Carbon Pricing Policies 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 between countries, and examines which factors are driving this decoupling. We expect that the implementation of carbon pricing policies facilitates decoupling, as they are designed to achieve cost-efficient GHG reduction. We analyze the panel data of 29 European countries between 1996 and 2014 to examine the relationships between two carbon pricing policies (emission trading and carbon tax) and emission intensity (GHG emissions per unit of GDP) we use to capture 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. Our additional analysis for robustness check suggests that even a single emission trading policy across different jurisdictions may render a heterogeneous effect on decoupling, conditions of which need a further investigation.

Keywords: Decoupling, Carbon pricing, Emission trading, Carbon tax, Emission intensity Climate change mitigation, Two-way fixed effects

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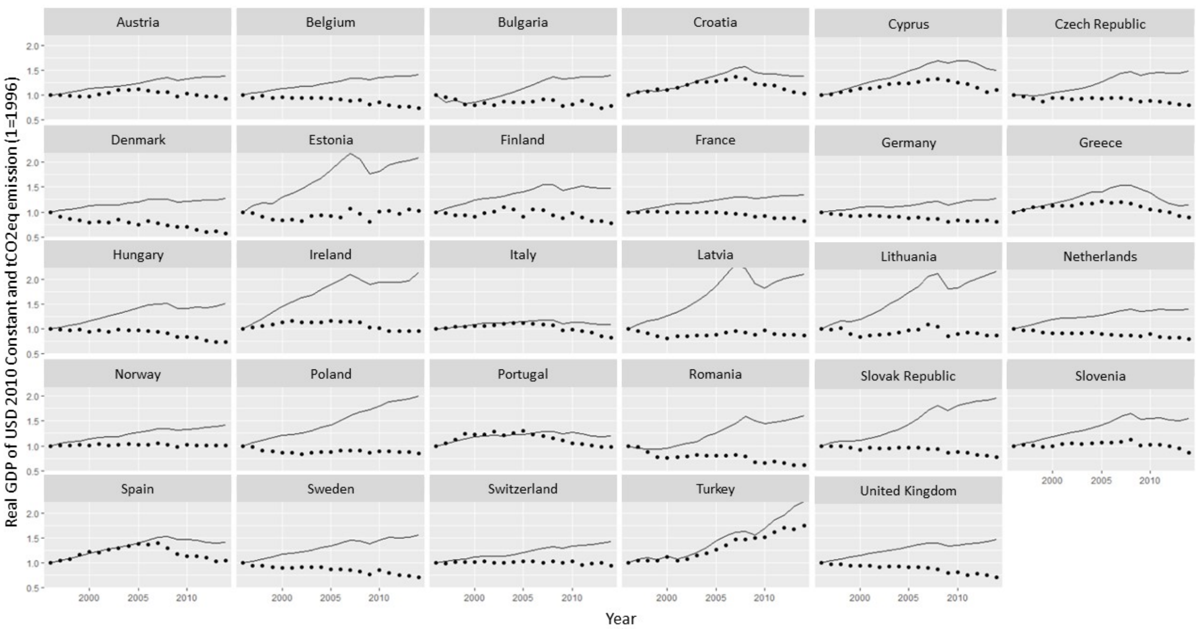
Introduction

It is imperative to mitigate greenhouse gas (GHG) emissions to meet the Paris Agreement target, to ensure sustainability both in the present and in the future. 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 (Andreoni and Galmarini 2012; Jorgenson and Clark 2012). Achieving a decoupling trend has been widely discussed as a potential breakthrough for the global climate change problem.

However, the current scenario does not conform to the idealistic discourse regarding decoupling: meaningful empirical variation exists in the degree of decoupling in different countries. Even among European countries, which have been most active regarding mitigation, some countries, such as Sweden or the United Kingdom, have largely achieved decoupling, whereas others, such as Italy or Portugal, have not. Figure 1 summarizes this variation at glance. It would therefore be interesting to see which factor, all else being equal, is a driver for a decoupling trend.

Figure 1. Time-series graphs showing 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})).

To answer this question, we examine the relationship between a decoupling trend and carbon pricing policies which aim to promote cost-efficient mitigation actions. 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 socially desirable *quantity* of emission reduction, carbon tax sets its socially desirable *price*.

