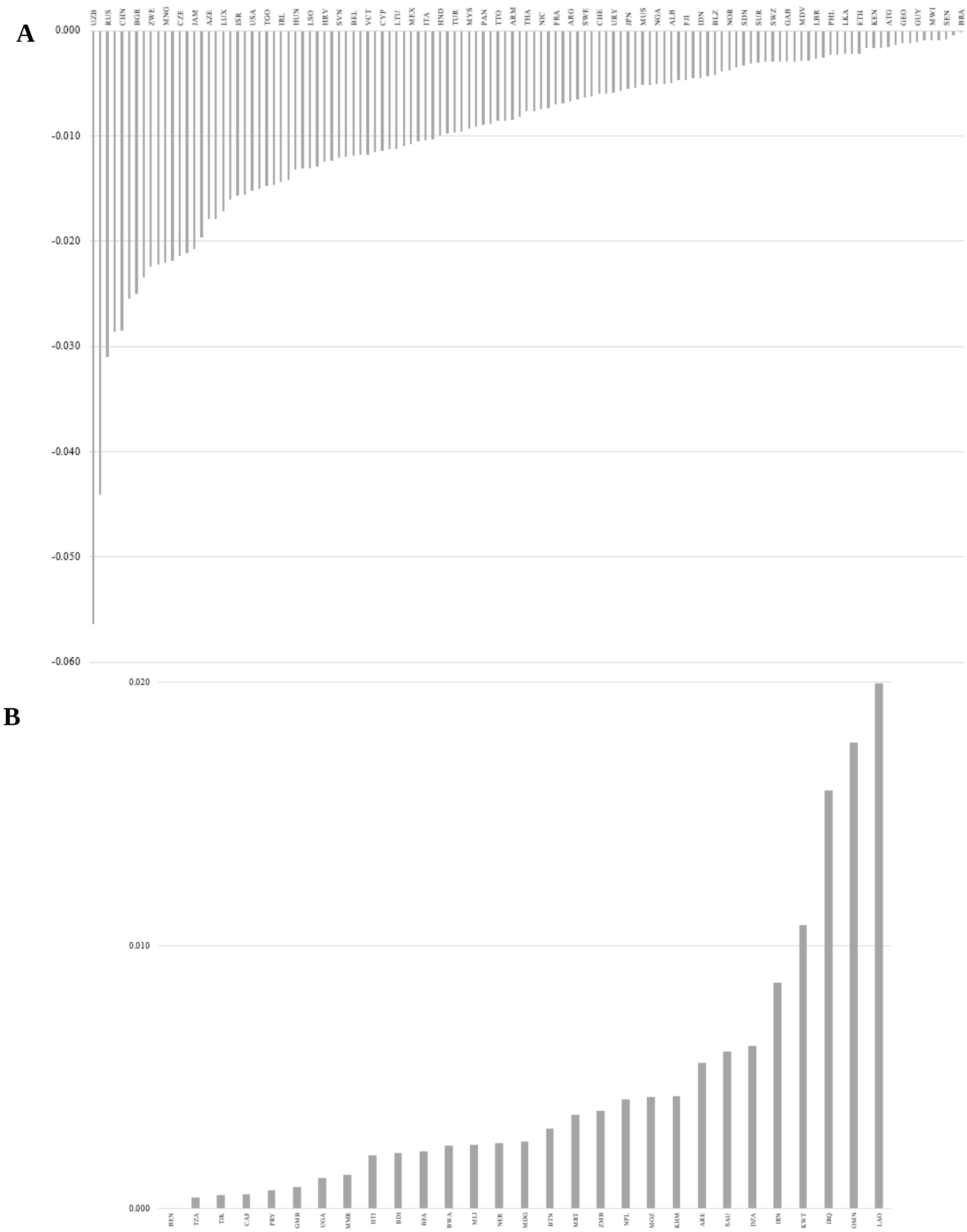

Figure S2. Heterogeneity in the annual change in carbon intensity of economies. Out of 150 countries, 121 (i.e., 80%) countries in the sample have reduced carbon intensity during the period 2005-2018. Panel a shows the annual change for countries where carbon intensity has reduced during this period (e.g., Uzbekistan, Ukraine, Russia, Estonia, China, Bulgaria, Poland). Panel b shows the annual change for countries where carbon intensity has increased during this period (e.g., Lao, Oman, Iraq, Kuwait, Iran, Algeria, Saudi Arabia).

