Climate Policy and the Economy:

Evidence from Europe's Carbon Pricing Initiatives*

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Abstract

This paper examines the impact of carbon pricing on the economy, with a focus on European carbon taxes and the carbon market. Our analysis reveals three key findings. First, while both policies have successfully reduced emissions, the economic costs of the European carbon market are larger than for national carbon taxes. Second, we explore four factors that explain this difference: fiscal policy and revenue recycling, pass-through and sectoral coverage, spillovers and leakage, and monetary policy. Our findings point to important differences in pass-through and revenue use that help reconcile the differential effects between the two policies. Third, we document substantial regional heterogeneity in the impacts of the carbon market, which depend on the share of freely allocated emission permits and the degree of market concentration in the power sector.

JEL classification: E32, E62, H23, Q54, Q58

Keywords: Cap and trade, carbon taxes, emissions, macroeconomic effects, regional impacts

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1. Introduction

Climate change is one of the greatest challenges of our time, with far-reaching implications for society, the economy, and the environment. Carbon pricing is increasingly used as a tool to mitigate climate change, with a growing number of jurisdictions adopting such policies either in the form of carbon taxes or cap and trade systems. However, the empirical evidence on the macroeconomic and environmental impacts of carbon pricing is still limited, and even less is known about the differential effects across regions. Developing a deeper understanding of these effects is essential to inform decision-making and guide the transition towards a sustainable future – balancing climate action, economic growth and equity concerns.

In this paper, we perform a comprehensive assessment of the aggregate and regional impacts of carbon pricing policies, with a focus on the European experience. We start with a discussion of the empirical strategies to study the economic impacts of carbon pricing. A key challenge concerns the endogeneity of carbon prices, as economic factors can influence policymakers' climate policy stance. A common identification strategy, following Metcalf and Stock (2023), is to control for macroeconomic conditions that could affect the rate at which carbon is priced. With the appropriate set of controls, the argument is that any remaining variation in carbon prices is driven by plausibly exogenous factors, such as changes in political preferences for ambitious environmental policies, international climate policy pressure, or historically legislated policy schedules. This approach can be employed both in the context of carbon taxes and cap and trade prices.

For cap and trade prices, controlling for potential endogeneity is challenging because these market prices are more directly influenced by supply and demand factors. However, identification can be refined using high-frequency identification techniques, exploiting the institutional setting of carbon markets. As proposed in Känzig (2023) in the context of the European Union Emissions Trading System (EU ETS), the idea is to isolate some plausibly exogenous variation in carbon prices by measuring how carbon futures prices change in a narrow window around regulatory policy news on the supply of emission allowances. This approach allows for more credible identification of the causal effects of ETS prices.

Our main goal is to document and understand the potentially different impacts of European carbon prices and taxes. While the European carbon market is the cornerstone of the EU's policy to combat climate change, many European countries have also enacted national carbon taxes. These taxes cover sectors and industries that are not part of the carbon market, such as the transportation and buildings sectors as well as smaller, less energy-intensive industries. The EU ETS on the other hand covers the most energy-intensive sectors, such as the power sector and heavy-emitting industrial sectors, including oil refineries, steel and the chemical industry, and accounts for over 40 percent of the bloc's emissions.

We construct a yearly panel of 28 European countries containing detailed information on carbon emissions, economic activity, ETS prices and carbon taxes spanning the past two decades. To uniquely attribute any differences in results to policy design, we estimate the effects of the two polices based on the same empirical specification. Interestingly, while both policies lead to significant emission reductions, at least at the national level, the economic effects of European carbon taxes are different from the European carbon market. An increase in EU ETS prices leads to a significant rise in energy and consumer prices, a significant fall in industrial production, and higher unemployment. By contrast, higher carbon taxes are only associated with a limited increase in prices and a short-lived economic downturn, particularly in the subset of Western and Northern European countries. These results confirm previous findings on the effects of European carbon taxes by Metcalf and Stock (2023) and Konradt and Weder di Mauro (2023) and on ETS prices by Känzig (2023).

We also illustrate the benefits of high-frequency identification techniques in the context the European carbon market. When not instrumenting ETS prices with the high-frequency carbon policy shocks, we find notable differences relative to our baseline estimates. This finding suggests that even the broad set of controls we use may not successfully account for all the endogeneity in ETS prices.

What can explain the differential impacts of ETS prices and carbon taxes? We investigate four hypotheses: fiscal policy and revenue recycling, pass-through and sectoral coverage, spillovers and leakage, and monetary policy. First, our results suggest that the recycling of tax revenues plays a crucial role in the transmission of carbon pricing policies. In the European carbon market, there is no direct redistribution scheme to compensate affected households. The majority of the revenues in the market are used for climate-related purposes. In contrast, European carbon taxes were often implemented as part of a broader tax reform, which included income tax reductions or subsidies to cushion the levy on households.

In fact, focusing on the more homogeneous subset of Western and Northern European countries we find significant heterogeneity in the effects of carbon taxes depending on whether carbon tax revenues are recycled or not. Countries that do not recycle revenues experience a substantial economic downturn while countries that recycle revenues only display a muted impact on economic activity. Interestingly, the emission response turns out to be comparable, suggesting that recycling tax revenues does not necessarily undermine emission reductions.

A second explanation relates to differences in sectoral coverage and pass-through across the two policies. European carbon taxes generally exclude the power sector, which is part of the European carbon market. However, pass-through in the power sector tends to be particularly high because of market segmentation and dependence on energy, while pass-through in other economic sectors tends to be lower (Fabra and Reguant, 2014). Indeed, we find that higher ETS prices lead to a significant increase in consumer and producer prices, whereas the price impacts for European carbon taxes are more muted. The difference is particularly stark for producer prices. We document a sizable and persistent increase in producer prices following an increase in ETS prices. In contrast, producer prices do not respond significantly in response to European carbon tax changes. These results underline the crucial role of sectoral coverage coupled with differences in pass-through.

Third, when comparing national carbon taxes with EU-wide carbon prices, it is important to account for the broader effects at the European level. For instance, while the strong economic integration among European countries could help cushion the impacts of national tax policies, the EU-wide carbon market affects all member states more uniformly. Supporting this notion, our findings suggest that carbon taxes, which cover only 10 percent of the bloc's total emissions, lead to comparatively smaller EU-wide emission reductions. Further, national carbon taxes are potentially subject to carbon leakage to other European countries without a carbon tax, which could undermine the overall effectiveness of the policy. Although carbon leakage from the EU ETS to non-European countries is a possibility, the barriers are likely larger (see Dechezleprêtre et al., 2022).

Fourth, we examine the role of monetary policy in accounting for the differential effects of the two policies. While it is conceivable that monetary policy leans against inflationary pressures emerging from higher EU ETS prices, we would not expect a similar response to national carbon policies, especially given that the effects on prices appear muted to start with. Indeed, we estimate a significant increase in interest rates only after an increase in ETS prices, but not for national carbon taxes.

Based on a variance decomposition exercise, we document that changes in EU ETS prices explain a more substantial part of the historical variation in prices and economic activity than carbon taxes. While national carbon taxes only account for a limited share of the variation in energy prices, emissions and output, EU ETS prices explain a more meaningful portion of these variations – consistent with the EU ETS being the cornerstone of the EU's climate policy.

Finally, we investigate potential differences in the regional impacts of the carbon market. Although all European countries are subject to the emissions trading scheme, not all countries are equally exposed. In fact, our results point to meaningful heterogeneity, depending on the share of free allowances countries receive and the concentration in national electricity markets. We find that countries which received a larger share of free allowances display weaker economic impacts, as pass-through in these countries tends to be lower. On the other hand, countries with highly concentrated electricity markets experience stronger economic effects. The energy price increase in these countries is larger, causing a stronger fall in output and employment. Furthermore, our results imply somewhat more severe economic effects in countries that have labor-intensive economies reliant on services. This finding is likely related to the fact that labor-intensive sectors tend to be more cyclical and thus any second-round effects through the labor market are more pronounced. Conversely, we that find the composition of countries' energy mix plays a limited role, as countries with more carbon-intensive sectors received a larger share of free allowances.

These country-level determinants have important implications for the distributional effects across European regions. We find the strongest economic impacts are not concentrated in the poorest countries but in the middle portion of the per capita income distribution. The fact that countries in the bottom percentiles are disproportionately compensated with free allowances can account for these findings. Countries in the middle percentiles on the other hand receive relatively few free allowances and tend to have more concentrated electricity markets.

Related literature. This paper contributes to a growing literature studying the effects of climate policy and the effects of carbon pricing specifically. Although there is a expanding body of evidence showing the effectiveness of such policies in reducing emissions (Martin, De Preux, and Wagner, 2014; Andersson, 2019, among others), less is known about their macroeconomic effects. A number of studies have analyzed the macroeconomic effects of the British Columbia carbon tax, finding no significant impacts on GDP (Metcalf, 2019; Bernard and Kichian, 2021). Metcalf and Stock (2020, 2023) study the macroeconomic impacts of carbon taxes in European countries. They find no robust evidence of a negative effect of carbon taxes on employment or GDP growth. In a similar vein, Konradt and Weder di Mauro (2023) document that carbon taxes in Europe and Canada do not appear to be inflationary.

In a recent study on carbon taxes in Scandinavian countries, Kapfhammer (2023) confirms the emission reductions but documents more pronounced adverse effects on economic activity. Similarly, Känzig (2023) finds that higher carbon prices in the EU ETS lead to a persistent increase in consumer prices and a temporary, but substantial fall in economic activity. This evidence is also consistent with theoretical studies based on computable general equilibrium models that tend to find contractionary output effects, albeit at somewhat smaller magnitudes (see e.g. McKibbin et al., 2017; Goulder and Hafstead, 2018). We contribute to this literature by providing a comprehensive assessment of carbon pricing initiatives in Europe, with the aim to reconcile the previous empirical evidence. Our results highlight that coverage, revenue use and monetary policy are important factors in determining the macroeconomic consequences of carbon pricing policies.

2. Identifying the Effects of Carbon Pricing

Identifying the dynamic causal effects of carbon prices on the economy and the environment is challenging for at least two reasons. The first concerns the possibility of simultaneity: poor economic outcomes could induce the government to reduce the carbon price or postpone a scheduled increase or reform. The second relates to potential confounding factors: other economic or financial shocks could affect both carbon prices and the economy.

In this section, we discuss two strategies to overcome these challenges and identify the economic and environmental impacts of carbon pricing policies: a "control-based" approach and a high-frequency identification approach that can be employed in the context of carbon markets.

2.1. Control-based identification

The conventional strategy to identify the effects of carbon prices is the so-called "control-based" approach. As discussed in Metcalf and Stock (2020), it is useful to think of carbon prices as having two components: one component that is driven by past economic and financial factors, the other being orthogonal to the economy. The latter component could include, for instance, changes in political preferences for ambitious environmental policies, international climate policy pressure, or historically legislated schedules. The idea is then to control for past economic and financial developments to isolate some variation in the carbon price that is plausibly exogenous.

