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Carbon pricing and decoupling between greenhouse gas emissions and economic growth: A panel study of 29 European countries, 1996–2014

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Abstract

This study explores why the levels of decoupling between greenhouse gas (GHG) emissions and economic growth vary across time and countries by examining to which extent carbon pricing instruments are driving this decoupling. We expect that the implementation of carbon pricing instruments facilitates decoupling, as they are designed to achieve cost-efficient GHG reduction. We analyze a panel data of 29 European countries between 1996 and 2014 to examine the relationships between two carbon pricing instruments (emission trading (ETS) and carbon tax) and emission intensity (GHG emissions per unit of GDP) which we use to measure decoupling trends. Results from two-way fixed effects models show that emission trading contributes to decoupling, whereas our evidence does not support the role of carbon tax. Furthermore, emission trading is negatively associated with both emission intensity and GHG emissions, implying that it contributes to strong decoupling. Using coarsened exact matching (CEM), our results suggest that even a single emission trading policy (e.g., EU-ETS) across different jurisdictions may render a heterogeneous effect on decoupling depending on their socioeconomic conditions.

KEYWORDS

carbon pricing, carbon tax, coarsened exact matching, decoupling, emission intensity, emission trading, two-way fixed effects

[INTRODUCTION

Much stronger greenhouse gas (GHG) mitigation is required to achieve global net-zero emissions by 2050 as outlined in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C. However, the concern that mitigation may dampen economic growth and prosperity has become a primary obstacle for active mitigation efforts. Decoupling in the context of climate policy literature refers to the trend whereby GHG emissions decrease without economic growth being undermined (Jorgenson & Clark, 2012). Achieving a decoupling trend has been widely discussed as a potential breakthrough for the global climate change problem (Wu et al., 2018).

However, the current scenario does not conform to the idealistic discourse regarding decoupling, as not all countries are successful in achieving a decoupling trend. Even among European countries which have been most active regarding GHG mitigation, there are two meaningful empirical variations in the degree of decoupling trends. The first variation is a cross-sectional variation: Some countries, such as Sweden or the United Kingdom, have largely achieved decoupling, whereas others, such as Italy or Greece, have not. The second variation is a temporal variation: Even among those which have been gradually performing decoupling trends, their timings vary. Figure 1 summarizes these variations at a glance. It would therefore be interesting to see which factor, all else being equal, is a driver for a decoupling trend.

To answer this question, we examine the relationship between a decoupling trend and carbon pricing policy instruments (or tools) which aim to promote cost-efficient mitigation actions. Goldemberg (2020) stressed that the adoption of adequate policies may determine the level of decoupling, yet his study does not account for the adoption of carbon pricing instruments. The idea of carbon pricing is to internalize negative externalities from GHG emissions. Emission trading and carbon taxes are two policy instruments that are commonly used to enable this, though they employ different ways (Tietenberg, 2013). For instance, while emission trading sets a desirable *quantity* of emission reduction, carbon tax sets its desirable *price* (Weitzman, 1974).

A careful examination of their relationship can provide two implications. First, understanding the relationship between decoupling and carbon pricing generates testable hypotheses that can explain the time-series and cross-country variation in the degree of decoupling. To test these hypotheses, we use panel data from 29 European countries, across the period of 1996–2014. Within this sample of European countries, there exists sufficient variation in the degree of economic growth, GHG emissions, and carbon pricing instruments. Specifically, we cover a region-wide emission trading (European Union Emission Trading Scheme, EU-ETS) and nation-wide carbon taxes that are different across our units. We leverage this variation in the adoption of carbon pricing across these European countries to empirically test its impact on decoupling. We further justify our sample selection in the following section.

Second, decoupling allows us to test the effectiveness of different policy instruments for pricing carbon. Theoretical approaches that predict carbon pricing to be effective in reducing GHG abatement cost are well established, yet few studies have used an empirical approach to examine whether or which type of policy instruments are most effective for putting a price on carbon. Here, we examine the effectiveness of two different carbon pricing instruments (emission trading and carbon tax) in promoting decoupling leveraging its single measurement, which is emission intensity (GHG emission per GDP), and showing how its relationship to each policy differs. Our two-way fixed effects model lends more support to the effectiveness of emission trading than that of carbon tax in facilitating decoupling, but there are two caveats. First, our measurement of carbon pricing instruments may not fully capture their various designs and scopes. This problem