Our analysis of the relationship between decoupling and carbon pricing instruments represents a novel contribution to the literature for two reasons. First, previous studies have examined the various conditions required for decoupling to occur, yet few of these studies included carbon pricing policies as their key independent variables. We can determine which policies help countries to better achieve decoupling by examining whether different types of carbon pricing policies have different impacts on decoupling. Second, researchers have discussed the effectiveness of emission trading or carbon tax, yet these studies mainly consist of single country cases (Lundgren et al 2015; Mascher 2018; Mo et al 2016; Rogge and Hoffmann 2010; Sandoff and Schaad 2009). Despite the possible link between decoupling and carbon pricing in terms of cost-efficient GHG mitigation, few studies have analyzed their relationship using time-series and cross-country comparisons.

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 policies. 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 different carbon pricing policies in promoting decoupling leveraging a single measurement for decoupling, which is emission intensity (GHG emission per GDP), and showing how its relationship to each policy differs.

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 and Clark 2012). Scholars have, however, often used different terms, such as, a low-carbon society or economic growth (Reilly 2013), green economy (Ferguson 2014), or green growth (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 hypothesis based on this idea is the Environmental Kuznets Curve (EKC) hypothesis, which predicts that a country can achieve decoupling after it has attained a certain level of economic development (Clulow 2016). 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 policies instead of economic development).

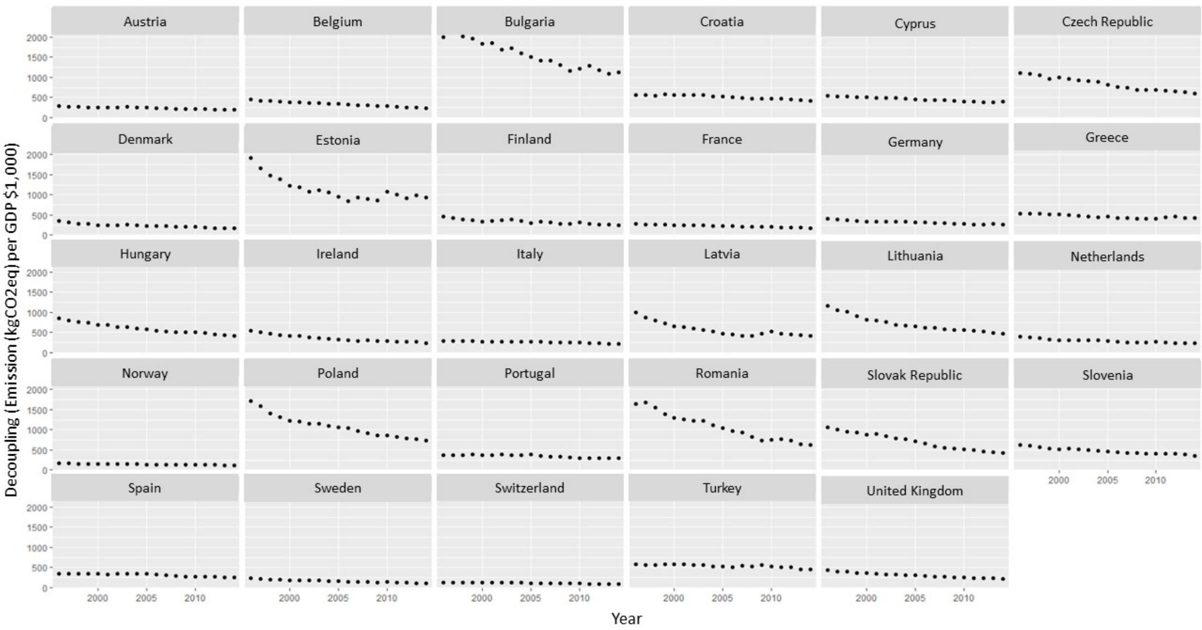
Among various indicators, decoupling can be measured with emission intensity, which is the volume of GHG emissions divided by the GDP of a given country in a given year. Consider an example of countries A and B for two periods, t and t+1, as shown in Table 1. For both A(t) and B(t), let GDP be US$ 1,000 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 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 and 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, a lower emission intensity can indicate a decoupling trend in a country, be it a strong or weak one.