Under this assumption, it is possible to estimate the dynamic causal effects of a change in the carbon price using local projections à la Jordà (2005) when including the relevant economic controls. The approach can be applied in the context of both carbon prices in the EU ETS and national carbon taxes. The relevant variation in these policy instruments is illustrated in Figure 1.

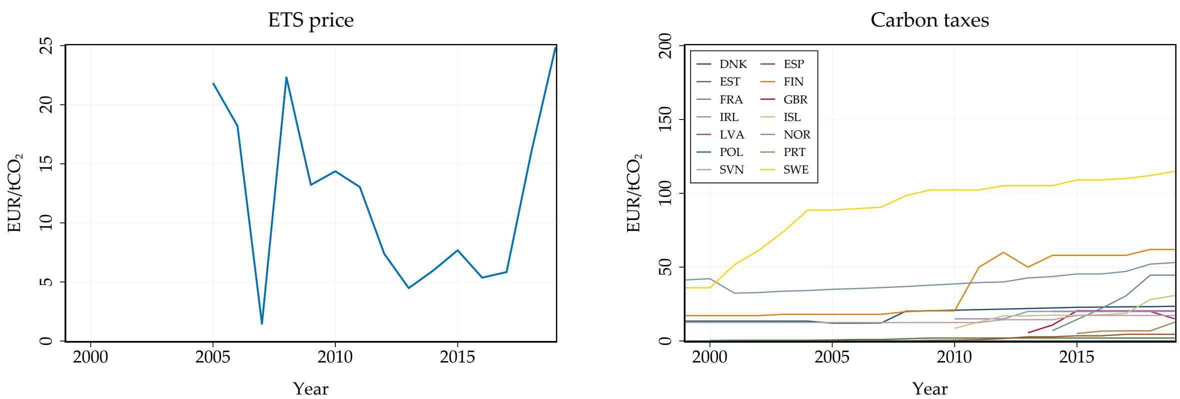

Figure 1: Carbon Prices in Europe

Notes: The left panel shows the EU ETS price since its introduction in 2005. The right panel shows European carbon taxes. Both are expressed in euro per metric ton of CO_2 or equivalent gas.

We can see that ETS prices experienced substantial variation, especially in the early phase. Carbon tax rates on the other hand are more stable. Furthermore, while the tax rates are on average quite comparable to ETS prices, there are some Scandinavian countries that levy substantially higher taxes. Following Metcalf and Stock (2023), we include carbon prices and taxes in real coverage-weighted terms, deflating them using the relevant GDP deflator and weighting by the country-specific ETS and carbon tax emission coverage.[1] Intuitively, this specification assumes that the impacts of carbon policies should be proportional to their overall tax burden.

To maximize comparability, we estimate the effects of changes in the ETS price, $cp_{i,t}^{ets}$,

[1]Coverage varies across countries also for the EU ETS, for instance because of differences in sectoral composition, but the variance is much smaller than for national carbon taxes which can differ substantially in the emissions and sectors covered, see Table B.3 in the Appendix.

and carbon tax, $\text{cp}^{tax}_{i,t}$, based on the same specification. Specifically, we estimate:

$$y_{i,t+h} - y_{i,t-1} = \alpha^h_i + \beta^h_k \text{cp}^k_{i,t} + \sum_{j=1}^{p} \theta^h_j \Delta y_{i,t-p} + \Delta \mathbf{x}'_{i,t} \boldsymbol{\theta}^h_x + \Delta \mathbf{z}'_t \boldsymbol{\theta}^h_z + \varepsilon_{i,t+h} \quad \text{for } k \in \{ets, tax\}, \tag{1a}$$

where $y_{i,t+h}$ is the outcome variable of interest in country i at time $t+h$ and β^h_k is the dynamic causal effect at horizon h to a carbon price change $\text{cp}^k_{i,t}$. For this identification strategy to work, the selection of controls is crucial. Therefore, in addition to the lags of the outcome variable, we include a comprehensive set of country-specific controls denoted by $\Delta \mathbf{x}_{i,t}$ and controls at the global or European level, $\Delta \mathbf{z}_t$. Furthermore, we control for time-invariant country-specific characteristics using country fixed effects.

When estimating the effects of supra-national carbon pricing initiatives, such as the European carbon market, it is not feasible to control for time fixed effects. In this case, since ETS prices vary at the European level, time fixed effects would absorb (most) of the relevant policy variation. By contrast, if we are interested in the effects of national carbon taxes, the policy variation is at the country level. In this case, including time fixed effects is feasible and arguably even desirable to flexibly control for any latent global and European developments. Therefore, we also consider a variant of (1a), including time fixed effects:

$$y_{i,t+h} - y_{i,t-1} = \alpha^h_i + \gamma^h_t + \beta^h_{tax} \text{cp}^{tax}_{i,t} + \sum_{j=1}^{p} \theta^h_j \Delta y_{i,t-p} + \Delta \mathbf{x}'_{i,t} \boldsymbol{\theta}^h_x + \varepsilon_{i,t+h}, \tag{1b}$$

which mirrors the specification used in Metcalf and Stock (2023) and Konradt and Weder di Mauro (2023).

For inference, we proceed as follows. When estimating the effects of carbon taxes we cluster standard errors by country, as in Metcalf and Stock (2023). For the EU ETS specifications, the carbon price is highly correlated across countries. Therefore, we use Driscoll and Kraay (1998) standard errors to allow for general forms of cross-sectional and serial correlation.

The main advantage of the control-based approach is that it is broadly applicable. In particular, we can study the effects of carbon taxes and cap and trade systems. Moreover, estimating these effects in a coherent framework allows for better comparison of the effects of EU ETS prices and European carbon taxes. However, a key challenge is the selection of adequate controls. This is particularly relevant for ETS prices, which are market prices and thus continuously driven by supply and demand forces.

2.2. High-frequency identification

To address the concern related to remaining endogeneity in ETS prices, we employ the high-frequency identification approach, developed in Känzig (2023).

This approach builds on the literature on high-frequency identification, which was developed in the monetary policy setting (Kuttner, 2001; Gürkaynak, Sack, and Swanson, 2005; Gertler and Karadi, 2015; Nakamura and Steinsson, 2018, among others) and more recently employed in the global oil market context (Känzig, 2021). Policy surprises are identified using high-frequency asset price movements around policy events, such as FOMC or OPEC meetings. The idea is to isolate the impact of policy news by measuring the change in asset prices in a tight window around the events.

Carbon markets provide a suitable setting for high-frequency identification. First, they were only established recently and the regulations in place are updated frequently. These update events can have significant effects on the price of emission allowances. Second, there exist liquid futures markets for trading emission allowances and price data is available at a high frequency. Exploiting this institutional framework, it is possible to construct a series of carbon policy surprises by isolating how carbon prices change around regulatory events in the carbon market. By measuring the price change within a narrow window around the event, reverse causality of the state of the economy can be plausibly ruled out because it is incorporated in the price prior to the news and unlikely to change within the event window. Känzig (2023) develops this strategy in the context of the European carbon market, however, the approach is very general and could also be implemented to evaluate the performance of other cap and trade systems.

As discussed in Stock and Watson (2018), high-frequency surprises are better thought of as instruments than actual shock measures. Therefore, Känzig (2023) employs the high-frequency carbon policy surprises as an external instrument in a structural VAR model of the European economy. Under the assumption of (partial) invertibility, it is possible to obtain an estimate of the structural carbon policy shock. A key advantage of the VAR approach relates to aggregation. Using high-frequency surprises in regression models with low-frequency data, such as quarterly or annual data, can be challenging because of a power problem. Intuitively, high-frequency surprises tend to be small and sparse. At the same time, macroeconomic variables are hit by a myriad of other shocks over multiple quarters or years, rendering the signal-to-noise ratio low (Nakamura and Steinsson, 2018). We circumvent this problem by obtaining a shock estimate using data at a higher frequency (in our case monthly), where the signal-to-noise ratio tends to be higher, and aggregating the extracted shock to the relevant frequency after (in our case yearly). In fact, using the shocks at the monthly, quarterly or even annual frequency produces consistent results while the results based on aggregated high-frequency surprises become less interpretable the lower the frequency (see Appendix A.1 for an illustration of this point).

We use the carbon policy shocks from Känzig (2023), aggregated to the annual frequency by summing over the relevant monthly shocks in a given year t, $\text{cps}_t = \sum_{m=1}^{12} \text{cps}_{m,t}$ (for more details on how the monthly shock is identified and estimated, see Känzig, 2023). The aggregated shock series is depicted in Figure 2.

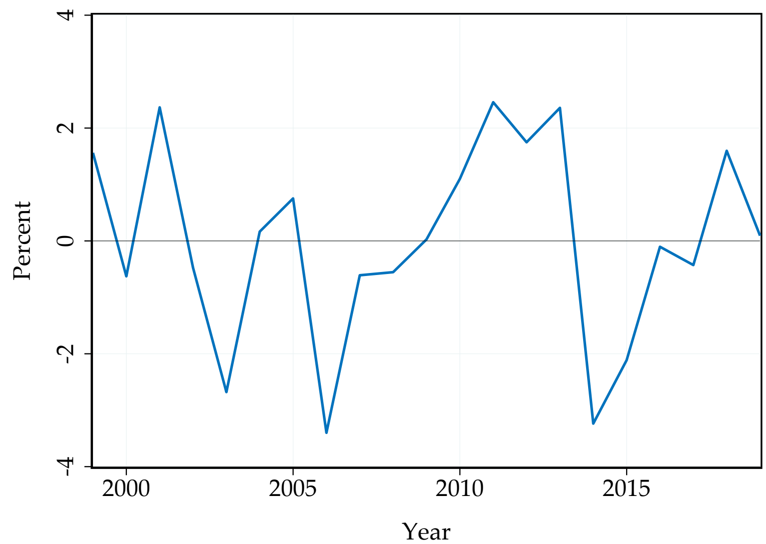

Figure 2: Carbon Policy Shocks in the European Carbon Market

We can then compute the impulse responses using a local projection instrumental variable (LP-IV) approach (Jordà, Schularick, and Taylor, 2015), instrumenting the ETS price $\text{cp}_{i,t}^{ets}$ in (1a) with the carbon policy shock. Note that Känzig (2023) actually provides two alternative shock measures: one based on an instrument expressed as the carbon price change relative to wholesale electricity prices (depicted above) and one based on an instrument expressed as the percentage change in carbon prices. We use both shocks jointly as instruments, as this improves the first stage and allows us to test for overidentifying restrictions. As for carbon prices, we express the shocks in coverage-weighted terms, weighting by the country-specific ETS coverage. Furthermore, note that while these shocks are generated regressors, this does not pose a challenge for inference, as we do use them as instruments, not independent regressors (Wooldridge, 2002, p. 117). Therefore, we keep using Driscoll and Kraay (1998) standard errors and refer to this specification as (1a-IV).

The key advantage of the high-frequency approach is more credible identification. However, as it relies on market prices at a sufficiently high frequency, it is only applicable in the context of cap and trade systems, not carbon taxes.