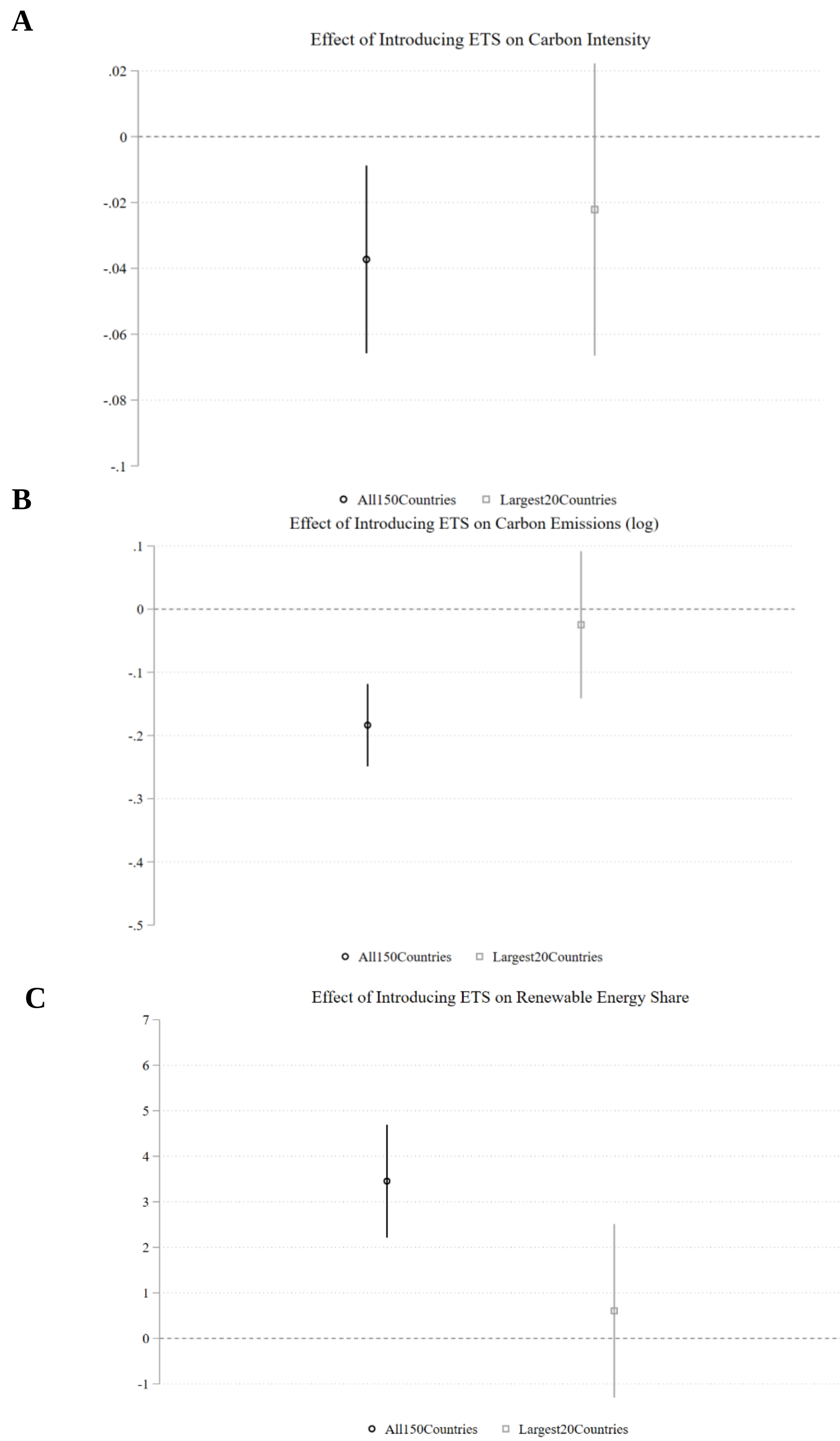

Figure S3. Effect of ETS introduction on major emitting nations versus all 150 countries. Panels A-C reveal the heterogeneity in the effect of ETS introduction for 20 largest emitting nations versus all 150 countries. The bars denote 95 percent confidence intervals.