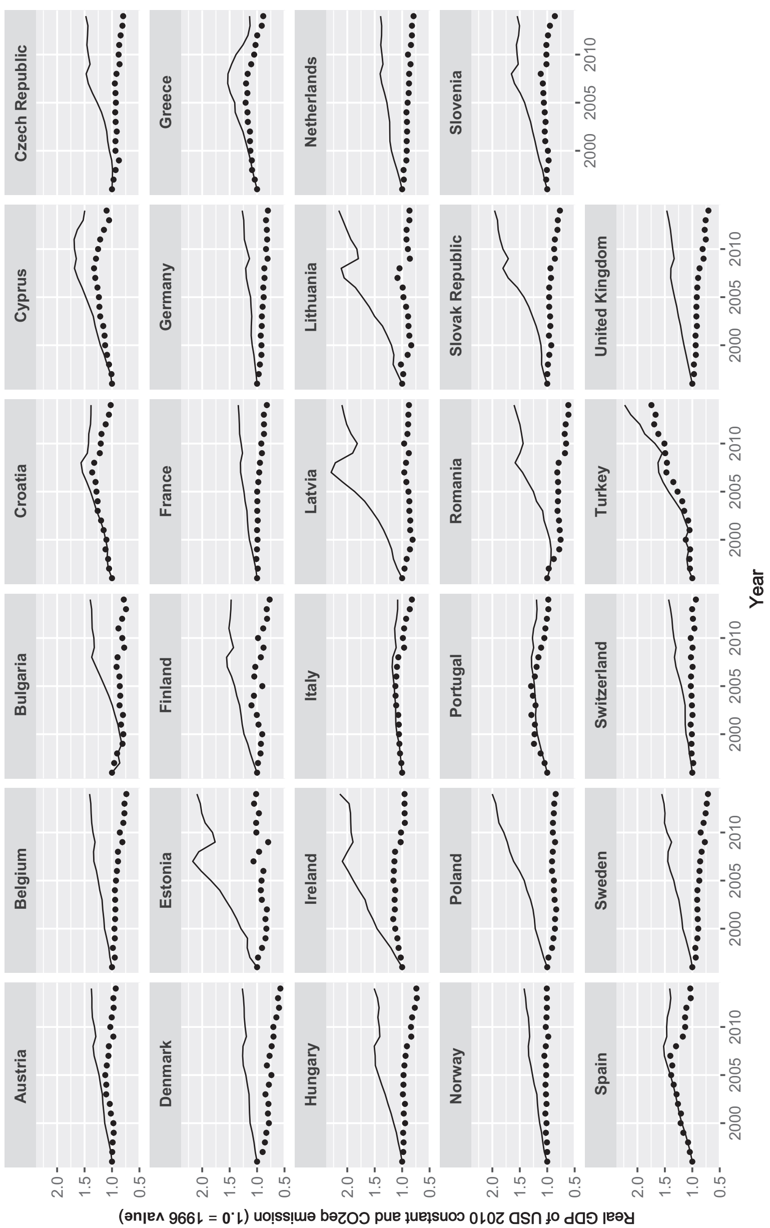

FIGURE 1 Time-series graphs of decoupling in 29 European countries, 1996–2014. (1.0 = 1996 value; the solid line is the real GDP (US$ 2010 constant), and the dotted line is GHG (tCO_{2eq}))

is more severe for carbon tax than emission trading, since our data suggest more possible heterogeneity across carbon taxes (i.e., each unit in our data has its own national-level carbon tax if it has one) than emission trading (i.e., almost all units in our data have adopted EU-ETS). Hence, our finding cannot fully reject the effectiveness of carbon tax in facilitating decoupling. Second, two-way fixed effects estimators still suffer potential bias from unobserved confounders, which makes our finding that emission trading is effective for decoupling still dubious. Therefore, we subject this finding to an additional test by using coarsened exact matching (CEM) which we explain in section "Results with coarsened exact matched data". While we find a general support for the effectiveness of emission trading in promoting decoupling, we suggest that even a single emission trading policy across different jurisdictions can vary in terms of its impact on decoupling depending on their socioeconomic conditions.

This paper is structured as follows. The next section reviews the literature on decoupling and carbon pricing, to identify the knowledge gap that we aim to fill. We also theorize the links between emission trading and carbon tax, and emission intensity. The following section presents data, data sources, and the method that this study uses. Analysis outcomes and discussion sections then follow. We conclude by highlighting the contributions and policy implications, and provide suggestions for future research.

LITERATURE REVIEW

Emission intensity as an indicator for decoupling

In environmental and climate policy literature, on a country level decoupling is referred to as a phenomenon whereby the national economy does not shrink, even though GHG emissions decrease (Jorgenson & Clark, 2012). Scholars have, however, used different terms, such as "a low-carbon society" or "low-carbon economic growth" (Reilly, 2013), "green economy" (Loiseau et al., 2016), or "green growth" (Antal & Bergh, 2016; Damonte, 2014) to refer to similar phenomena. Proponents of decoupling have argued that economic growth can be environment-friendly if energy efficiency is enhanced through technological innovation (Dinda, 2004), or if increased income leads to demands for environmental regulation (Mol, 2002). One argument based on this idea is the Environmental Kuznets Curve (EKC) hypothesis, which presents that a country can achieve decoupling after it has attained a certain level of economic development (Clulow, 2016; Dinda, 2004). Yet, the primary differences between the EKC and our research are the dependent variables (the level of energy intensity instead of pollution in EKC) and the key independent variables (the presence of carbon pricing instruments instead of economic development).

Among various indicators, decoupling can be measured with emission intensity, which is the volume of GHG emissions divided by the GDP of a given country-year. Our choice of term "emission intensity" instead of "carbon intensity" is to highlight our understanding that decoupling should account for not only carbon-related GHG (e.g., CO_2 or CH_4) but also non-carbon GHG emissions (e.g., N_2O or SF_6).

Table 1 justifies the use of emission intensity as a proxy to measure the degree to which decoupling occurs in our observation. Consider an example of countries A and B for two periods, t and $t + 1$. For both A (t) and B (t), let GDP be US$ 1,000 and GHG be 100 $kgCO_2eq$. At $t + 1$, country A's GDP increases by US$ 1 and its GHG decreases by 50 $kgCO_2eq$. This is an example of decoupling, and we now see that its emission intensity has fallen, even though there has been an increase in its GDP. For country B, let its GDP increase by US$ 500 and its GHG increase by

TABLE 1 Decoupling and emission intensity (examples)

Country/Time	GDP (US$)	GHG ($kgCO_2eq$)	ΔGDP	ΔGHG	Emission intensity	Decoupling
A (*t*)	1,000	100	0.001	−0.5	0.1	Strong (ΔGDP > 0 > ΔGHG)
A (*t* + 1)	1,001	50			0.05	
B (*t*)	1,000	100	0.5	0.02	0.1	Weak (ΔGDP > ΔGHG > 0)
B (*t* + 1)	1,500	102			0.068	
C (*t*)	1,000	100	1	4	0.1	Coupling (ΔGDP < ΔGHG)
C (*t* + 1)	2,000	500			0.25	

2 $kgCO_2eq$. Although both the GDP and the GHG have increased, GHG increased at a slower rate than GDP. Therefore, this is also a case of decoupling, and we see that the emission intensity has also fallen. Scholars have often labeled the case of country A as "strong decoupling" and the latter case as "weak decoupling" (Andreoni & Galmarini, 2012). However, as for country C, GHG increased at a higher rate than GDP: this is not decoupling, and its emission intensity has risen. In short, this shows that the decrease in emission intensity can serve as an indicator that either strong or weak decoupling has occurred.