2.3. Data and empirical specification

We limit our analysis to countries that are part of the EU ETS. In particular, we use data on all countries that were in the system starting from phase 1 or 2, including the UK which was part of the EU ETS until 2020. We exclude Malta and Liechtenstein because of data limitations, leaving us with 28 countries. Of these countries, 14 have enacted national carbon taxes in addition to participating in the emissions trading scheme. Table B.2 in the Appendix presents some descriptive statistics on the countries in our sample.

We focus on the period from 1999, when the euro was introduced, to 2019, stopping the sample prior to the outbreak of the Covid-19 pandemic. While some European countries had introduced carbon taxes as early as in the 1990s, these are relatively few. Focusing on this more recent sample ensures a balanced split of countries with and without carbon taxes. Furthermore, for many countries the relevant control variables are only available for this more recent period. While the EU emissions trading scheme was only introduced in 2005, the planning for the system started already in the late 1990s when the EU ratified the Kyoto protocol. Therefore, we use 1999 as the start of the sample in case of the EU ETS as well. The results are robust to starting the sample in 2005 after the EU ETS went online.

As country-specific controls in (1a)-(1b), we include HICP energy, HICP headline, real GDP, the unemployment rate and short-term interest rates. We also control for lags of the two carbon policy variables, e.g. when we estimate the effects of ETS prices, we control for lagged ETS prices and European carbon taxes. In the model with no time fixed effects (1a), we also include EU-level controls, in particular EU real GDP to track EU-wide demand, a stock price index to proxy financial conditions, and the two year rate. Furthermore, we use the Brent crude oil price to account for global developments in commodity markets. Controlling for financial variables is important as they are forward-looking and contain relevant information about the future economic development. As outcome variables, we focus on energy and headline consumer prices, GHG emissions, real GDP, industrial production, and the unemployment rate.

We include all variables in differences, except the policy rate, the unemployment rate, two year rate and real oil and stock prices, which enter in (log-) levels. However, the results are robust to including all variables in levels. We include 2 annual lags of all control and for each outcome variable as well as 2 lags of carbon prices and taxes, respectively.

Our study builds on data from a number of different sources. The EU ETS prices are from Datastream, which we complement with information on verified emissions from the European Union Transaction Log. For carbon taxes, we use data from the World Bank's Carbon Pricing Dashboard, which provides information on carbon tax rates and emission shares. The macroeconomic and financial data is sourced from the OECD, Eurostat and FRED. We provide a detailed overview of the data sources in Appendix Table B.1.

3. Results

3.1. The impacts of EU ETS prices

We now turn to the discussion of the empirical results. Figure 3 shows the impulse responses to an ETS carbon price increase, identified using the carbon policy shocks from Känzig (2023) as an instrument. The first-stage F-statistic of 59.2 is sufficiently above the rule-of-thumb value of 10. We also perform a Sargan–Hansen test of overidentifying restrictions. The corresponding J-statistic of 1.39 implies that we cannot reject the null hypothesis that the instruments are valid. Thus, we proceed by conducting standard inference.

We can see that a euro increase in the coverage-weighted ETS price leads to a significant increase in energy prices and a persistent fall in emissions. This has consequences for the economy as well. Headline consumer prices increase and economic activity falls, as indicated by the decline in real GDP and industrial production, and the uptick in unemployment. The responses are consistent with the effects reported in Känzig (2023) based on EU-wide aggregates, even though some of the responses turn out to be a bit more persistent. We confirm these results here in a panel of European countries, accounting for country-specific factors using national controls and fixed effects.

How far can our selection of controls get us in removing potential endogeneity in ETS prices? To answer this question, we compare the instrumental variable-based results with the impulse responses from the simple control-based approach. The corresponding responses are depicted as the red dashed line in Figure 3. Qualitatively, the responses turn out to be relatively similar. We see an increase in carbon prices leads to an increase in energy and consumer prices, a fall in emissions and output, and an increase in unem-

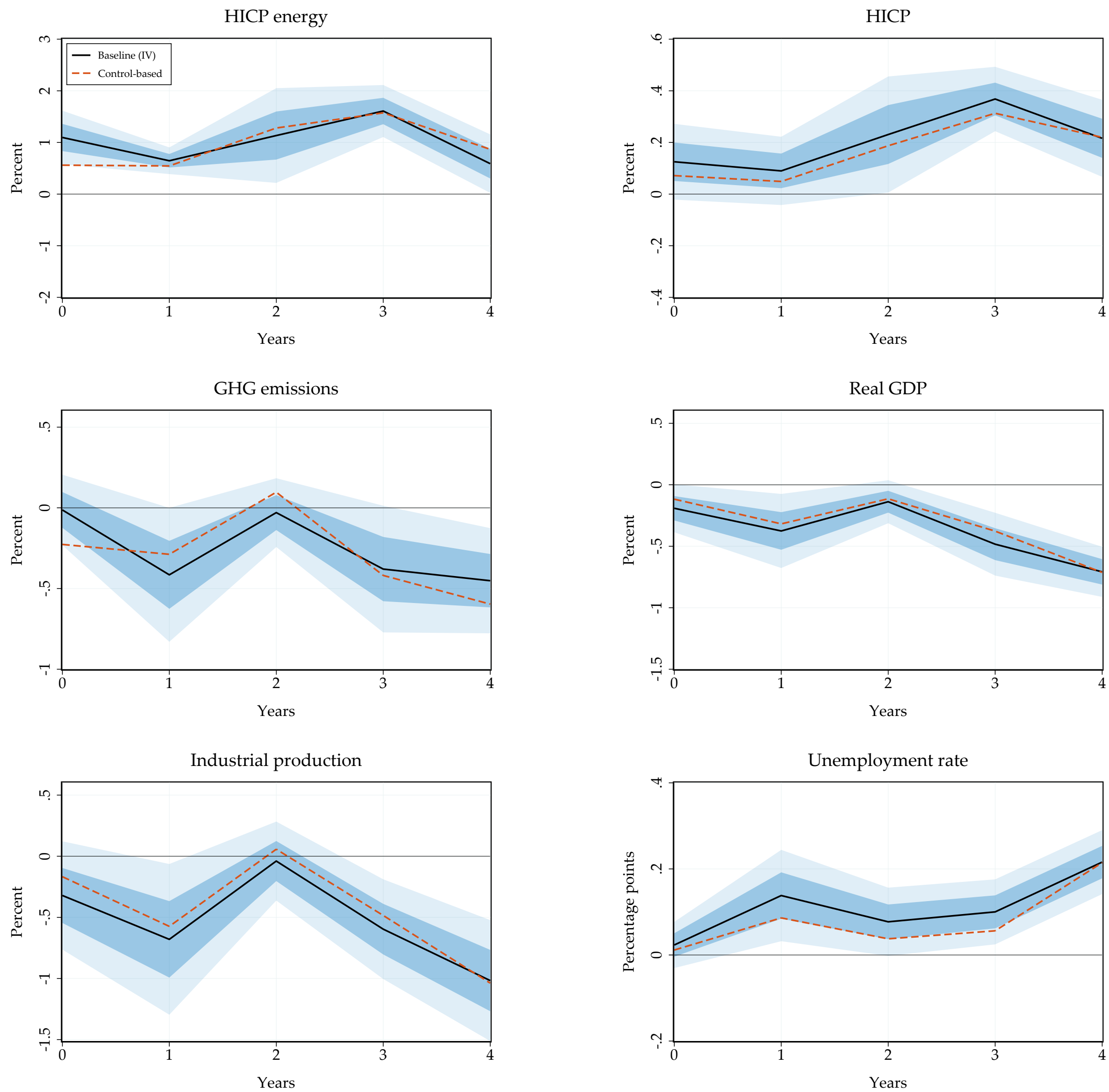

Figure 3: The Effects of an Increase in EU ETS Prices

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (1a-IV) which instruments the carbon price with the Känzig (2023) carbon policy shocks. The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively. For comparison, we also include the impulse responses from the control-based specification (1a) as the dashed red line.

ployment. However, the responses of consumer prices, emissions and the unemployment rate in particular are less pronounced.

These results suggest that the control-based approach cannot fully account for the potential endogeneity in carbon prices, at least in the context of the EU ETS. Therefore, we primarily focus on the instrumental variable approach to study changes in EU ETS prices going forward. However, we expect the control-based approach to work better in the context of European carbon taxes. As we have seen, carbon taxes display less variation over time and there tends to be a lot of sluggishness in the political process to adjust the taxes. More importantly, for carbon taxes we can flexibly control for many confounding factors using time fixed effects. This difference is also reflected in the fact that the results from the control-based approach for ETS prices can be sensitive to the selection of controls and the specification of the model. By contrast, the results for European carbon taxes are very robust to the controls included.

3.2. The effects of the European carbon taxes

How do the effects of European carbon taxes compare to the impact of changes in EU ETS prices? Figure 4 presents the responses to an increase in the carbon tax by one euro in coverage-weighted terms from the specification with time fixed effects. While carbon taxes also lead to a persistent fall in GHG emissions, we can immediately see that the economic effects are quite different from price changes in the carbon market. Energy prices increase, but the response is not that pronounced and rather imprecisely estimated.

Turning to the economy, we do not find a significant response of headline consumer prices, output or unemployment. Headline consumer prices tend to increase over time but the response is not significant. GDP does not change much over the first couple of years and even tends to increase afterwards. Industrial production falls slightly in the short term but subsequently reverses. The unemployment rate does not change significantly. Apart from emissions and the short-term increase in energy prices, all responses are rather imprecisely estimated and not statistically significant. Overall, these results confirm the findings in Metcalf and Stock (2023) and Konradt and Weder di Mauro (2023) who estimate a similar model, albeit on a longer sample and with a smaller set of controls.

For comparison, we also show the responses of the model with global and EU-wide controls instead of year fixed effects. We can see that the responses of the two models are quite similar, with some notable differences. This illustrates again that it is challenging to account for all potential confounding factors using global and region-wide controls.