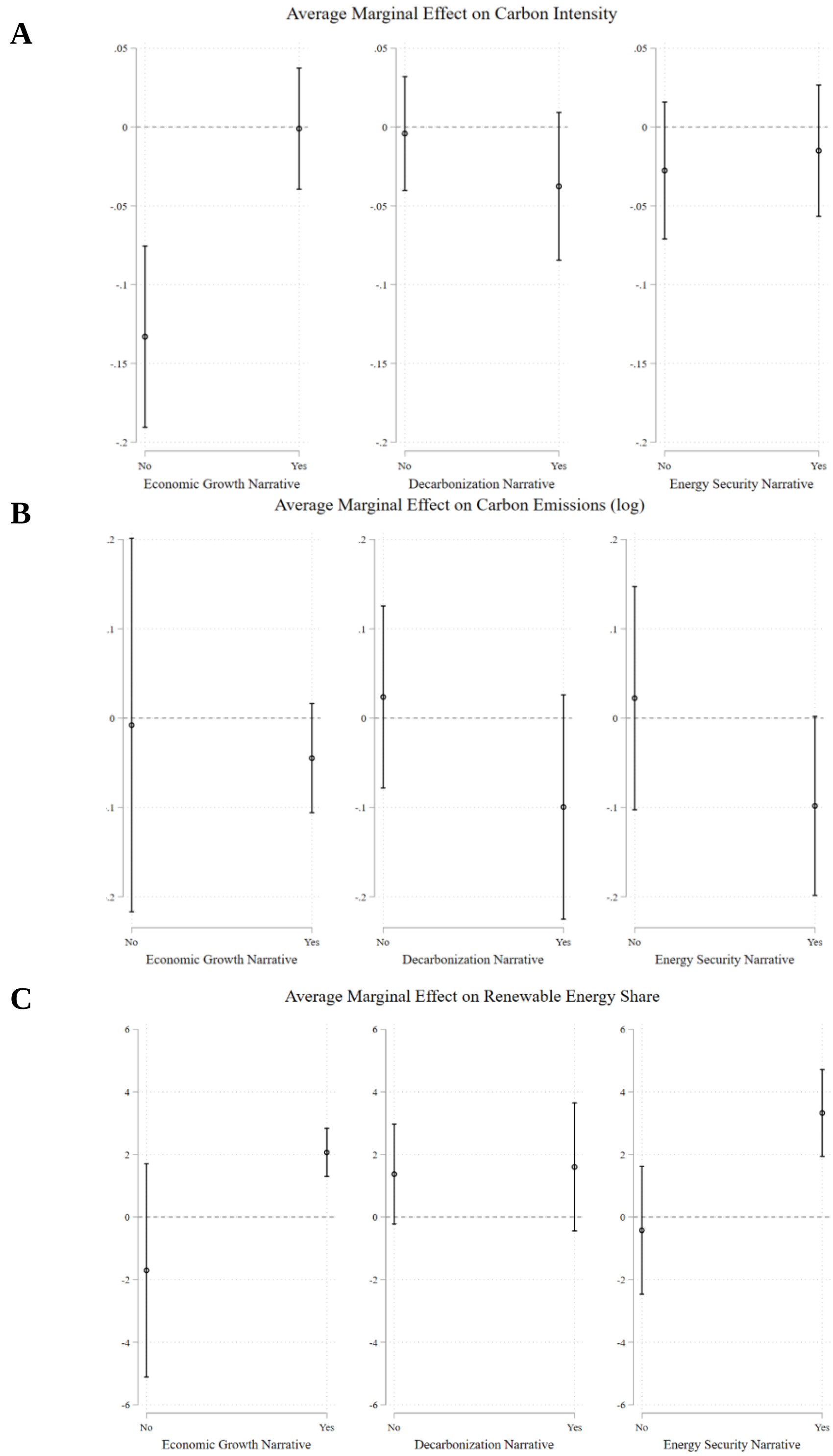

Figure S4. Average marginal effects of introducing ETS across distinct climate narratives. Panels A-C reveal the average marginal effects of introducing ETS across distinct climate narratives. The bars denote 95 percent confidence intervals.