Carbon pricing and decoupling

Linking between decoupling and carbon pricing is a novel attempt with which we contribute to the literature. Previous studies have examined the various conditions for decoupling to occur (Andreoni & Galmarini, 2012; Goldemberg, 2020; Jorgenson & Clark, 2012; Wu et al., 2018), yet few of these studies included carbon pricing instruments as their key explanatory variables. We examine this link with a time-series and cross-country comparison. Most of extant studies that examined the adoption (Karapin, 2020; Skovgaard et al., 2019) or the efficacy of carbon pricing instruments mainly consist of single country cases (Lundgren et al., 2015; Mascher, 2018; Mo et al., 2016; Rogge & Hoffmann, 2010; Sandoff & Schaad, 2009). A recent study by Best et al. (2020) has conducted cross-country comparison on the efficacy of carbon pricing instruments, yet they focus on GHG reduction from fuel combustion sector, not on the degree to which economic development is decoupled from GHG emissions.

We theorize the link between decoupling and carbon pricing, which is often understood as one type of policy instruments for GHG mitigation. As explained earlier, carbon pricing is designed to make GHG emissions costly by, as its name implies, "pricing carbon." Generally, carbon pricing instruments regulate specific GHGs, and convert the degree to which they contribute to global warming into CO_2eq, or carbon dioxide equivalent; CO_2 is used as a reference point. Then, they impose a certain amount of cost per unit of CO_2eq, and internalize pollution as a negative externality to producers' or consumers' economic activities. Economists have pointed to the advantage of this market-based mechanism for environmental regulation, compared to the command-and-control mechanism, in terms of minimizing the aggregate cost of environmental protection (Stavins, 1998).

Emission trading and carbon tax are commonly used policy instruments to employ carbon pricing, though they employ different ways to impose such a fee (Narassimhan et al., 2018; Tietenberg, 2013). Emission trading creates a market where liable firms (polluters) can trade emission allowance units with each other at market price (Lederer, 2017). While the carbon price is determined indirectly by the market in emission trading system by restricting the amount of carbons to enter the market, it is directly determined by the regulator in a carbon tax system. Therefore, emission trading system is widely known as quantity-based regulation while a carbon tax is often called as price-based regulation on GHG emissions (Weitzman, 1974).

For decades researchers have debated on which carbon pricing policy outperform than the other, with mixed results from various theoretical and empirical studies showing the difficulty in discussing their general performances (Goulder & Schein, 2013; Weitzman, 2014). Instead of relying on a hastily drawn dichotomy between carbon tax and emission trading in our study, we clarify what components we expect to see in a policy that can facilitate decoupling trend and discuss whether each carbon pricing policy has those components.

We suggest that there are two key factors for a mitigation policy to bring about decoupling trend: (1) whether it can make GHG mitigation "less costly," and (2) whether it can ensure substantial GHG mitigation. First, the cost of GHG mitigation (or abatement cost) can be considered as an opportunity cost for economic growth. Therefore, a lowered abatement cost can lead to a better allocation of resources for economic growth. When reducing the same amount of GHG emissions, it is likely for a country to achieve a decoupling trend when it implements a policy instrument more capable of lowering the abatement cost. Second, a policy instrument that succeeds in reducing abatement cost, without reducing the actual amount of GHG emission, is only partially contributing to a weak decoupling trend which refers to higher GDP growth rate than the rate of GHG emission reduction. Only when it succeeds in both aspects can it be considered to have contributed to strong decoupling (see Table 1).

While both carbon tax and emission trading are carbon pricing instruments designed to curb GHG emissions in more efficient way than command-and-control regulation does, two policies employ different mechanisms to attain the goal. First, emission trading can effectively deal with the first factor: lowering abatement cost. Under emission trading scheme, liable firms whose abatement cost is below the price of carbon in the market have incentives to further reduce their GHG emissions, as they can have more allowance units, which they can sell to other firms whose abatement costs are higher than the price. Furthermore, it can encourage technological development (environmental innovation), which can gradually enhance polluters' energy efficiency (Rogge et al., 2011). Therefore, heavy polluters can reduce their abatement cost by simply buying allowances at a lower cost from the market, while other firms can offset their cost of innovation for efficient GHG reduction using the funds that heavy polluters pay to them. As existing research has identified, participants of emission trading have incentives to reduce GHG with lower costs and innovative technologies (Boyce, 2018; Haites, 2018; Rogge & Hoffmann, 2010).

Additionally, emission trading schemes adopt a "cap," or total upper bound for GHG emission. This cap is normally designed to gradually decline over time to reduce emissions, and to increase the price of emission permits. This ensures that the emission reduction target is met. In theory, emission trading can both achieve cost-efficient GHG reduction and the actual mitigation of GHG emissions in a flexible way (Boyce, 2018). Yet, there may exist transaction cost from allocating emission permits across different industry sectors that a government has to moderate (Goulder & Schein, 2013).

Compared to emission trading, carbon tax may be less effective in encouraging investment in technological innovation which is crucial in reducing abatement cost across economic actors. Carbon tax operates by setting a tax rate per unit of emissions or fossil fuel use. It aims to gradually dampen the use of taxed fossil fuels or GHG emissions by increasing tax rates. If any economic actors reduce GHG emissions by investing in cleaner production, they will be able to save costs from not paying taxes. However, if the expected net benefit of investment is lower than the total amount of carbon tax they need to pay if investment is not made, economic actors will not take mitigation actions. Haites (2018) pointed out that too low tax rate and uncertainty in tax rate change are two major reasons for the ineffectiveness of carbon tax policies in European countries. Some studies acknowledge that it is hard to observe high carbon tax rates due to public resistance, as individuals tend to associate carbon taxes with higher personal costs than other mitigation policy alternatives (Carattini et al., 2018; Jagers & Hammar, 2009).

Most importantly, since carbon tax does not set a cap, it may not ensure actual GHG reduction if there are a significant number of firms or individuals who find paying taxes to be less costly than engaging in GHG reduction efforts. Unlike emission trading, carbon tax is put on both households and firms (Jenkins, 2014; Lundgren et al., 2015). That is, primary entities for paying carbon tax encompass all economic actors including not only producers but consumers (including households). Compared to firms, households may have lower level of innovative capacity since their energy use is less elastic. Yet, the number of households is far greater than the number of firms impacted by carbon tax. Therefore, carbon tax may not lead to efficient reduction by promoting technological innovation from a larger number of economic actors than emission trading can.