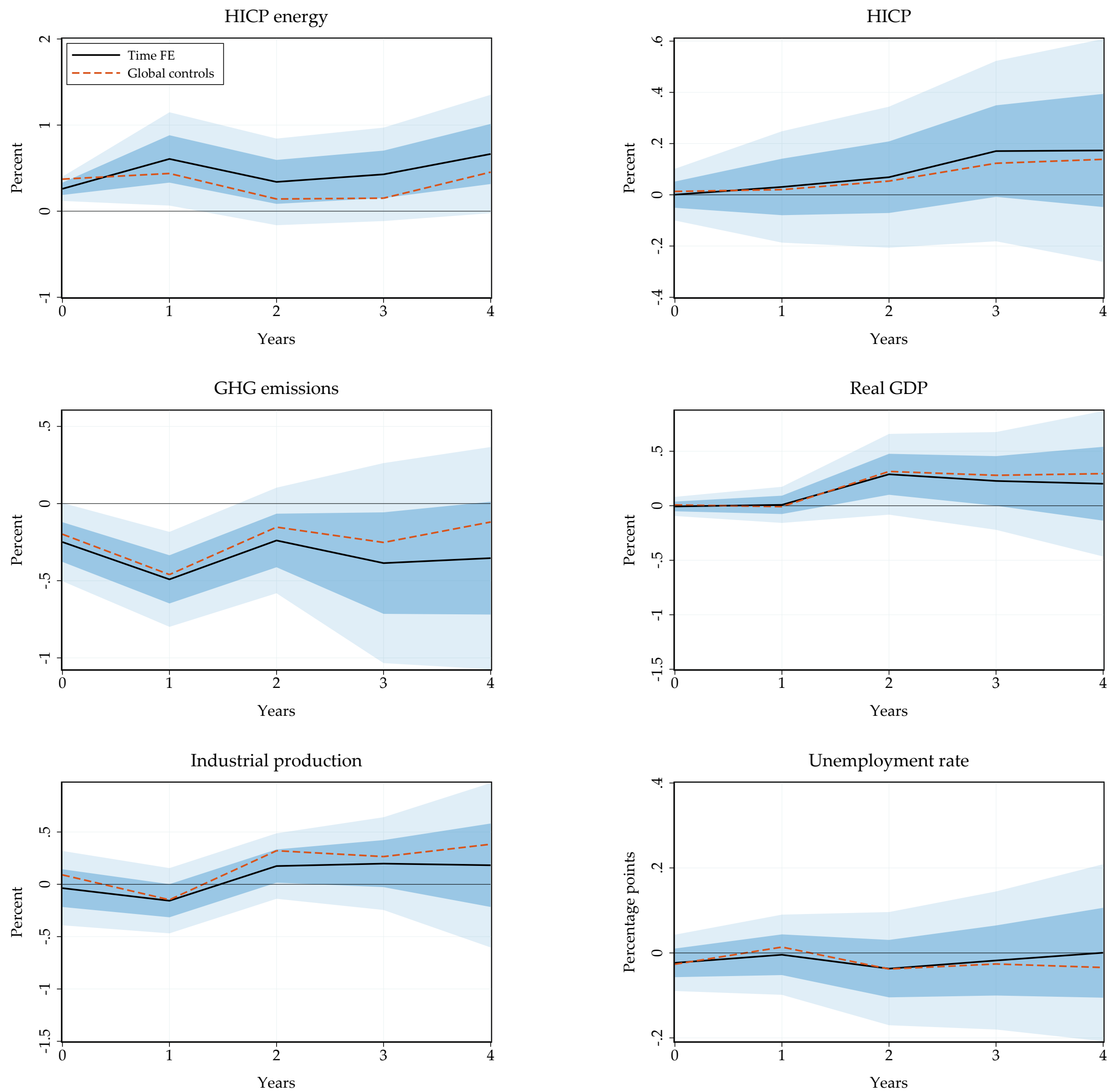

Figure 4: The Effects of an Increase in European Carbon Taxes

Notes: Impulse responses to an European carbon tax increase by one euro in real coverage-weighted terms, estimated based on the specification with time fixed effects (1b). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on standard errors clustered at the country level, respectively. For comparison, we also report the responses based on the specification with global controls (1a).

Therefore, we use the specification with time fixed effects as our baseline.

The European Union is a diverse group of countries with varying levels of economic development. Carbon taxes have primarily been adopted in Western and Northern Europe, regions that are not only wealthier but have also experienced higher economic growth in recent years. In contrast, Southern and Eastern European countries tend to be relatively poorer and exhibit higher unemployment rates. Among these countries, only Poland, Portugal, Slovenia and Spain have adopted a carbon tax. However, Portugal and Spain have done so only recently, in the mid-2010s, and Poland has a very low tax rate that covers a negligible share of emissions. It is therefore interesting to explore to what extent the impact of carbon taxes may vary across different regions. To this end, we estimate the effects of carbon taxes on the more homogeneous sample of Western and Northern European countries that is also more balanced in terms of carbon tax adopters and non-adopters.[2]

Figure 5 shows the responses to an increase in carbon taxes in the sample of Western and Northern European countries. We find that the fall in emissions is somewhat stronger in these countries compared to the overall sample. However, we also find more pronounced economic effects. GDP and industrial production fall, at least in the short term and the unemployment rate increases persistently. These effects are at least qualitatively similar to the impacts of EU ETS prices, even though they are not very precisely estimated. Quantitatively, the economic effects remain smaller, in particular for output and industrial production.

In the Appendix, we also display the results for the sample of Southern and Eastern European countries (see Figure A.4). For these countries, we find that both emissions and economic activity tend to increase after an increase in the carbon tax. However, the responses turn out to be very imprecisely estimated. These results should however be interpreted with a grain of salt given that with the exception of Slovenia, the coverage-weighted carbon tax rates in Southern and Eastern European countries tend to be around zero on average and display little variation over time, which complicates identification.

[2]We classify countries based on the United Nations geoscheme. According to this classification the Northern and Western European countries in our sample are Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Sweden, and the UK.

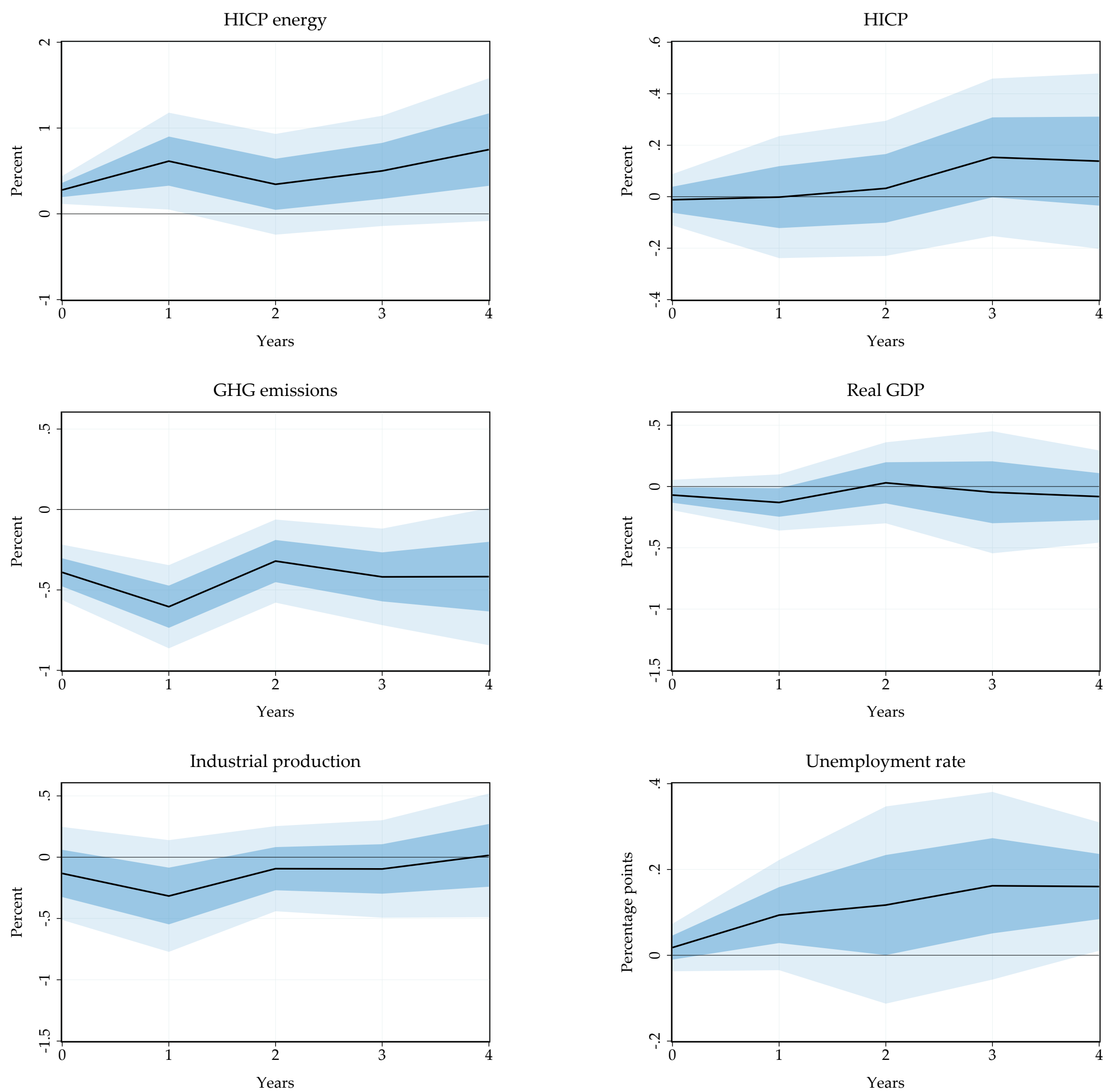

Figure 5: The Effects of an Increase in Carbon Taxes in Western and Northern Europe

Notes: Impulse responses to a carbon tax increase by one euro in real coverage-weighted terms in Western and Northern European countries, estimated based on the specification with time fixed effects (1b). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on standard errors clustered at the country level, respectively.

3.3. What explains the differential impact?

What drives the differential impact of the cap and trade and carbon tax policies? In this section we explore several factors that may account for the observed differences. In particular, we focus on fiscal policy and revenue recycling, pass-through and sectoral coverage, spillovers and leakage, and monetary policy.

Fiscal policy and revenue recycling. A crucial factor for the transmission of carbon pricing policies is how carbon revenues are used. If revenues are used for subsidies or cutting other taxes, this can lower the burden for households and firms and thus mitigate potential adverse macroeconomic consequences (Goulder et al., 2019; Bernard and Kichian, 2021).

Many European carbon taxes were implemented with the goal of recycling carbon tax revenues. The Scandinavian countries in particular enacted carbon taxes as part of green tax reforms, which included cuts to marginal income taxes. Similarly, some of the carbon tax increases coincided with reductions in income tax rates.[3] In contrast, there is no direct redistribution scheme in the European carbon market to offset the higher costs faced by households. Instead, the majority of auctioning revenues feed into member states' national budgets, as well as EU funds supporting low-carbon innovation and the energy transition (see European Comission, 2024, for more information). Therefore, we would expect stronger adverse economic effects compared to carbon taxes.

To shed more light on this channel, we compare the effects of carbon taxes in countries that stated an intention to recycle carbon tax revenues to countries that did not. We continue to focus on the more homogeneous sample of Western and Northern European countries. In that sample, the group of revenue recycling countries includes Denmark, Finland, Sweden, and Norway.

In Figure 6, we see that carbon taxes had larger economic effects in countries that did not recycle tax revenues. GDP and industrial production fall strongly and significantly and the unemployment rate increases persistently. In fact, the magnitudes are comparable to an increase in ETS prices of similar proportion. By contrast, countries that recycled revenues display much weaker and insignificant economic effects. This evidence is suggestive that recycling revenues to lower the tax burden helps to cushion the economic impact of climate policies. Interestingly, recycling revenues does not seem to

[3] As an example, Sweden enacted its carbon tax in 1991 alongside a reduction in personal income taxes and further reduced labor taxes as part of carbon tax reforms during the 2000s (see Carl and Fedor, 2016, for more details).