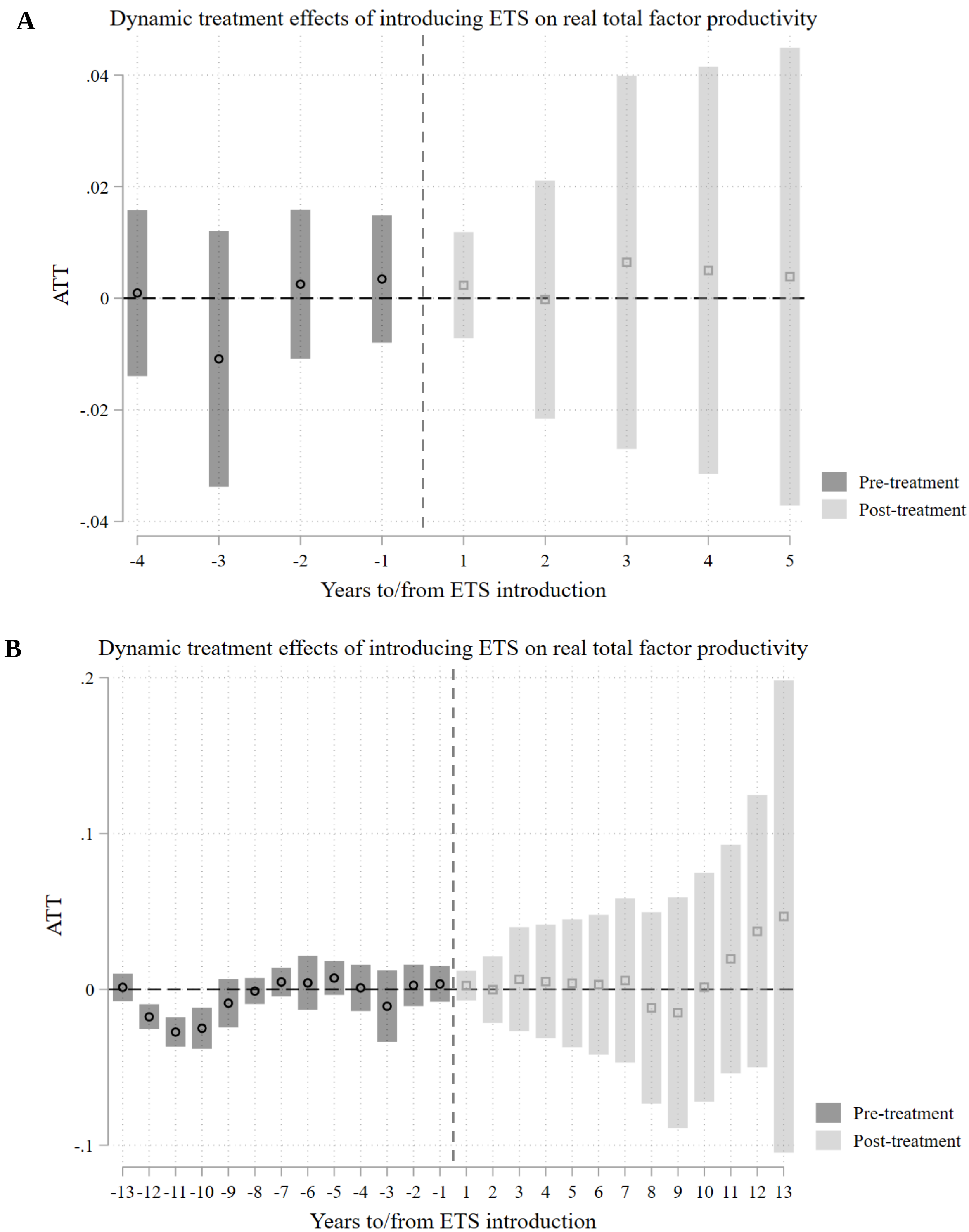

Figure S5. Dynamic treatment effects of introducing ETS on real total factor productivity. The figure shows the event-study estimates for the dynamic effects of ETS introduction on real TFP in a narrow time window (Panel A) and across the entire observation period (Panel B). Bars denote 95 percent confidence intervals (wild bootstrapped standard errors with 100 replications) around each estimated coefficient, which measures the change in real TFP relative to the year before the introduction of ETS.