Yet, carbon tax may also incentivize cleaner production by allocating the tax revenue (Baranzini et al., 2000). Carbon tax may bring an "environmental double dividend" to those activities of emission reduction- the first dividend from saved costs by not paying a tax, and the second dividend from government funds from tax revenues. In addition, swapping (or cutting) distortionary taxes such as income or sales taxes with carbon tax can bring cost savings of tax system. Revenues from environmental taxes including carbon tax can internalize negative externalities (here GHG emission) as well as reduce revenues from distortionary taxes (Goulder, 1995).

Our survey of the difference between emission trading and carbon tax generates testable hypotheses regarding the relationship between decoupling and carbon pricing. We test whether carbon pricing instruments have a positive impact on decoupling trend, but at the same time whether emission trading and carbon tax have different impacts. Hence, we use both emission trading and carbon tax as two independent variables to capture the role of carbon pricing instruments in decoupling trend. Along with other variables, we explain our data, method, and models in the next section.

DATA AND METHOD

Data

We use a time-series cross-sectional data of 29 European countries from 1996 to 2014. Our use of the time frame (1996–2014) is due to data availability- most of our control variables we retrieved from the World Bank are available only up to 2014. A recent study which examines the differences in GHG reduction among countries with renewable energy development pathways and those with nuclear energy development pathways also analyzes observations earlier than 2014 for a similar reason (Sovacool et al., 2020).

Choosing European countries as a sample group has two reasons. First, focusing on a single region like Europe mitigates unobserved variable biases that arise when comparing countries from different regions. For instance, the European Union Emission Trading System (EU-ETS) and the ETS in South Korea (KETS) differ significantly in terms of their scope, design, and policy goal. The second reason is a practical one. The European Environment Agency (EEA) and OECD provide us with data for almost all European countries, including various economic, social, and policy indicators, as well as GHG emissions of all types.

Our key dependent variable is the extent of decoupling which is measured as emission intensity ($kgCO_{2eq}$ per real GDP of $1,000, 2010 constant). We use all 7 types of greenhouse gases (CO_2, CH_4, HFCs, N_2O, NF_3, PFCs, SF_6) and their CO_2 equivalent values. If $\Delta GDP > \Delta GHG$ in a given country in a given time, that is, if decoupling occurs, emission intensity decreases. Therefore, a decrease in emission intensity is a proxy for decoupling. If the result indicates that a one unit increase of a certain independent variable contributed to a decrease in emission intensity, said variable is considered to have facilitated decoupling.

Our key explanatory variables are the adoption of emission trading and carbon tax.[1] For each policy instrument, we coded it as one if each policy was implemented and operational in each country-year and zero otherwise. If each instrument is negatively associated with our dependent variable (emission intensity), it can be interpreted that each instrument is associated with more decoupling trend in a society. Furthermore, to see if they also reduce the absolute amount of GHG emissions, we use an additional dependent variable, which is the amount of GHG emissions (million CO_{2eq}). If each instrument is negatively associated with both emission intensity and GHG emissions, it promotes strong decoupling. If it is negatively associated only with emission intensity and not with GHG emissions, it promotes weak decoupling.

To elicit the effect of carbon pricing in our analysis as much as possible, we included several control variables that may also affect decoupling. First, energy and electricity efficiency can promote decoupling (Dinda, 2004; Goldemberg, 2020). Therefore, we used carbon intensity and electricity inefficiency as control variables. Here, carbon intensity refers to the capacity of a society to produce less GHG emissions for a unit of energy use, calculated as $kgCO_{2eq}$ per kg oil equivalent, not per unit of GDP. Electricity inefficiency refers to a loss of electric power in the process of its transmission and distribution, compared to the initial output (%). Higher rate of electricity inefficiency is likely to impede decoupling.

Next, decoupling can vary according to how the national energy mix is shaped (Harris & Lee, 2017). Therefore, we also included the shares of renewable energy (%) and fossil fuel (%) in the national primary energy mix. Adopting more renewable energy makes decoupling easier by reducing GHG emissions from fossil fuel usage. In a similar vein, countries with higher level of fossil fuel portion in the national primary energy mix are likely to increase GHG emissions because energy sectors tend to be dominated by the fossil fuel industry interests and infrastructure.

The level of democracy is introduced to consider the impact of fairer elections and the degree of political participation on the environmental quality of a country. Democratic regime has been known to be responsive to environmental degradation since elected leaders require to provide public goods including climate change mitigation (Farzin & Bond, 2006; Harris & Lee, 2017). The urbanization rate is also included to control for its impact on environmental quality, in that cities are primary GHG emitters, not only globally but in Europe as well. On the other hand, cities are centers for climate experiment and innovation. The impacts of urbanization on decoupling need to be tested with empirical analyses (Lee, 2018).

We control for several economic variables that might be associated with decoupling. The GDP growth rate is included as emission intensity may increase or decrease simply because the rate of GDP growth changes. Finally, we included how much industry output consists of GDP, measured by all value added in mining, manufacturing, construction, electricity, water, and gas. This is to consider how much each country's economic dependence on industry affects the level of decoupling and control for it. Appendix A shows the descriptive statistics of all covariates we have explained so far.

Model specification

We devise several model specifications for the robustness of our findings. First, Model 1 includes all explanatory and control variables with its dependent variable being emission intensity. In Model 2, we add to Model 1 an indicator of government effectiveness retrieved from the World Government Index (WGI). Even if an environmental policy instrument is adopted in democracies due to high public demand for better environmental quality, it may prove to be ineffective if the quality of their institution is low. Therefore, we let government effectiveness interact with our two explanatory variables. Since government effectiveness indicator has been missing observations in certain years, we include it in a separate model.

Additionally, Model 3 is the same model with Model 1 and Model 4 with Model 2 except for the dependent variable. Since the decrease in emission intensity does not tell us whether there is a strong or weak decoupling trend in a country, we use GHG emissions (including all 7 types of GHG) as a dependent variable in Model 3 and 4. As explained earlier, a country is experiencing a strong decoupling trend when both emission intensity and GHG emissions are falling. We compare all four models to see if either an emission trading or a carbon tax facilitates either a strong or weak decoupling, or does not facilitate any at all.