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	

Measuring decoupling with emission intensity allows us to compare the degree of decoupling across countries. Figure 2 shows the variations in emission intensity across the countries of our sample group that we leverage in this research. Why does emission intensity vary across European countries, which have stood out as the most active country-group regarding mitigation actions?

Figure 2. Emission intensities of 29 European countries, 1996-2014



Carbon pricing and decoupling

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 policies regulate specific GHGs, and covert 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 (Tietenberg 2013). Emission trading creates a "political market" (Keohane et al 1999) where liable firms (polluters) can trade emission allowance units with each other at market price (Lederer 2017). While the market determines a carbon price in emission trading, for a carbon tax, the government determines the price. The government imposes an additional tax on goods and services, based on how much GHG they emit in their production process, or how much they possess in their contents.

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 partially contributing to a decoupling trend—in this case weak decoupling. Only when it succeeds in both aspects can it be considered to have contributed to strong decoupling.

While both carbon tax and emission trading are carbon pricing policies designed to curb GHG emissions in more efficient way than command-and-control regulation does, two policies employ different mechanisms to attain the goal, and may thus produce different outcomes for decoupling. First, emission trading can effectively deal with the first factor: lowering abatement cost. Under an 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 and Hoffman 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.

Meanwhile, carbon tax is 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 prices (Haites 2018). 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. It also may not translate into economic incentives from selling tradable permits to heavy emitters as emission trading allows. Furthermore, as with different types of taxes, carbon tax not only makes the direct emission of GHGs more costly, but also makes indirect emission (i.e. energy consumption) more costly, the latter of which is essential for the production of goods and services. In sum, not only can it fail to incentivize cleaner production if tax rate is not higher than the expected utility of investment for it, but also it can incur additional costs on firms that might have been spent in investment.

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 active in emission reduction- the first dividend from saved costs by not paying a tax, and the second dividend from government funds from tax revenues. Previous studies suggest, however, that carbon tax may have a negative impact on GDP if revenues from carbon tax are not properly used to promote innovation or alternative economic activities (Allan et al 2014; Meng et al 2013). It is also likely that the allocation of tax revenue incurs a high transaction cost, as it is hard to set not only an appropriate tax rate but also criteria of which firm to reward with tax revenue.

In addition, carbon tax does not set a cap, which may not ensure that actual GHG reduction is achieved, if there are a significant number of firms or individuals who find paying taxes to be less costly than investing in cleaner production. Unlike emission trading, carbon tax is put on both households and firms (Jenkins 2014; Lundgren et al 2015). Compared to firms, households may have lower level of innovative capacity as 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 more economic actors.

To conclude, 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 policies 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 policies in decoupling trend. Along with other variables, we explain our data, method, and models in the next section.

Data and method

We use a panel data of 29 European countries from 1996 to 2014. Our time frame of 1996-2014 is due to data availability- most of our control variables are available only up to 2014. 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. Additionally, focusing on a single data source helps us control for the method of measuring greenhouse gas emissions across all units of analysis.

Our key dependent variable is decoupling. The extent of decoupling is measured in this paper as emission intensity (kgCO_{2eq} per real GDP of $1,000, US$ 2010 constant) shown in Table 1 and Figure 2. If ΔGDP > ΔGHG in a given country in a given time, that is, if decoupling occurs, the 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 independent variables are the adoption of emission trading (0-1) and carbon tax (0-1). For each policy instrument, we coded 1 if each policy was implemented and operational in each country-year and 0 if not. 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 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 with only emission intensity, it promotes weak decoupling. **Table 2** presents the descriptive statistics of the panel data. 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). Therefore, we used carbon intensity and electricity inefficiency as control variables. 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. 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.

Table 2. Descriptive statistics

Variable	Description	Mean	S.D.	(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	A percentage of renewable energy in final energy consumption	16.47	13.22	(.85, 60.19)	WDI
Fossil Fuel	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
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

Next, decoupling can vary according to how the national energy mix is shaped (Harris and 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 and Bond 2006; Harris and 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.

We chose a two-way fixed effects model for the analysis. This is because we suspect that unobserved unit- and time-specific confounders may lie between our dependent and independent variables. 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, time-specific conditions of regional economy may have affected each unit's decoupling level. For these reasons, we center our interpretation on the results from the fixed effects model.