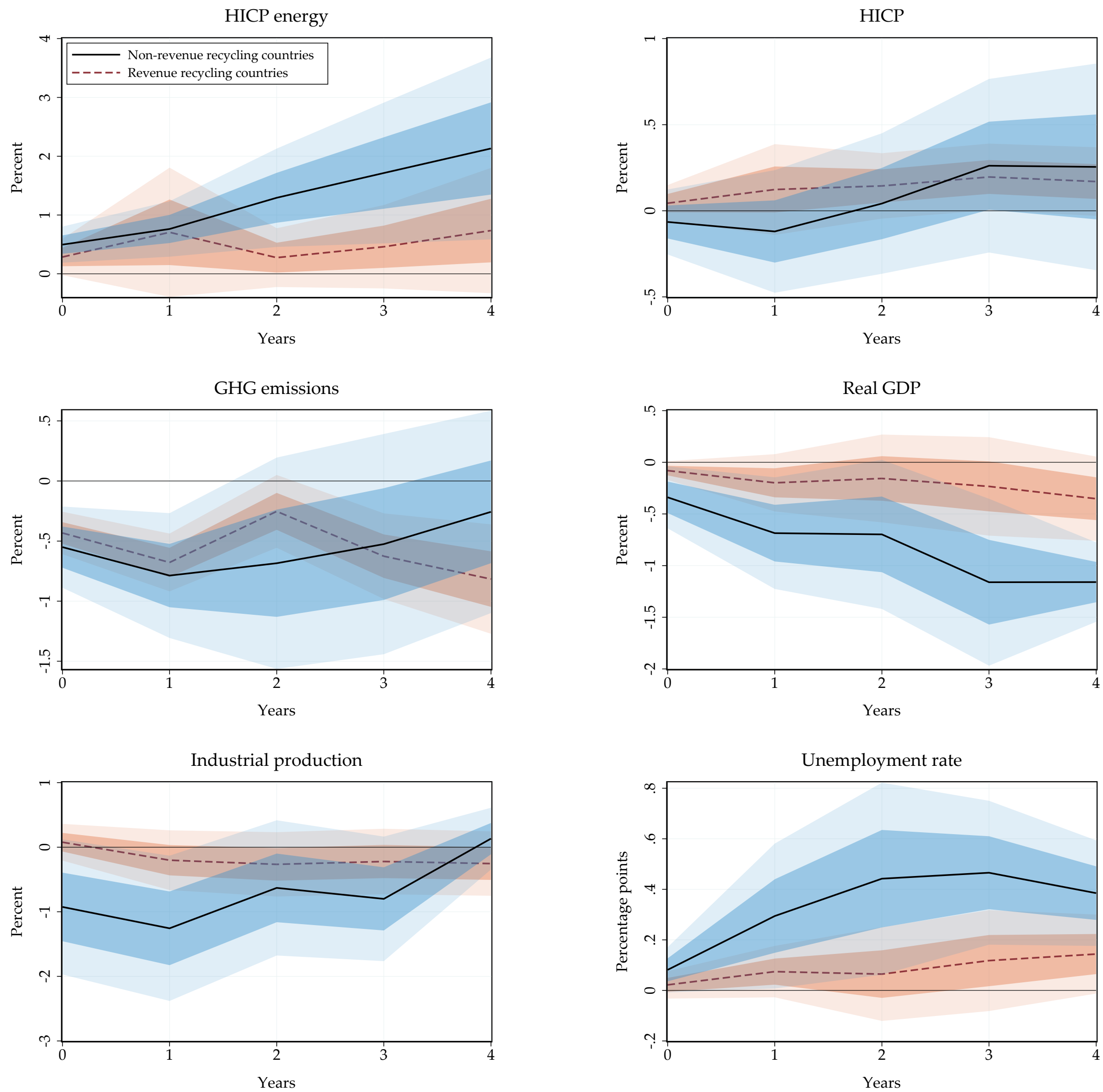

Figure 6: The Role of Revenue Recycling

Notes: Impulse responses to a carbon tax increase by one euro in real coverage-weighted terms in Western and Northern European countries, estimated based on the specification with time fixed effects (1b). The red dashed line shows the responses in revenue recycling and the solid line the responses in non-revenue recycling countries. The dark and light shaded areas are 68 and 95 percent confidence bands based on standard errors clustered at the country level, respectively.

have a significant effect on the response of emissions. We find that both in recycling and non-recycling countries, emissions fall significantly. These results are consistent with the evidence in Känzig (2023), showing that redistributing carbon revenues can lower the economic costs of carbon pricing policies without compromising emission reductions to a significant extent.

It should be noted, however, that energy prices also increase more strongly in non-revenue recycling countries which, all else equal, implies larger economic effects. Therefore, we cannot attribute all the observed difference to revenue recycling. Furthermore, we classify countries to be revenue recycling based on stated intentions rather than actual outcomes, which could differ in practice. Nevertheless, our results are suggestive that revenue recycling plays an important role for the transmission of carbon tax policies.

Panel A: European ETS

Panel B: European carbon taxes

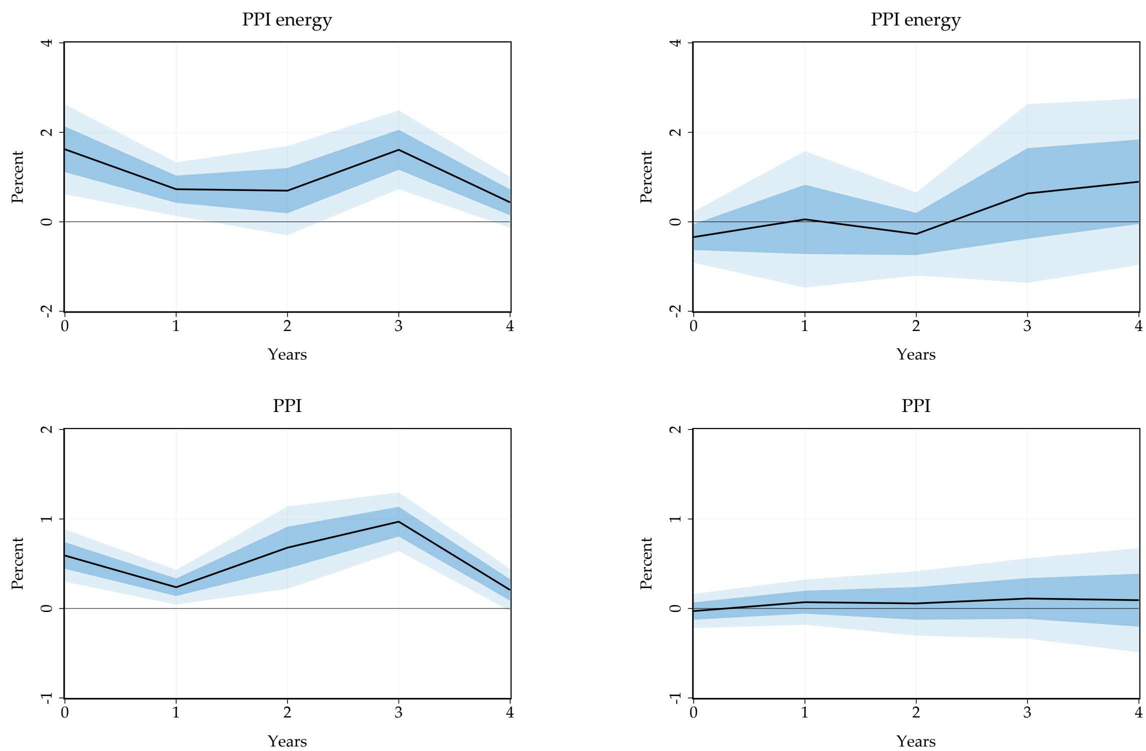

Figure 7: The Impact on Producer Prices

Notes: Impulse responses to an increase in ETS prices (Panel A) and carbon taxes (Panel B) on producer prices. The responses in Panel A are estimated based on (1a-IV) using Driscoll and Kraay (1998) standard errors, the responses in Panel B are estimated based on (1b), using standard errors clustered at the country level, restricted on the Western and Northern European sample. The dark and light shaded areas are 68 and 95 percent confidence bands, respectively.

Pass-through and sectoral coverage. Another potential explanation is related to pass-through. As we discusss above, the EU ETS and national carbon taxes apply to different sectors of the economy.[4] This is potentially important, as the strength of pass-through

[4]We provide a more comprehensive overview of the main sectors covered by the EU ETS and European carbon taxes in Table B.3 in the Appendix.

may vary across sectors. Indeed, Fabra and Reguant (2014) show that pass-through in the power sector, in which carbon is predominantly priced through the EU ETS, is almost complete. By contrast, pass-through in other sectors is likely to be much lower. For instance, Ganapati, Shapiro, and Walker (2020) document that changes in energy input costs of US manufacturing firms are only partially passed on to consumers.

Consistent with this view, we find that consumer prices display a stronger, more significant response to changes in ETS prices compared to carbon taxes. The differences in price impacts are even more apparent for producer prices. Figure 7 shows the responses of the energy and headline producer price index to similarly sized increases in ETS prices and European carbon tax rates. While producer prices display a significant increase in the case of the EU ETS, they do not show any response to a change in carbon taxes. This is true for both energy and headline producer prices.

The lack of a producer price response to carbon taxes is interesting, especially given the modest positive response of consumer prices. One explanation could be that carbon taxes are often levied on liquid fuels, for instance in transportation or heating, which leads to direct cost increases for households. For firms on the other hand, carbon taxes do not appear to lead to significant increases in input prices, which could be related to exemptions for firms in some European countries (see e.g. Martinsson et al., 2024). The situation is quite different for ETS price changes, which increase both producer and consumer prices significantly, consistent with a strong pass-through of the increased energy costs.

Spillovers and leakage. Unlike European carbon taxes, which are implemented in a relatively uncoordinated fashion at the national level in select countries, the EU ETS is an EU-wide policy that affects all European countries. European member states are highly integrated and trade extensively with one another. This integration can help cushion the impact of national policies, as economic activity in other countries will not be directly impacted by the policy. In fact, we find substantial differences in the effects of European carbon taxes in Western and Northern, and Southern and Eastern European countries, with the caveats discussed above. By contrast, the impacts of the EU ETS turn out to be somewhat more uniform (see Figures A.5-A.6 in the Appendix. In Section 3.5 we study potential heterogeneities of the EU ETS in more detail).