All four models are two-way fixed effects models[2] to control for unobserved country- and year-specific confounders. For instance, countries that were Economies in Transition (EITs) may have different characteristics from non-EITs that contribute to the different level of decoupling. Also, given the high level of economic integration of European region, the level of decoupling in all observations may have been affected by the same regional economic circumstances in each year. Lastly, since our observations are largely homogeneous due to their regional proximity, we report Driscoll and Kraay (1998) standard errors clustered by each country for our coefficient estimates in all models. These standard errors are robust for panel regressions with cross-sectionally and serially correlated errors across observations.

RESULT AND DISCUSSION

Two-way fixed effects model

Table 2 shows the results of all models. If any variable shows negative coefficient estimates in Model 1 and 2, we understand it is a contributing factor to the decoupling trend. Model 3 and 4 help us further determine whether the variable contributes to strong or weak decoupling trend. If the variable also shows negative coefficient estimates in Model 3 and 4, it is considered a contributing factor to the strong decoupling trend. If it does not, then it contributes to the weak decoupling trend. When the variable has positive coefficient estimates in all models, we suggest it does not facilitate any types of decoupling trend.

The results show that the adoption of emission trading has a negative and significant coefficient estimate in Model 1 and 2, which implies that it has contributed to the decoupling trend. This result is in line with our expectation on the ability of emission trading to facilitate lower abatement costs, which is also consistent with a recent empirical analysis by Cludius et al. (2019)

TABLE 2 Two-way fixed effects model results

	Model 1	Model 2	Model 3	Model 4
Dependent variable	**Emission intensity**		**GHG emissions**	
ETS	−86.34***	−250.22***	−31.25*	−17.54
	(30.62)	(41.91)	(17.76)	(16.65)
Carbon tax	−28.23	−173.67	−13.87	−9.50
	(66.90)	(162.82)	(14.97)	(20.51)
Carbon intensity	150.01	73.70	−42.58	−29.03
	(137.51)	(108.25)	(50.01)	(20.51)
Electricity inefficiency	12.79	3.96	−1.67	−1.14
	(8.32)	(2.94)	(1.28)	(.96)
Renewable consumption	−9.10	−7.56	−2.85**	−2.51**
	(8.37)	(4.45)	(1.42)	(1.24)
Fossil fuel consumption	−7.85	−3.18	2.06	1.70
	(6.17)	(4.25)	(1.57)	(1.42)
Urbanization	14.40*	7.78	−.18	1.13
	(8.13)	(7.34)	(1.35)	(1.76)
Democracy	−10.65	−.81	−1.06	−2.24*
	(14.46)	(17.01)	(1.01)	(1.24)
Government effectiveness	–	−167.56***	–	35.44
		(30.81)		(23.86)
ETS × Government effectiveness	–	133.83***	–	−4.33
		(30.91)		(6.50)
Carbon tax × Government effectiveness	–	98.64	–	−2.03
		(82.88)		(17.44)
Economic growth	−3.00	−1.04	−.33	−.69
	(2.41)	(1.76)	(.66)	(.56)
Industry	−20.01***	−11.90***	1.64	.99
	(6.80)	(3.81)	(1.25)	(1.06)
N × T	29 × 19	29 × 16	29 × 19	29 × 16
Adjusted *R*-squared	.216	.410	.120	.132
Hausman test *p*-value	.000	.017	.003	.133

Note: Driscoll and Kraay standard errors clustered by countries are reported in parentheses.
*$p < .1$; **$p < .05$; ***$p < .01$.

which supported the impact of EU-ETS in improving cost efficiency in reducing GHG emissions. Model 3 also shows that the adoption of emission trading has a negative and significant coefficient, which further suggests that it was a contributing factor to the strong decoupling trend. However, this finding is less credible since Model 4 does not support that the adoption of emission trading is negatively associated with GHG emissions. Even if we use random effects model, the adoption of emission trading is not a significant factor for GHG reduction in Model 4.

We report that our evidence does not support the role of carbon tax in promoting any types of decoupling trend, as the adoption of carbon tax in all models do not have significant coefficient estimates. This is not to say, however, that we conclude there is no meaningful relationship between carbon tax and decoupling trend. Unlike emission trading in our data which is largely from the single policy (EU-ETS), carbon tax policies took different designs in different countries, introduced in different time periods. Therefore, the heterogeneity across carbon tax policies in our observations is more severe than that across emission trading policies, which is hardly captured by using a binary variable. Therefore, we suggest that the lack of evidence for the role of carbon tax in decoupling trend is largely due to the limit in our research design rather than due to its actual components and their ability to promote decoupling.

Interestingly, the introduction of government effectiveness indicator in the model amplifies the negative association of emission trading with emission intensity. In Model 2, the adoption of emission trading is associated with the decline in emission intensity by around 250.22 kg per gross production of $1000, which is about three times stronger decline due to the adoption of emission trading estimated in Model 1. Also, when considering interaction term between government effectiveness and emission trading, government effectiveness reinforces the negative association of emission trading with emission intensity.

Figure 2 compares the marginal effects on emission intensity and their 95% confidence interval between when emission trading is in effect and when not, conditional on the level of government effectiveness whose score ranges from −2.5 to 2.5. Note that the left pane of this plot shows that the marginal effect of emission trading on emission intensity gets lower when the level of government effectiveness gets higher. In other words, the higher the government effectiveness is, the stronger the effect of its emission trading on decoupling becomes. This finding is in line with our expectation that not all emission trading will have the same effect on decoupling: Its effectiveness, like any other type of policy instrument, can be conditioned by the administrative capacity of the government to better formulate and carry out policy options.

There are several other things to note from this plot. First, this plot captures the marginal effect of emission trading itself. If government effectiveness score is lower than zero, the marginal effect on emission intensity is higher than zero when emission trading is not in effect, which is not the case when emission trading is in effect. Moreover, if government effectiveness score is higher than two, while the marginal effect on emission intensity is much lower when emission trading is not in effect than when it is, the lower bound of its 95% confidence interval reaches far down to almost −700 when emission trading is in effect, which is lower than that when emission trading is not in effect.