Result and discussion

Table 3 shows the results of two models. The first model uses an emission intensity to investigate the relationship between decoupling and independent variables. The second model uses an absolute GHG emission to see inform the results from the first model of whether each variable contributes to strong or weak decoupling.

We conducted a Hausman test for both models. 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 (Bell et al 2019). However, as we are aware of the unobserved confounders as mentioned earlier, we center our interpretation on the results of two-way fixed effects model. Also, a Hausman test for both models has shown significantly low p-values, which supports our choice of two-way fixed effects instead of random effects. All results were shown with Beck-Katz panel corrected standard errors (1995).

Confirming that the signs of the coefficients in Models 1 and 2 are not different from each other, a variable is understood to facilitate strong decoupling when it shows negative coefficients in both Models 1 and 3. A variable is interpreted to facilitate weak decoupling when it shows a negative coefficient in Model 1 (emission intensity as a dependent variable) but a positive one in Model 2 (GHG emissions as a dependent variable). When a variable has positive coefficients in both Models 1 and 2, it does not facilitate any type of decoupling.

Our analysis of the factors that influence the level of decoupling confirms our hypothesis that emission trading and carbon tax present different outcomes. Emission trading is negatively associated with emission intensity as well as GHG emissions. Using our previous example in Table 1, countries that adopted emission trading are more likely to resemble the case of country A rather than B. This shows that emission trading leads to strong decoupling. However, our results are less confident with the effect of carbon tax on decoupling as well as GHG reduction than that of emission trading.

Table 3. Model Estimation Results

	Model 1 DV: Emission intensity	Model 2 DV: GHG emissions
Model	**Two-way Fixed Effects**	
Emission Trading	-86.34* (45.74)[1]	-31.25** (12.19)
Carbon Tax	-28.23 (57.23)	-13.87 (15.79)
Carbon Intensity	150.01 (168.51)	-42.58 (44.47)
Electricity Inefficiency	12.79** (5.17)	-1.67 (1.32)
Renewable	-9.10 (6.43)	-2.85* (1.68)
Fossil Fuel	-7.85 (6.31)	2.06 (1.71)
Urbanization	14.40 (9.90)	-0.18 (2.50)
Democracy	-10.65 (11.43)	-1.06 (2.37)
Economic Growth	-3.00 (2.25)	-0.33 (0.57)
Industry	-20.00*** (5.90)	1.64 (1.46)
Intercept	-	
N X T	29 X 19	29 X 19
Adj. R^2	.227	.5159

Note: Adjusted R^2 is reported. Beck-Katz panel corrected standard errors (Beck and Katz 1995) are reported in parentheses. *- p<0.1, **- p<0.05, ***- p<0.01

[1] We report the result that has the largest standard error among all other variations we tested. Other types of panel robust standard errors were as follow: Arellano's (1987) standard error: 32.3932; Driscoll and Kraay's (1998) standard error: 29.2684. None of these different types of standard error for the coefficient of carbon tax were low enough to present it as statistically significant.

Among the other control variables, electricity inefficiency and economic dependence on industry showed coefficients with low standard errors. Specifically, 1% increase in the loss of electric power in the process of its transmission and distribution is associated with the increase in emission intensity by 12kgCO_2 per $1,000 of GDP. This means that inefficient electric power system can hinder a progress toward decoupling. Also, 1% increase in the proportion of industrial output in GDP is associated with its decrease by the same unit of 20, implying that industrial development may facilitate weak but not strong decoupling.

Next, we examine whether our result for the effect of emission trading in decoupling is robust. We focus on the fact that 25 out of 29 countries in our data introduced emission trading (EU-ETS) in 2005. This enables us to regard the introduction of emission trading as a policy intervention, and therefore estimate its effect on emission intensity, all else being equal. Therefore, we check if the effect of emission trading in decoupling is significant by estimating it with the longitudinal pre-post quasi-experimental design (Leatherdale 2018). This design enables us to estimate the implementation of emission trading by comparing the treatment and control groups.

Inarguably, the adoption of emission trading is not randomly assigned across countries. To overcome this obstacle, we attempt to make the treatment and control group 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 group. The observed variables we use for matching are the same as in our previous models, including carbon tax as a binary variable. Through matching, 292 country-years without emission trading are reduced to 32 (control group), whereas 259 country-years with 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. We use this matching result to estimate the sample average treatment effect on the treated (SATT) of emission trading implementation on emission intensity between two groups, which is summarized in Table 4.