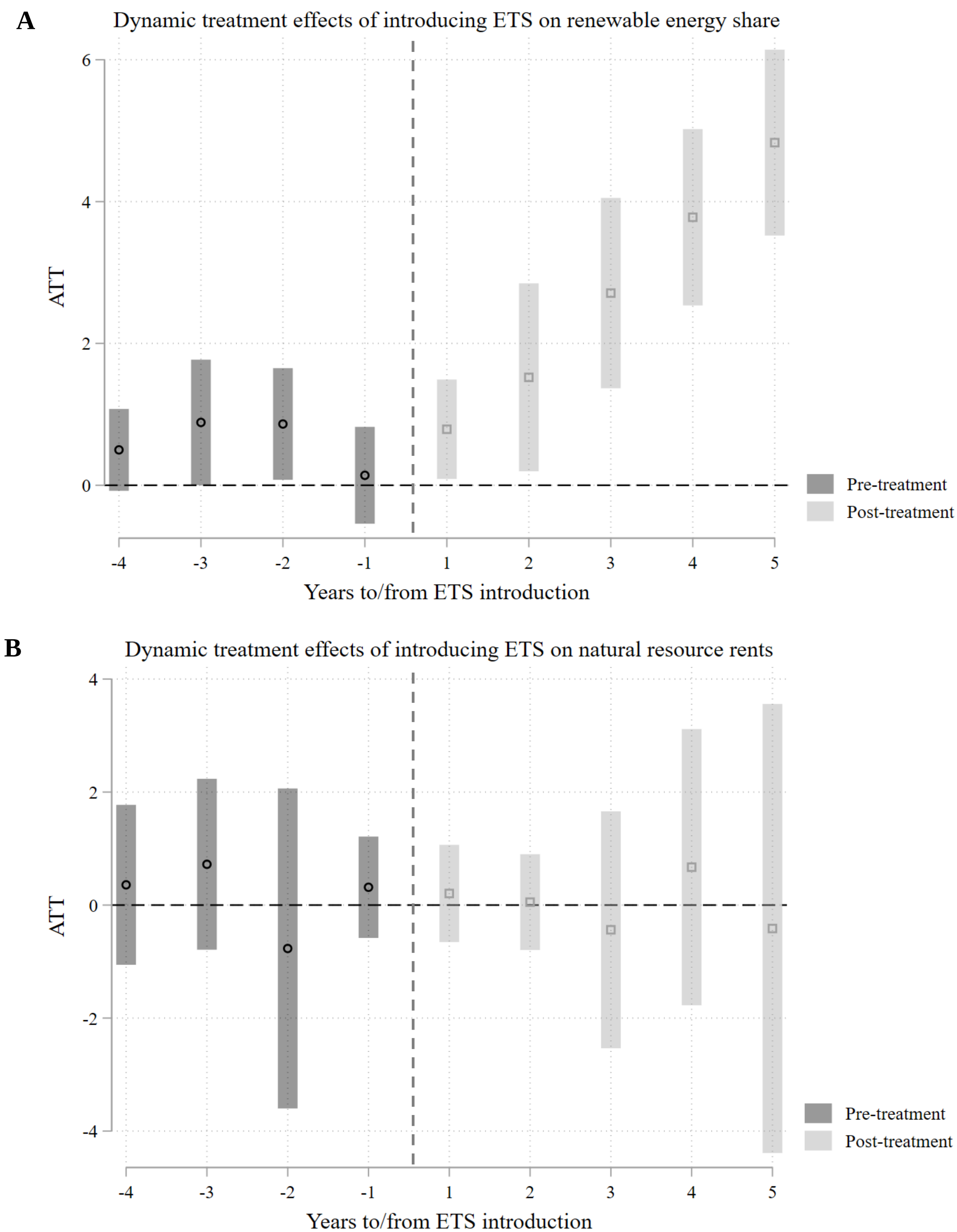

Figure S6. Dynamic treatment effects of introducing ETS on renewable energy share but no effect on natural resource rents. The figure shows the event-study estimates for the dynamic effects of ETS introduction in a narrow time window on the renewable energy share (Panel A) and natural resource rents (Panel B). Bars denote 95 percent confidence intervals (wild bootstrapped standard errors with 100 replications) around each estimated coefficient.