For the same reason, national carbon tax policies could be subject to carbon leakage. In response to higher carbon taxes in one European country, affected industries may move part of their operations to other countries without a carbon tax. This threat may be par-

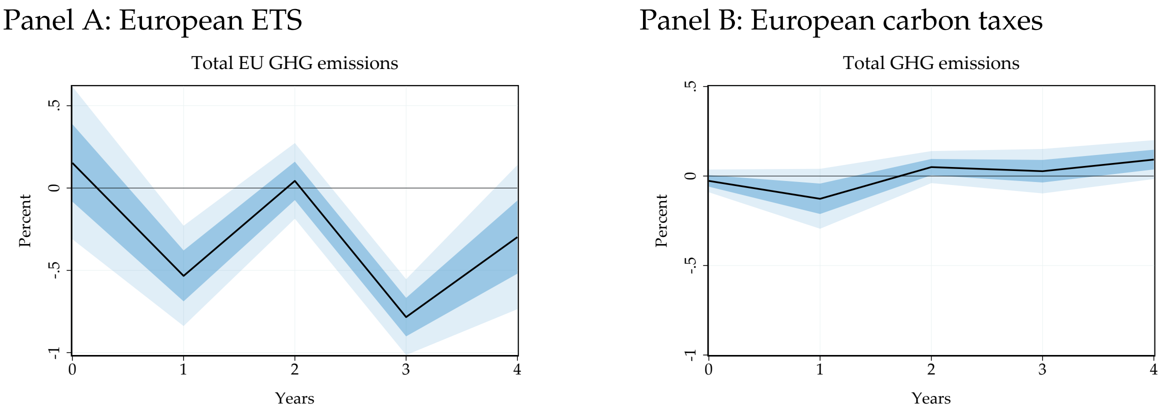

Figure 8: The Effect on EU-wide GHG Emissions

Notes: Impulse responses to an increase in ETS prices (Panel A) and carbon taxes (Panel B) on EU-wide GHG emissions. The responses in Panel A are estimated based on (2) with weak-instrument robust confidence bands. The responses in Panel B are estimated based on (1a) with EU-wide emissions as the dependent variable, using Driscoll and Kraay (1998) standard errors and focusing on variation in the Western and Northern European sample. The dark and light shaded areas are 68 and 95 percent confidence bands, respectively.

ticularly acute within Europe, as the barriers for carbon leakage are likely lower. This can compromise or even reverse the emission reductions if emissions are shifted to countries with a higher emissions intensity.

To more formally assess this, we study the aggregate effect of ETS prices and European carbon taxes. Given that for ETS prices there is only little variation across EU countries, we aggregate the variables of interest and estimate a time-series local projection:

$$y_{t+h} - y_{t-1} = \alpha^h + \beta_k^h \mathrm{cp}_t^{ets} + \sum_{j=1}^{p} \theta_j^h \Delta y_{t-p} + \Delta \mathbf{z}_t' \boldsymbol{\theta}_z^h + \varepsilon_{t+h}, \tag{2}$$

where we instrument the ETS prices with the carbon policy shocks as before.[5]

For carbon taxes, we still leverage variation at the country level but use EU-level emissions as the dependent variable. Thus, we estimate how national carbon taxes affect emissions in the entire bloc. Because the dependent variable is the same for all countries, we allow for cross-sectional correlation in the residuals using Driscoll and Kraay (1998) standard errors.

[5]However, in the time series, the annual carbon policy shocks turn out to be weaker instruments, which is why we report weak-instrument robust confidence bands. Furthermore, we can only include a smaller set of controls, given the fewer degrees of freedom in the time series. However, the results are robust with respect to the controls included.

Figure 8 shows the corresponding responses for aggregate EU GHG emissions. Following an increase in the ETS price, EU emissions fall persistently. Reassuringly, the aggregate response is very similar to the average response from Figure 3. The situation is quite different for European carbon taxes. We have seen that these policies lead to a substantial reduction in emissions at the national level. However, at the EU level, we are no longer able to detect a significant fall in emissions. This finding is suggestive that some of the emission reductions in countries that have adopted a carbon tax may have shifted to other European countries, thus offsetting the overall reduction in emissions to some extent.

Monetary policy. Monetary policy could also play an important role in accounting for the different effects of EU-wide and national carbon pricing policies. As Känzig (2023) documents, the European central bank appears to lean against the inflationary pressures associated with higher ETS prices, which likely exacerbates the effect on economic activity. As the policy is at the EU level and leads to an increase in EU-wide inflation, it is not implausible to expect a response of the European central bank. By contrast, for national carbon pricing policies in the euro area, we would not expect a monetary response, especially given that the effects on consumer prices seem to be muted to start with. We do find some support of this channel in the data. Figure 9 shows the impulse responses of short-term and long-term interest rates. While interest rates tend to rise after increase in ETS prices, the response to a carbon tax increase turns out to be weaker and insignificant.

Discussion. We have seen that both European carbon taxes and the carbon market have been successful at reducing emissions, however, there are also short-term economic costs. We provide evidence that revenue recycling and the sectoral coverage play an important role for the transmission of these policies. By recycling some of the carbon revenues, it is possible to mitigate the economic costs of the policy without compromising emission reductions to a significant extent. Furthermore, carbon pricing policies may be associated with different price effects depending on the sectors covered and the pass-through in these sectors. The pass-through turns out to be particularly strong in the energy sector, leading to widespread inflationary pressures. The effects on economic activity can be exacerbated if monetary policy leans against these inflationary pressures. Finally, we have seen that it is crucial that carbon pricing policies are broad in coverage. While we do not study carbon leakage to countries outside of the European union, we find some suggestive evidence on carbon leakage within the bloc in response to national carbon tax

Panel A: European ETS　　Panel B: European carbon taxes

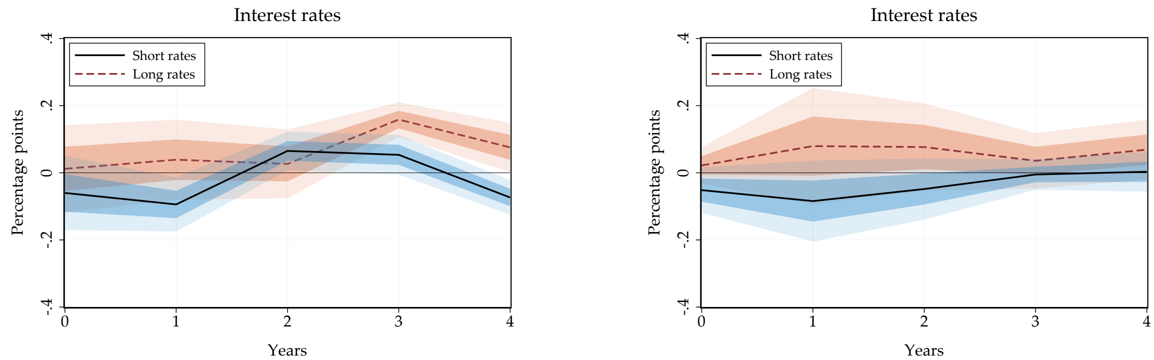

Figure 9: The Effect on Interest Rates

Notes: Impulse responses to an increase in ETS prices (Panel A) and carbon taxes (Panel B) on interest rates. The responses in Panel A are estimated based on (1a-IV) using Driscoll and Kraay (1998) standard errors, the responses in Panel B are estimated based on (1b), using standard errors clustered at the country level, restricted on the Western and Northern European sample. The dark and light shaded areas are 68 and 95 percent confidence bands,

policies.

Our results show that differences in pass-through as well as the fiscal responses play an important role in accounting for the differential impacts of the European carbon market and carbon taxes. Another aspect that we abstract from is that due to data limitations, we only use explicit carbon taxes. In a recent study for Scandinavian countries, Kapfhammer (2023) computes effective tax rates, taking into account differences in coverage over time as well as implicit carbon taxes, such as energy taxes on liquid fuels. Based on the effective rates, the study confirms the emission reductions but also finds more pronounced adverse effects on economic activity. We find similar effects for Scandinavian carbon taxes in our Western and Northern European sample, see Figure A.8 in the appendix. However, the responses are less precisely estimated – highlighting the importance of assembling more detailed carbon tax data for other European countries to be able to draw sharper inference on the effects of carbon taxes.

3.4. Importance of European carbon price changes

Until now, we have studied how changes in European carbon prices affect emissions and the economy. An equally important question is how much of the variation in the variables of interest can carbon policy account for? To this end, we perform a variance decomposition exercise. In particular, we use the R^2 estimator from Gorodnichenko and Lee (2020), extended to a panel setting with controls. The fraction of the forecast error variance of variable $y_{i,t}$ explained by $\text{cp}^k_{i,t}$ at horizon h can be estimated as the R^2 of the following regression:

$$\widehat{f}_{i,t+h|t-1} = \alpha_{cp,0}\widetilde{\text{cp}}^k_{i,t+h} + \cdots + \alpha_{cp,h}\widetilde{\text{cp}}^k_{i,t} + v_{i,t+h|t-1} \quad \text{for } k \in \{ets, tax\}, \tag{3}$$

where $\widehat{f}_{i,t+h|t-1}$ is the forecast error from the following regression

$$y_{i,t+h} - y_{i,t-1} = \alpha^h_i + \sum_{j=1}^{p} \theta^h_j \Delta y_{i,t-p} + \Delta \mathbf{x}'_{i,t}\boldsymbol{\theta}^h_x + \Delta \mathbf{z}'_t \boldsymbol{\theta}^h_z + f_{i,t+h|t-1}, \tag{4}$$

and $\widetilde{\text{cp}}^k_{i,t}$ is the residual from regressing $\text{cp}^k_{i,t}$ on the same set of predictors as in (4). To stay consistent with our LP-IV approach, we use the fitted value of ETS prices from a first-stage regression on the carbon policy shock as the relevant measure of $\text{cp}^k_{i,t}$. We compute confidence bands using a block bootstrap. For details, see Gorodnichenko and Lee (2020).

Table 1: Historical Importance of EU ETS Prices and Carbon Taxes

	Carbon prices			Carbon taxes		
Horizon	HICP energy	GHG emissions	Real GDP	HICP energy	GHG emissions	Real GDP
1	0.03 [0.00, 0.06]	0.06 [0.03, 0.12]	0.07 [0.03, 0.13]	0.03 [0.01, 0.09]	0.02 [0.00, 0.07]	0.00 [0.00, 0.04]
4	0.23 [0.13, 0.37]	0.06 [0.02, 0.17]	0.09 [0.02, 0.22]	0.07 [0.03, 0.18]	0.01 [0.00, 0.10]	0.01 [0.01, 0.11]

Notes: The table shows the forecast error variance decomposition of HICP energy, GHG emissions and real GDP at the one and four year horizon for EU ETS price and carbon tax innovations, computed based on (3). 95 percent confidence intervals, computed based on a block bootstrap, are reported in brackets.

Table 1 shows the results. We can see that changes in ETS prices explain a meaningful share of the variation in prices and quantities. At the four year horizon, they explain about one quarter of the variations in the HICP energy, over 6 percent of the variation in GHG emissions and and close to 10 percent of the variation in real GDP. Although non-negligible, these results based on the panel of EU countries are somewhat smaller than the EU-wide estimates presented in Känzig (2023). By contrast, changes in European carbon taxes explain a much smaller share of the variation in the variables of interest. While they still explain up to 7 percent of the variation in energy prices, the contributions to emissions and output are negligible.

The finding that carbon taxes explain a smaller share of the variation than ETS prices, especially for emissions, is consistent with the fact that the ETS targets sectors with relatively low marginal costs. By contrast many of the sectors targeted by national carbon taxes, such as transportation and building sectors, have relatively high marginal abatement costs.

More generally, these results are consistent with the notion that the EU ETS is the cornerstone of the EU's climate policy. As we have seen in Section 3.3, the EU ETS has more pervasive effects on EU-wide emissions and the economy than national carbon taxes, and therefore likely explains a more substantial part of the historical variation in prices and economic activity.