Table 4. SATT of emission trading on emission intensity in CEM matched data

Model	Mean difference
Linear regression (no control variables)	-47.73 [-181.20, 85.74]
Linear regression (with control variables)	-28.56 [-76.30, 19.18]
Linear random effect model (with control variables)	-31.15 [-36.20, -26.08]

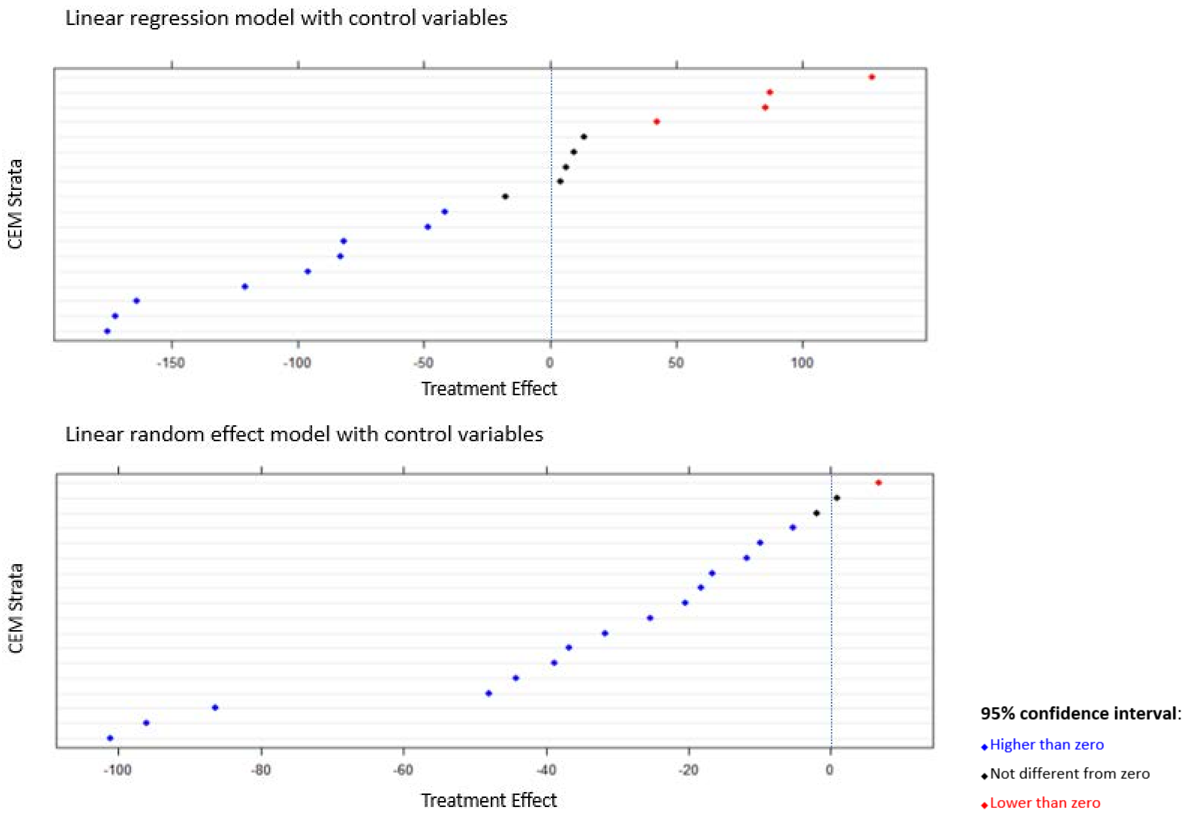
* 95% confidence interval is shown in parentheses.

The mean difference of emission intensity on CEM matched data is negative and significant only in a linear random effect model (-31.15). In Figure 3, when conducting a linear regression model, only 9 strata rendered treatment effects that were significantly lower than zero, but when assuming a linear random effect model, 16 out of 18 rendered those significantly lower than zero. Linear model with random effects in CEM assumes that each stratum after matching has an unknown stochastic strata-specific effect, and observations in each stratum are considered as much identical as possible given other control variables.