Table S1. Variables description and data sources. This table presents the variables description and data sources.

Variables	Description	Data Source
Carbon Intensity	Measures the carbon dioxide emissions in kg per PPP $ at the country-year level	World Bank Database and World Resources Institute (https://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD)
Carbon Emissions (log)	Measures the carbon dioxide emissions in kiloton at the country-year level and log-transformed	World Bank Database and World Resources Institute (https://data.worldbank.org/indicator/EN.ATM.CO2E.KT)
Renewable Energy Share	Measures the renewable energy consumed as a percentage of total final energy consumed at the country-year level	World Bank Database and Sustainable Energy for All Database (https://data.worldbank.org/indicator/EN.ATM.CO2E.KT)
Post ETS	A time-varying indicator equal to 1 if the focal country has introduced emissions trading scheme by the focal year; otherwise, it is equal to 0	World Bank Carbon Pricing Database (https://carbonpricingdashboard.worldbank.org/map_data)
Natural Resource Rents	Measures total natural resources' rents (in % of GDP) as the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents at the country-year level	World Development Indicators (https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS)
Economic Growth Narrative	Indicator equal to 1 if economic growth narrative is present in the focal country; otherwise, it is equal to 0	Guy, Shears, and Meckling (2023) (https://www.nature.com/articles/s41558-022-01589-x)
Decarbonization Narrative	Indicator equal to 1 if decarbonization narrative is present in the focal country; otherwise, it is equal to 0	Guy, Shears, and Meckling (2023) (https://www.nature.com/articles/s41558-022-01589-x)
Energy Security Narrative	Indicator equal to 1 if energy security narrative is present in the focal country; otherwise, it is equal to 0	Guy, Shears, and Meckling (2023) (https://www.nature.com/articles/s41558-022-01589-x)
CTS	Indicator equal to 1 if the focal country has introduced carbon tax scheme by the focal year; otherwise, it is equal to 0	World Bank Carbon Pricing Database (https://carbonpricingdashboard.worldbank.org/map_data)
Population	Measures the population (in million) at the country-year level	World Development Indicators (https://data.worldbank.org/indicator/SP.POP.TOTL)
Climatological Disasters	Measures the number of climatological disasters (e.g., drought, wildfire) at the country-year level	EM-DAT (the international disaster database) (https://public.emdat.be/)
FDI	Measures the foreign direct investment (FDI) net inflows divided by GDP (expressed in percent) at the country-year level, where FDI refers to the net inflows of investment to acquire a lasting management interest (10% or more of voting stock) in an enterprise operating in a country other than that of the investor	World Development Indicators (https://data.worldbank.org/indicator/BX.KLT.DINV.WD.GD.ZS)

Access to Electricity	Measures the percentage of population with access to electricity at the country-year level	World Bank Global Electrification Database (https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS)
Forest Area	Measures the forest area (in thousand square km) as land under natural or planted stands of trees of at least 5 meters in situ, whether productive or not, and excludes tree stands in agricultural production systems (for example, in fruit plantations and agroforestry systems) and trees in urban parks and gardens at the country-year level	Food and Agricultural Organization (https://data.worldbank.org/indicator/AG.LND.FRST.K2)
Land Area	Measures land area (in thousand square km) as a country's total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones at the country-year level	Food and Agricultural Organization (https://data.worldbank.org/indicator/AG.LND.TOTL.K2)
Agricultural Land	Measures the percentage share of land area that is arable, under permanent crops, and under permanent pastures	Food and Agricultural Organization (https://data.worldbank.org/indicator/AG.LND.AGRI.ZS)
GDP	Measures the real GDP at constant 2017 national prices (in million 2017 US$) at the country-year level	World Development Indicators (https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD)

Table S2. List of countries in the sample. This table lists all countries in the sample. The largest 20 nations (in alphabetical order) by carbon emissions include: Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Iran, Japan, Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, United Kingdom, United States, and Vietnam. Korea refers to South Korea.