3.5. Regional heterogeneity of carbon prices

In contrast to national carbon taxes, the European carbon market is a EU-wide policy and thus affects all European countries. However, given that the EU is a heterogeneous union, there are reasons to suspect that the impacts may vary across countries. In this section, we explore the potential unequal effects of carbon prices for different European regions.

We focus on ETS prices in evaluating the regional component of carbon pricing. We have already documented some regional heterogeneity in the effects of carbon taxes. However, doing so more systematically is challenging because only a subset of European countries have adopted carbon taxes and for many we only have a short time series. By contrast, all countries in our panel participate in the ETS and we have data for 15 years, which is sufficiently long to study potential heterogeneity.

To study how the effects vary depending on a countries' exposure, we include an interaction term in our local projections:

$$y_{i,t+h} - y_{i,t-1} = \alpha_i^h + \beta^h \text{cp}_{i,t}^{ets} + \gamma^h \text{cp}_{i,t}^{ets} * \text{exposure}_{i,t_0-1} + \ldots + \varepsilon_{i,t+h}, \tag{5}$$

where γ^h captures the differences in the response to ETS carbon prices depending on the exposure. As before we instrument carbon prices with the carbon policy shocks from Känzig (2023). We standardize the exposure variable such that γ^h can be interpreted as the effect of having a one standard deviation higher exposure compared to the average country. As exposure variables, we mainly focus on the share of freely allocated allowances (relative to total emissions) and market concentration in electricity markets, constructed from the number of retail companies in each country. In addition, we also consider the share of non-renewables in primary energy consumption, and the service share of value added. To ensure that climate policy does not affect the exposure variable, we use the latest annual observation before the start sample period.[6]

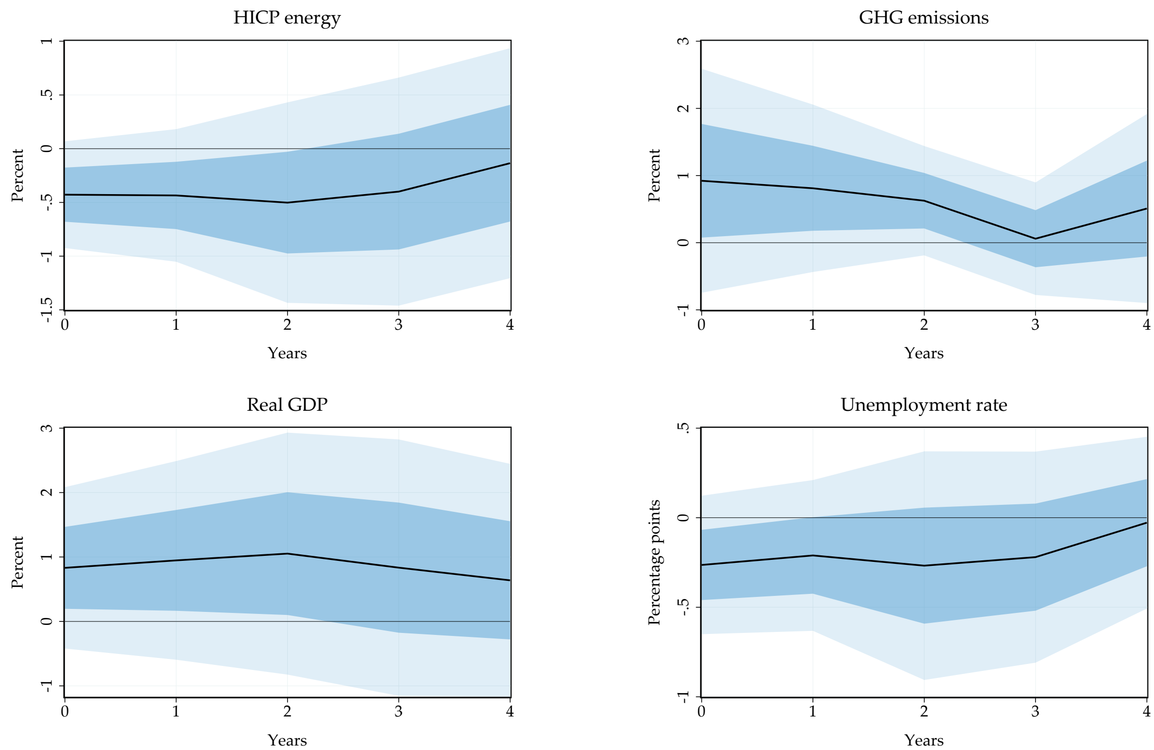

Figure 10: The Role of Free Allowances in the EU ETS

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for an interaction term with a country's share of free allowances to total emissions (standardized). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

We find meaningful differences in the estimated responses depending on the share of freely allocated allowances. Figure 10 displays a weaker initial response of energy prices and a muted decline in emissions for countries with a higher share of free allowances. Moreover, we see markedly different effects on economic activity, with countries that received more free allowances experiencing attenuated effects on GDP and unemployment, even though these effects are not very precisely estimated. The share of free allowances varies substantially across EU ETS members (see Figure A.9 of the Appendix), between 56

[6]Due to data limitations, we use the country-specific sample average over the period between 2011 to 2019 to measure market concentration. In case of free allowances, we rely on data from 2005, the first year where free allowances were allocated.

percent in Norway and 123 percent in Lithuania, on average. In addition to targeting towards poorer member countries, free allowances were allocated based on an assessment of countries' sectors that could be prone to carbon leakage.[7]

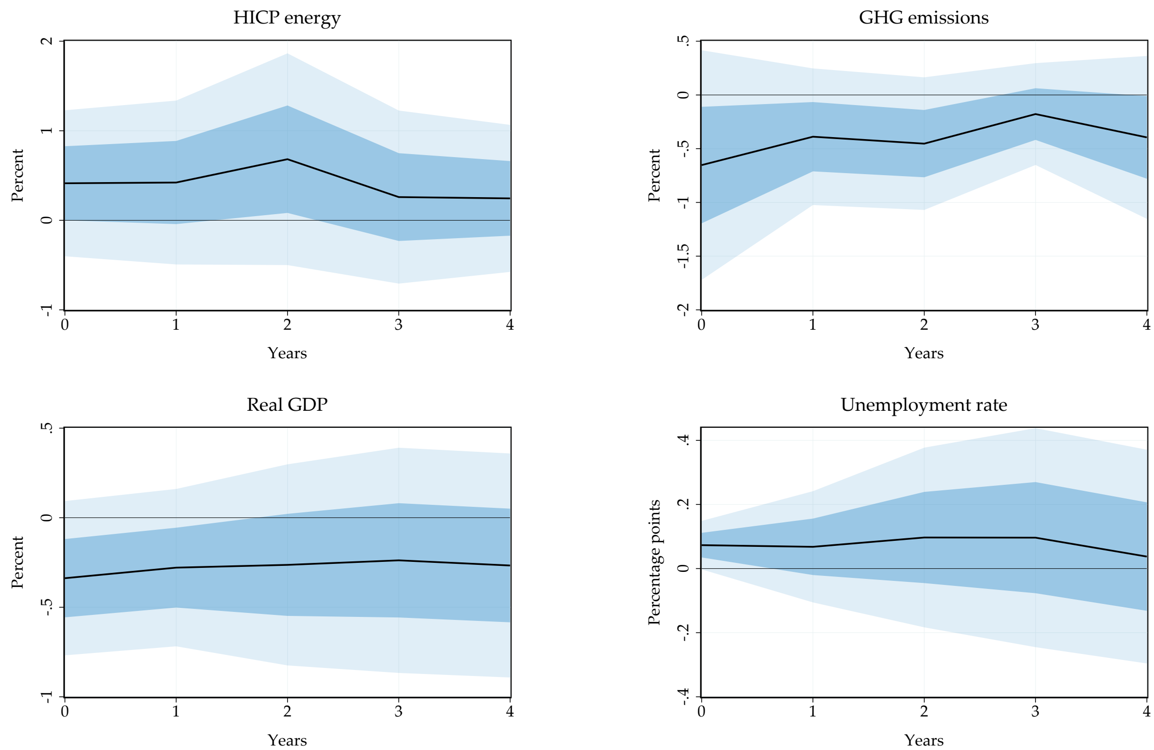

Figure 11: The Role of Market Concentration in the EU ETS

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for an interaction term with a country's share of primary energy consumption per electricity retailer (standardized). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

Next, we evaluate how the degree of market concentration in European electricity markets, which is markedly different across countries, promotes the effects of carbon pricing. Figure A.10 of the Appendix illustrates these regional differences. For instance, the average French electricity retailer accounted for 15.7 terawatt hours (TWh) of primary energy consumption between 2011 to 2019, compared to only 2.7 TWh for German retailers. We find that the degree of market concentration in turn affects the pass-through from carbon prices to energy and consumer prices, as shown in Figure 11. The effects on energy

[7]We show however, that the share of free allowances still accounts for a meaningful part of the heterogeneity even when we control for differences in countries' sectoral composition (see Figure A.13 in the appendix).

prices are stronger in countries where electricity markets are more concentrated. Higher energy prices contribute to a greater fall in emissions. Furthermore, countries with more concentrated electricity markets experience a larger decline in output and more unemployment following a carbon price increase.

We also investigate whether the effects of carbon policy shocks differ depending on the energy mix and the sectoral composition of the domestic economy. We test both channels by using the share of non-renewables in primary energy consumption and the service share, respectively. We present these results in Figures A.11 and A.12 in Appendix A.6. There is surprisingly little heterogeneity depending on countries' energy mix. One reason could be that it is important to account for the allocation of free allowances, as countries with a relatively brown energy mix received a disproportionate share of free allowances. We do find more meaningful heterogeneity with respect to the service share. Specifically, countries with a high service share display a more pronounced increase in the unemployment rate. This result illustrates that the sectoral composition matters not only for the direct effects of the policy via energy prices, but also for the indirect effects via wages and employment, as emphasized in Känzig (2023).

Another important question is whether rich and poor countries are equally affected by carbon pricing. To test for different effects by income, we partition the 28 countries into three groups, depending on their GDP per capita level in 1998. We choose the 30th and 70th percentile of the GDP per capita distribution as cutoffs, and compute impulse responses for these groups using interaction terms as in (5). We focus on the responses of real GDP and the unemployment rate, depicted in Figure 12. Interestingly, we find little evidence for adverse economic impacts for the poorest group of countries. Instead, it seems that countries belonging to the second group suffer the largest fall in output and rise in unemployment. As we explain above, the distribution of free allowances and concentration of national electricity markets offer one explanation for these results. In fact, countries in the first income group received the largest share of free allowances and have the least concentrated electricity markets, on average (see Table A.1 in the Appendix). Conversely, the average country belonging to the second group received the fewest amount of free allowances and has the highest concentration in electricity markets. For the third, richest group, we also document non-negligible effects, even though they are less pronounced relative to the second group.