Results with coarsened exact matched data

Our two-way fixed effects model suggests the effect of emission trading on the level of decoupling which is not biased by country- and year-specific unobserved confounders. However, to be more confident about our inference of its causal effect, we need to make sure whether countries with and without emission trading are homogenous in every possible aspect. In other words, much bias on our estimated coefficient of emission trading from two-way fixed effects model can arise from the unobserved differences between treatment group (countries *with* emission trading) and control group (countries *without* emission trading). Also, it is difficult to infer causal effect from two-way fixed effects estimators when the treatment is given at different periods of time, which is the case of our sample (Imai & Kim, 2021). To overcome these limits, we used

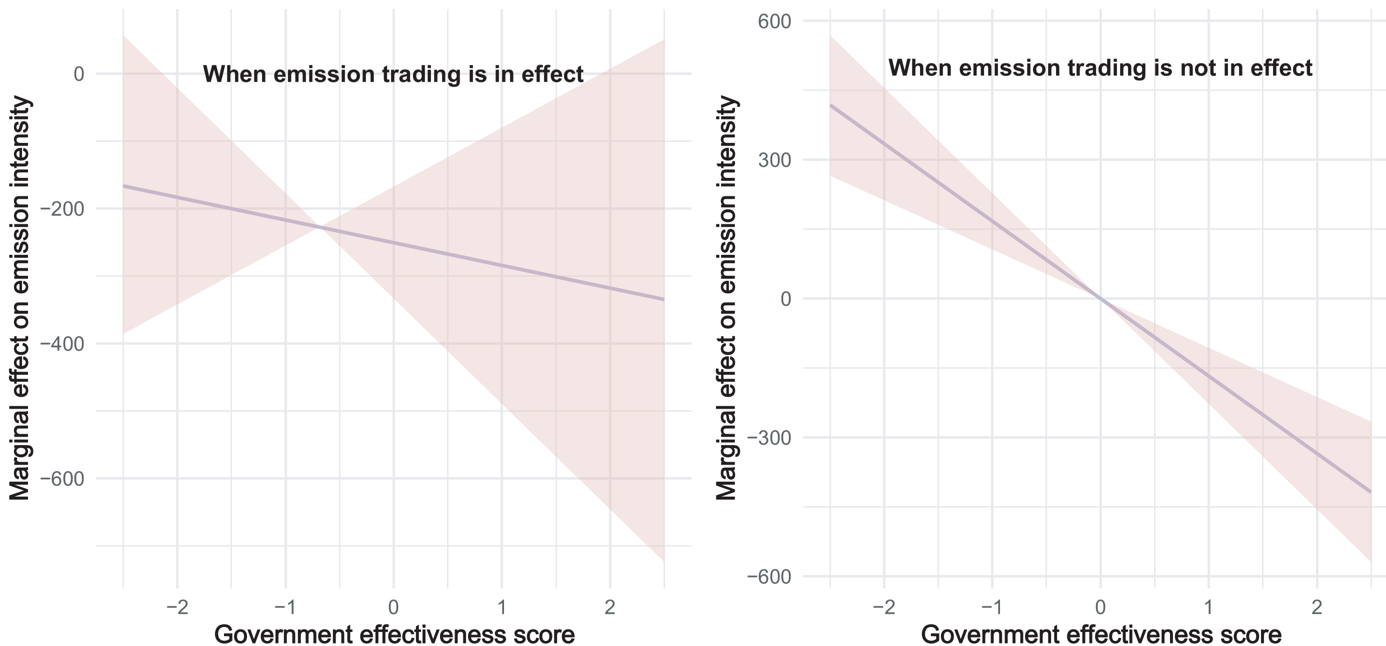

FIGURE 2 Marginal effects on emission intensity conditioned by government effectiveness (95% confidence interval shaded)

TABLE 3 SATT of emission trading on emission intensity in CEM matched data

Models	SATT
1. Linear regression	−47.73
(no control variables)	[−181.20, 85.74]
2. Linear regression	−28.56
(with all control variables)	[−76.30, 19.18]
3. Linear random effect model	−31.15
(with all control variables)	[−36.20, −26.08]

Note: 95% confidence interval is shown in parentheses.

a matching method to ensure as much homogeneity as possible between countries with and without emission trading and make a better inference of the causal effect of emission trading in decoupling.

Specifically, we attempted to make these treatment and control groups as identical as possible by using Coarsened Exact Matching (CEM) (Iacus et al., 2012). CEM enables us to match the means and distributions of control variables between treatment and control groups. The observed variables we use for matching are the same as in Model 1, yet we treat the adoption of emission trading as a single treatment variable and that of a carbon tax as a control variable. We could not use government effectiveness indicator for matching as it reduces the number of observations due to missing years.

Through matching, 292 country-years *with* emission trading are reduced to 32 (control group), whereas 259 country-years *without* emission trading are reduced to 27 (treatment group). These matched units are spread across 18 strata where each stratum has at least one treatment and one control unit that are matched. Therefore, units on the same stratum are matched as much as possible in terms of all variables except for the adoption of emission trading, which is the treatment variable. We use this matched data to estimate the sample average treatment effect on the treated (SATT) on emission intensity between treatment and control groups.

Table 3 summarizes the SATT of three different models using matched data. The first model is a linear regression model which includes the adoption of emission trading as a treatment variable. The second model is also a linear regression model but includes the treatment variable and all control variables we included in our previous two-way fixed effects model. The third model is a linear random effects model with all variables included. Linear model with random effects in CEM assumes that each stratum after matching has an unknown stochastic strata-specific effect. The SATT was negative and significant only in the third linear random effects model. Note that the magnitude of the coefficient for emission trading was reduced to −31.15 from that in Model 1 in section "Two-way fixed effects model" which is −86.34. This suggests that our previous two-way fixed effects model possibly exaggerated the effect of emission trading on decoupling.