Sl. No.	Country	Code	Sl. No.	Country	Code	Sl. No.	Country	Code
1	ALBANIA	ALB	51	GABON	GAB	101	NEPAL	NPL
2	ALGERIA	DZA	52	GAMBIA	GMB	102	NETHERLANDS	NLD
3	ANGOLA	AGO	53	GEORGIA	GEO	103	NEWZEALAND	NZL
4	ANTIGUAANDBARBUDA	ATG	54	GERMANY	DEU	104	NICARAGUA	NIC
5	ARGENTINA	ARG	55	GHANA	GHA	105	NIGER	NER
6	ARMENIA	ARM	56	GREECE	GRC	106	NIGERIA	NGA
7	AUSTRALIA	AUS	57	GRENADA	GRD	107	NORWAY	NOR
8	AUSTRIA	AUT	58	GUATEMALA	GTM	108	OMAN	OMN
9	AZERBAIJAN	AZE	59	GUINEA	GIN	109	PAKISTAN	PAK
10	BAHAMAS	BHS	60	GUINEA-BISSAU	GNB	110	PANAMA	PAN
11	BANGLADESH	BGD	61	GUYANA	GUY	111	PARAGUAY	PRY
12	BARBADOS	BRB	62	HAITI	HTI	112	PERU	PER
13	BELARUS	BLR	63	HONDURAS	HND	113	PHILIPPINES	PHL
14	BELGIUM	BEL	64	HUNGARY	HUN	114	POLAND	POL
15	BELIZE	BLZ	65	INDIA	IND	115	PORTUGAL	PRT
16	BENIN	BEN	66	INDONESIA	IDN	116	QATAR	QAT
17	BHUTAN	BTN	67	IRAN	IRN	117	ROMANIA	ROM
18	BOLIVIA	BOL	68	IRAQ	IRQ	118	RUSSIA	RUS
19	BOSNIAANDHERZEGOVINA	BIH	69	IRELAND	IRL	119	RWANDA	RWA
20	BOTSWANA	BWA	70	ISRAEL	ISR	120	SAUDIARABIA	SAU
21	BRAZIL	BRA	71	ITALY	ITA	121	SENEGAL	SEN
22	BULGARIA	BGR	72	JAMAICA	JAM	122	SEYCHELLES	SYC
23	BURKINAFASO	BFA	73	JAPAN	JPN	123	SIERRALEONE	SLE
24	BURUNDI	BDI	74	JORDAN	JOR	124	SLOVAKIA	SVK
25	CAMBODIA	KHM	75	KAZAKHSTAN	KAZ	125	SLOVENIA	SVN
26	CAMEROON	CMR	76	KENYA	KEN	126	SOUTHAFRICA	ZAF
27	CANADA	CAN	77	KOREA	KOR	127	SPAIN	ESP
28	CAPEVERDE	CPV	78	KUWAIT	KWT	128	SRILANKA	LKA
29	CENTRALAFRICANREPUBLIC	CAF	79	KYRGYZ	KGZ	129	ST.VINCENTANDTHEGRENADINES	VCT
30	CHAD	TCD	80	LAO	LAO	130	SUDAN	SDN
31	CHILE	CHL	81	LATVIA	LVA	131	SURINAME	SUR
32	CHINA	CHN	82	LEBANON	LBN	132	SWEDEN	SWE
33	COLOMBIA	COL	83	LESOTHO	LSO	133	SWITZERLAND	CHE
34	CONGO	COG	84	LIBERIA	LBR	134	TAJIKISTAN	TJK
35	COSTARICA	CRI	85	LITHUANIA	LTU	135	TANZANIA	TZA
36	CROATIA	HRV	86	LUXEMBOURG	LUX	136	THAILAND	THA
37	CYPRUS	CYP	87	MADAGASCAR	MDG	137	TOGO	TGO
38	CZECHREPUBLIC	CZE	88	MALAWI	MWI	138	TRINIDADANDTOBAGO	TTO
39	DENMARK	DNK	89	MALAYSIA	MYS	139	TUNISIA	TUN
40	DOMINICA	DMA	90	MALDIVES	MDV	140	TURKEY	TUR
41	DOMINICANREPUBLIC	DOM	91	MALI	MLI	141	UGANDA	UGA
42	ECUADOR	ECU	92	MAURITANIA	MRT	142	UKRAINE	UKR
43	EGYPT	EGY	93	MAURITIUS	MUS	143	UNITEDARABEMIRATES	ARE
44	ELSALVADOR	SLV	94	MEXICO	MEX	144	UNITEDKINGDOM	GBR
45	ESTONIA	EST	95	MOLDOVA	MDA	145	UNITEDSTATES	USA
46	ESWATINI	SWZ	96	MONGOLIA	MNG	146	URUGUAY	URY
47	ETHIOPIA	ETH	97	MOROCCO	MAR	147	UZBEKISTAN	UZB
48	FIJI	FJI	98	MOZAMBIQUE	MOZ	148	VIETNAM	VNM
49	FINLAND	FIN	99	MYANMAR	MMR	149	ZAMBIA	ZMB
50	FRANCE	FRA	100	NAMIBIA	NAM	150	ZIMBABWE	ZWE