This suggests our analysis lends support to the effect of emission trading on decoupling if we assume a heterogeneous treatment effect. Although emission trading in our data exhibits a similar design across countries (EU-ETS), the heterogeneity of its treatment may come from two sources. First, its effect on decoupling might vary depending on the level of control variables we included in our model. 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 weakened (less negative) as energy inefficiency variables (carbon intensity and electricity inefficiency) increase.[2] This suggests that even though emission trading is in its operation, it may promote less decoupling if a society has a lower level of energy efficiency.

[2] When we included interaction terms between emission trading and all other variables in Model 1, the coefficient of the interaction term between emission trading and carbon intensity was -73.32 with Beck & Katz

Figure 3. Treatment effect on each stratum in linear regression and linear random effect model



In other words, the effect of emission trading on decoupling can be conditioned by how much efficiently a society produces and consumes energy.

Second, if we believe that observations on each stratum are homogeneous even in terms of their unobserved time-varying characteristics, this suggests that the effect of emission trading on decoupling can also be conditioned by these confounders. For instance, some countries may have more energy-intensive industry sectors in their national economy while others may not, which may lead to the different effect of emission trading on decoupling trends. This implies that the policy effect of emission trading may be different not only because of the difference in its designs (i.e. allocation methods, industry coverage, emission banking or borrowing) but due to socio-economic conditions under which it is implemented. Therefore, future research on decoupling and carbon pricing can benefit from controlling for the policy design of emission

panel corrected standard error of 36.32, and that between emission trading and electricity inefficiency was -15.01 with standard error of 5.08.

trading and see how variation in other socio-economic conditions moderate its effect in decoupling. Then, we can further investigate how these conditions interact with different policy components of emission trading. For instance, we can investigate whether energy inefficiency penalizes the effect of emission trading more if allocating the permits is done by grandfathering or more if done by benchmarking methods.

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. The analysis outcomes presented here suggest that countries which implement emission trading are likely to achieve strong decoupling. Countries with higher proportion of industry in their total GDP may achieve weak decoupling, and those with less efficient electric power system have lower level of decoupling in their society. Evidence from our data could not support any relationship between carbon tax and decoupling. However, we are not to argue that carbon tax does not have any impact on decoupling in different research design and regional context.

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 policies 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. Based on theoretical and empirical contributions, this study suggests that adopting emission trading is likely to achieve strong decoupling. In addition, our estimation with CEM-matched data suggests that emission trading may have positive but different impacts on decoupling depending on country-specific contexts.

Despite the above contributions, future research would strengthen decoupling studies. Our result suggests that not all carbon pricing policies encourage decoupling. The utilization of sophisticated measures with stringency and prices for carbon pricing policy may result in nuanced outcomes regarding carbon pricing effects. Above all, we are confronted with less confidence in the role of carbon tax for promoting decoupling compared to emission trading. Future studies could explore the different types and policy components of carbon tax, and how its 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.

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Appendix A. Timing of adopting emission trading and carbon tax

Country	**Emission trading**	**Carbon tax**	**Country**	**Emission trading**	**Carbon tax**
Austria	2005	-	**Latvia**	2005	2004
Belgium	2005	-	**Lithuania**	2005	-
Bulgaria	2005	-	**Netherlands**	2005	-
Croatia	2013	-	**Norway**	2008	1991
Cyprus	2005	-	**Poland**	2005	1990
Czech Republic	2005	-	**Portugal**	2005	2015
Denmark	2005	1992	**Romania**	2005	-
Estonia	2005	2000	**Slovak Republic**	2005	-
Finland	2005	1990	**Slovenia**	2005	1996
France	2005	2017[3]	**Spain**	2005	-
Germany	2005	-	**Sweden**	2005	1991
Greece	2005	-	**Switzerland**	2013[4]	2008
Hungary	2005	-	**Turkey**	-	-
Ireland	2005	2010	**United Kingdom**	2005	2013
Italy	2005	-			

[3] France has passed a bill for carbon tax system in 2014 which was implemented in 2017. However, it was suspended since 2018.

[4] Since 2008, Switzerland has implemented its own national ETS combined with carbon tax system. However, until 2012 it was a voluntary phase and the overall cap was introduced in 2013.