Furthermore, Figure 3 visualizes the comparison of results between linear model and linear random effects model with all variables included. The line indicates a stratum where at least one treatment unit and one control unit exist, and there are 18 lines since our CEM result produced 18 strata. The point on each line indicates the difference in emission intensity between treatment and control units on each stratum, which is the treatment effect for each stratum. The SATT for each model in Table 3 is calculated by averaging all values of the points in each model. In a linear regression model, only 9 out of 18 strata showed the treatment effects significantly lower

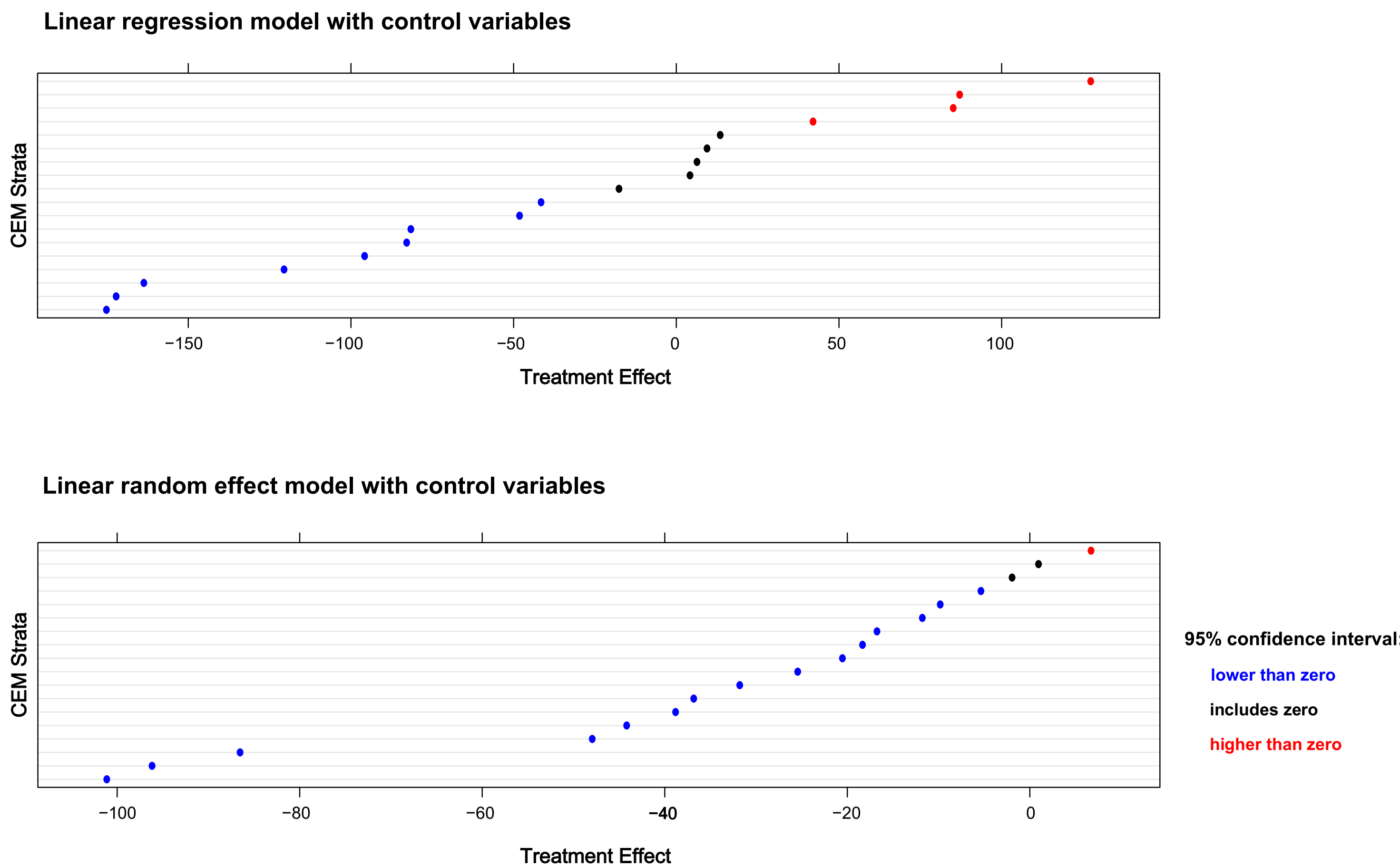

FIGURE 3 Treatment effects on each stratum in linear regression and linear random effect models with all variables included

than zero. However, in a linear random effect model, 16 out of 18 showed the treatment effects significantly lower than zero.

This suggests our analysis further lends support to the effect of emission trading on decoupling only if we assume a heterogeneous treatment effect, which is also shown in Model 2. Plainly speaking, even though the same policy for emission trading (EU-ETS in our study) is adopted across almost all observations, its impact on decoupling trends varies depending on unobserved socioeconomic condition of each observation, which is represented as a random strata effect in Figure 3. For instance, if we include interaction terms between emission trading and control variables in Model 1, the effect of emission trading on emission intensity has become weaker (less negative) as energy inefficiency variables (carbon intensity and electricity inefficiency) increase.[3] This suggests that even though emission trading is being operated, it may promote less decoupling if a society has a lower level of energy efficiency. In other words, the effect of emission trading on decoupling can be conditioned by how much efficiently a society produces and consumes energy. In addition, emission trading can have an impact on energy efficiency level in the long run. Although this example uses observed socioeconomic conditions that are included as control variables in our analysis, this demonstrates the way in which how further unobserved conditions that are not included in our analysis can condition the effect of emission trading on decoupling. This is also consistent with how EU-ETS has been operated, as it had set different caps across countries depending on their level of economic development, industrial composition, and energy mix until 2012.

CONCLUSION

Achieving higher level of decoupling is a goal for countries that aim to both achieve economic growth and reduce their GHG emissions. However, not all countries are achieving decoupling. Our result from two-way fixed effects model suggests that the countries are more likely to have lower emission intensity and therefore move toward decoupling trends after adopting emission trading. The SATT estimate from linear random effects model based on CEM-matched data suggests, however, that the impact of emission trading on decoupling may be conditioned depending on the country-specific conditions such as energy efficiency and other unobserved factors which we could not account for in our study. For instance, countries with higher proportion of industry in their total GDP or those with less efficient electric power system have lower level of decoupling in their society.