Table S3. Descriptive statistics. This table shows the descriptive statistics based on panel data from 150 countries for all variables except climate narratives (economic growth, decarbonization, energy security), which are measured for the cross-section of 20 largest emitting nations.

Variables	Mean	Std. Dev.	Min	Max
Carbon Intensity	0.24	0.15	0.04	1.19
Carbon Emissions (log)	9.81	2.27	4.79	16.17
Renewable Energy Share	33.85	29.63	0.00	96.01
Post ETS	0.18	-	0	1
Natural Resource Rents	7.32	10.73	0	66.69
Economic Growth Narrative	0.85	-	0	1
Decarbonization Narrative	0.50	-	0	1
Energy Security Narrative	0.50	-	0	1
CTS	0.08	-	0	1
Population	44.95	155.51	0.07	1,427.65
Climatological Disasters	0.15	0.47	0	5
FDI	5.45	10.39	-6.22	122.48
Access to Electricity	79.71	30.06	1.3	100
Forest Area	255.11	880	0	8,153.12
Land Area	801.41	2,051.84	0.30	16,381.39
Agricultural Land	39.81	20.93	0.45	84.74
GDP	661.51	2,065.42	0.64	20,128.58
Year	-	-	2005	2018
Country	-	-	1	150

Table S4. Effect of introducing ETS across distinct climate narratives. The unit of analysis is country-year. Standard errors are clustered at the country level; exact p-values from two-sided tests are reported in brackets. Sample includes 20 largest countries by absolute carbon dioxide emissions. OLS regression models are employed.

Variables	(1) Carbon Intensity	(2) Carbon Emissions (log)	(3) Renewable Energy Share
Post ETS × Economic Growth Narrative	0.1321	-0.0370	3.7689
	[0.000]	[0.744]	[0.050]
Post ETS × Decarbonization Narrative	-0.0335	-0.1232	0.2305
	[0.006]	[0.231]	[0.893]
Post ETS × Energy Security Narrative	0.0126	-0.1206	3.7500
	[0.345]	[0.231]	[0.027]
Post ETS	-0.1224	0.1165	-3.7332
	[0.000]	[0.295]	[0.044]
Controls Included	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes
Observations	255	255	255
Adjusted R-squared	0.952	0.993	0.987
Mean (DV)	0.329	13.433	14.472

Table S5. Examining the effect of introducing ETS on real total factor productivity. The unit of analysis is country-year. Standard errors are clustered at the country level; exact p-values from two-sided tests are reported in brackets. OLS regression models are employed.

Variables	(1) Real TFP
Post ETS	0.0066
	[0.726]
Controls Included	Yes
Year Fixed Effects	Yes
Country Fixed Effects	Yes
Observations	1,388
Adjusted R-squared	0.583
Mean (DV)	0.995