Also, evidence from our data could not support any relationship between carbon tax and decoupling. However, as explained in section “Result and Discussion”, we are not to argue that carbon tax does not have any impact on decoupling, since our research design may not capture its stringency and impact well. Unlike emission trading in our sample which was largely EU-ETS, carbon taxes in our sample have different scopes and policy designs across countries. Therefore, the use of dichotomous variables might be more inappropriate for measuring the impact of carbon tax than for measuring that of emission trading, and this could have biased our results.

This study contributes to the literature of the political economy of climate policy, particularly decoupling and carbon pricing literature, by posing questions regarding the variation in decoupling between different European countries. Theoretically, we propose a causal relationship between carbon pricing instruments and decoupling. Carbon pricing was originally designed and implemented to reduce GHG emissions in an efficient manner (Tietenberg, 2013).

Market-based mechanisms grounded in carbon pricing facilitate innovation to mitigate climate impacts (Jenkins, 2014). In agreement with extant studies of the impact of emission trading on environmental efficacy, this study finds that the adoption of emission trading is a driver for decoupling. Empirically, by using panel data analysis with a series of model specifications, this study tests this theoretical argument for European cases. Compared to existing literature with a focus on a specific country, an industrial sector, or a company, the time-series and cross-section data analysis presented here empirically covers 29 European countries over 19 years. Also, this is among the first studies to use matching methods to estimate the causal effect of carbon pricing instrument on decoupling.

This finding also provides policy implications for those countries where plan to adopt carbon pricing instruments for GHG emission reduction. ETS is a tool that can help the decarbonization of countries and company in an efficient manner. Given the increase of countries' pledge for carbon neutrality, carefully planned and effectively implemented ETS can bring significant economic and environmental benefits.

Despite the above contributions, future research would strengthen decoupling studies. Our result suggests that not all carbon pricing instruments encourage decoupling. The utilization of sophisticated measures with stringency and prices for carbon pricing policy may result in nuanced outcomes regarding carbon pricing effects. For instance, having different level of carbon tax of \$119/tCO_2eq in Sweden and \$10/tCO_2eq in Latvia may have a varying impact on GHG emissions and decoupling. In a similar vein, the impacts of \$33/tCO_2eq ETS price in South Korea and \$14/tCO_2eq ETS price in New Zealand may also vary (World Bank, 2020). Future studies could explore the different types, price, and policy components of carbon pricing instruments, and how their effect in decoupling varies. Empirically, extending this analysis to other regions and countries would generalize the suggested findings. This expanded scope can also benefit researchers who wish to test whether heterogenous treatment effect of emission trading is present by looking at more diversified country-level characteristics.

CONFLICT OF INTEREST

None.

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ENDNOTES

1 One can ask whether countries in our sample have adopted emission trading at the same time, which is EU-ETS, since our regional scope is Europe. However, while EU-ETS was initiated in 2005, not all countries in our sample have adopted EU-ETS in the same year: Iceland and Norway joined at the 2nd period of EU-ETS (2008), Croatia joined at its third period (2013), and Turkey never joined. Switzerland did not join EU-ETS until they linked their own ETS to EU-ETS in 2020, which changed its stipulation from voluntary to mandatory participation of regulated entities in 2013. Therefore, we coded that Switzerland adopted emission trading since 2013.

2 We conducted a Hausman test to confirm whether modeling country and year effects as fixed effects is more favorable than modeling them as random effects. Admittedly, there is a growing concern that the result of a Hausman test should not be the sole reference to decide whether to use fixed or random effects model (Bell et al., 2019). As we are aware of the unobserved confounders as mentioned earlier, we center our interpretation on the results of two-way fixed effects model. Nevertheless, we report the results of a Hausman test in the table for reference. If the test results are more favorable to random effects, we report whether the results from fixed effects model and random effects model are greatly different.

3 When we included interaction terms between emission trading and all other variables in Model 2, the coefficient estimate of the interaction term between emission trading and carbon intensity was −74.26 with Driscoll and Kraay's standard error of 25.38, and that between emission trading and electricity inefficiency was −14.98 with standard error of 6.17. The coefficient estimate of the adoption of emission trading was significant at 90% confidence level.

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APPENDIX A

DESCRIPTIVE STATISTICS

Variable	Description	Mean	*SD*	(Min, Max)	Source
Dependent variables					
Emission intensity	$kgCO_{2eq}$/$1,000 of Real GDP (USD 2010 constant)	505.90	367.76	(85.91, 2229.13)	EEA (European Environmental Agency)
GHG emissions	Million tCO_{2eq}	193.20	241.74	(8.26, 1155.28)	WDI (World Developmental Indicators)
Independent variables					
Emission trading	1 = implementation, 0 = no implementation	.47	.50	(0, 1)	EEA
Carbon tax	1 = implementation, 0 = no implementation	.28	.45	(0, 1)	carbontax.org
Control variables					
Carbon intensity	$kgCO_2$ per kg of oil equivalent	2.33	.58	(.90, 3.44)	WDI
Electricity inefficiency	A loss of electric power output in the transmission and distribution (%)	8.45	4.52	(1.82, 46.58)	WDI
Renewable consumption	A percentage of renewable energy in final energy consumption	16.47	13.22	(.85, 60.19)	WDI
Fossil Fuel consumption	A percentage of fossil fuel energy in final energy consumption	73.59	17.87	(14.49, 98.53)	WDI
Urbanization	A ratio of urban population to total population (%)	70.55	10.76	(49.70, 97.82)	WDI
The level of democracy	Polity IV score	9.44	1.42	(−5, 10)	Polity IV
Government effectiveness	Government effectiveness indicator	1.15	0.67	(−.57, 2.35)	WGI (World Government Index)
GDP growth rate	Real GDP growth rate (%)	2.55	3.54	(−14.81, 11.89)	WDI
Economic dependence on industry	Industry (including construction), % of GDP	25.54	4.93	(9.89, 40.29)	WDI