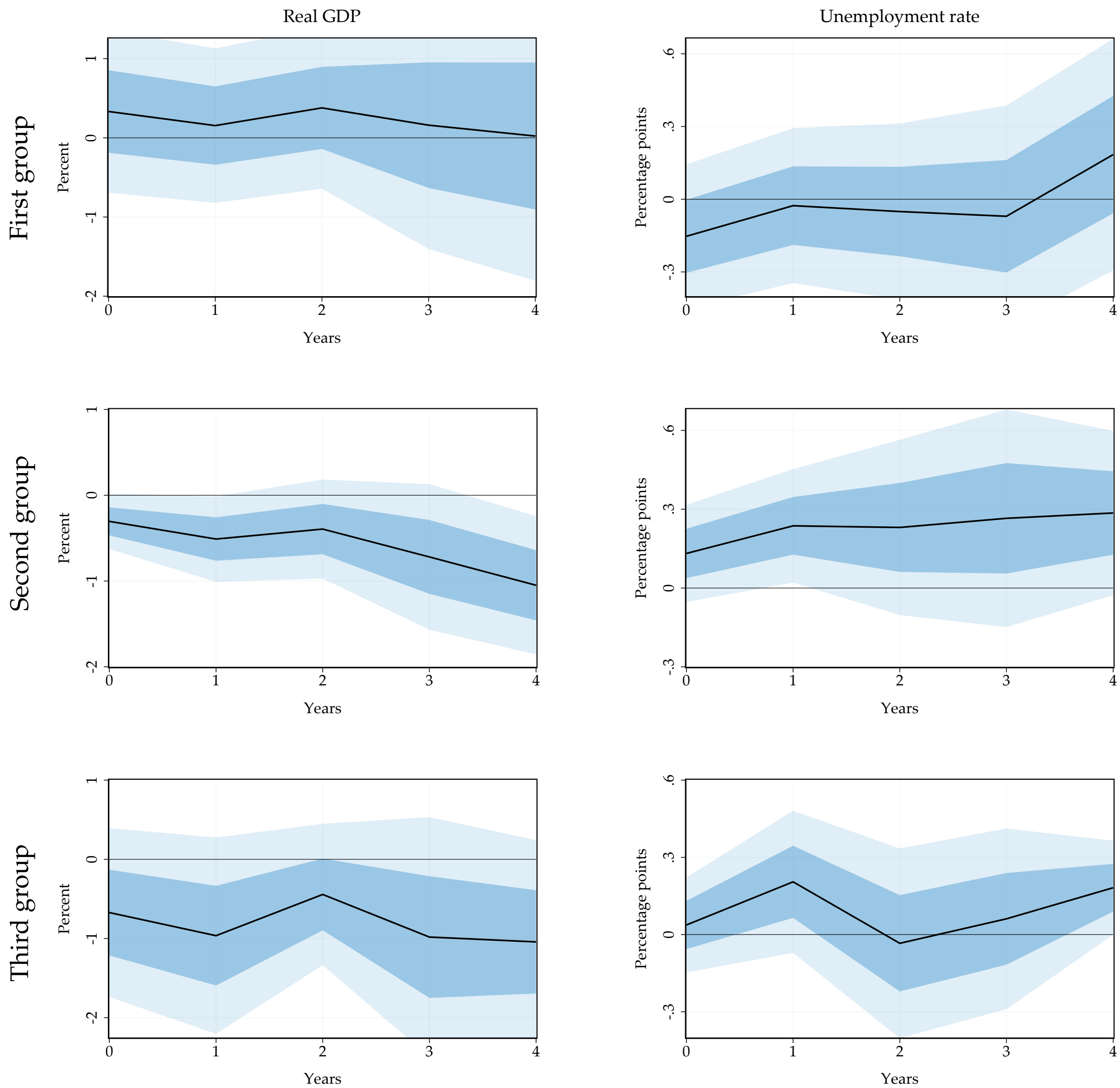

Figure 12: The Effect of the EU ETS by Income

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for interaction terms capturing a country's income level (First group: bottom 30 percent, second group: middle 40 percent, third group top 30 percent). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

4. Conclusion

Despite broad consensus among economists and policymakers that carbon pricing is the key tool to confront the climate challenge, the empirical evidence on the impact of these policies on emissions and the economy is still sparse. This paper provides new evidence in the context of Europe, contrasting the two major climate policies: the European carbon market and national carbon taxes. In a panel setting with a unified empirical approach, we find that carbon prices were successful at reducing emissions but this comes at an economic cost. Interestingly, the economic consequences turn out to be larger for the European carbon market than for carbon taxes. We examine four different hypotheses for the differential impacts: the recycling of tax revenues, sectoral coverage and differences in pass-through, spillovers and carbon leakage, and monetary policy. We find that all four channels have likely played a role, but revenue recycling as well as differences in pass-through seem to be particularly important. Finally, we document significant heterogeneity in the regional impacts of the European carbon market, which depend meaningfully on the share of freely allocated allowances and the degree of market concentration in electricity markets. Our results have important implications for policy design: recycling carbon revenues can mitigate potential adverse economic effects of carbon pricing, however, any complementary fiscal policies should take the sectoral composition and strength of pass-through into account.

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Appendix

A. Additional analyses, figures and tables

This appendix provides more detail on some of the supplementary analyses discussed in the main body of the paper and presents additional figures and tables not included in the main text.

A.1. Aggregation of carbon policy shocks

A potential concern with our estimates is that increases in carbon prices may coincide with other economic shocks that could confound our inference. In our baseline specification, we try to account for this with a wide set of macro and financial controls in addition to using the Känzig (2023) carbon policy shocks as an instrument.

To operationalize this approach we have to aggregate the carbon policy shocks, which are estimated in Känzig (2023) at the monthly frequency, to the annual frequency. Note that aggregating the high-frequency carbon policy surprises would not work because of the power problem discussed in Nakamura and Steinsson (2018). Therefore, we use the carbon policy shocks as estimated from the monthly external instruments VAR in Känzig (2023). We aggregate these shocks to the annual frequency by summing over them, as is customary in the literature (see e.g. Kilian, 2009).

We illustrate the implications of the temporal aggregation of carbon policy shocks in a similar specification as in Känzig (2023), using a time-series local projection instrumenting the HICP energy price by the carbon policy shock. We do this at the monthly frequency, repeat the same exercise after having aggregated the data at the quarterly frequency, and finally also at the annual frequency. Figure A.1 shows the results. We focus here on the responses of consumer prices. It turns out that the results that are very much comparable across different frequencies – illustrating the benefits of our approach.

Compared to the estimates based on our panel, these time-series estimates display a somewhat less persistent increase in consumer prices. Importantly, however, the responses are consistent across the monthly, quarterly, and annual frequency.[8]

[8]We cannot directly illustrate our approach to aggregation in the panel, as many of our series are only available at the annual frequency.

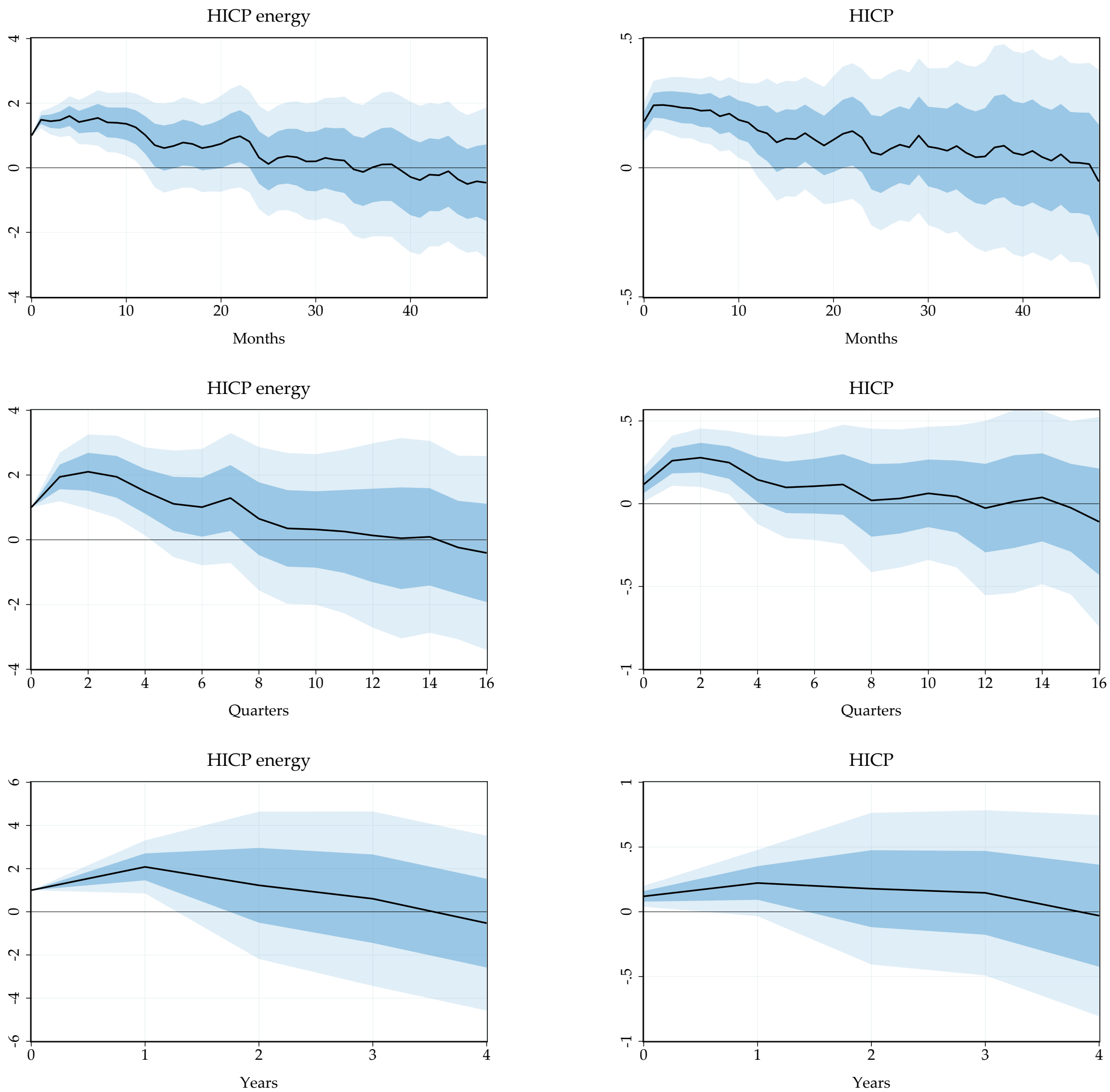

Figure A.1: Aggregating Carbon Policy Shocks

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on a simple time-series LP-IV, instrumenting the energy price by the carbon policy shocks from Känzig (2023). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands, based on robust standard errors, respectively. The underlying data is subsequently aggregated from monthly, to quarterly, to annual by averaging/summing the respective series.

A.2. Controlling for potential confounding episodes

To further address the concern that increases in carbon prices may coincide with other economic shocks, confounding our inference, we also try to control for large economic shocks using a set of dummy variables. Specifically, we use a crisis dummy variable that takes the value one in the early 2000s recession (2000-2001), the Global Financial Crisis (2007-2008), the European Sovereign Debt Crisis (2009-2011), as well as a dummy for the oil price shock in 2014.

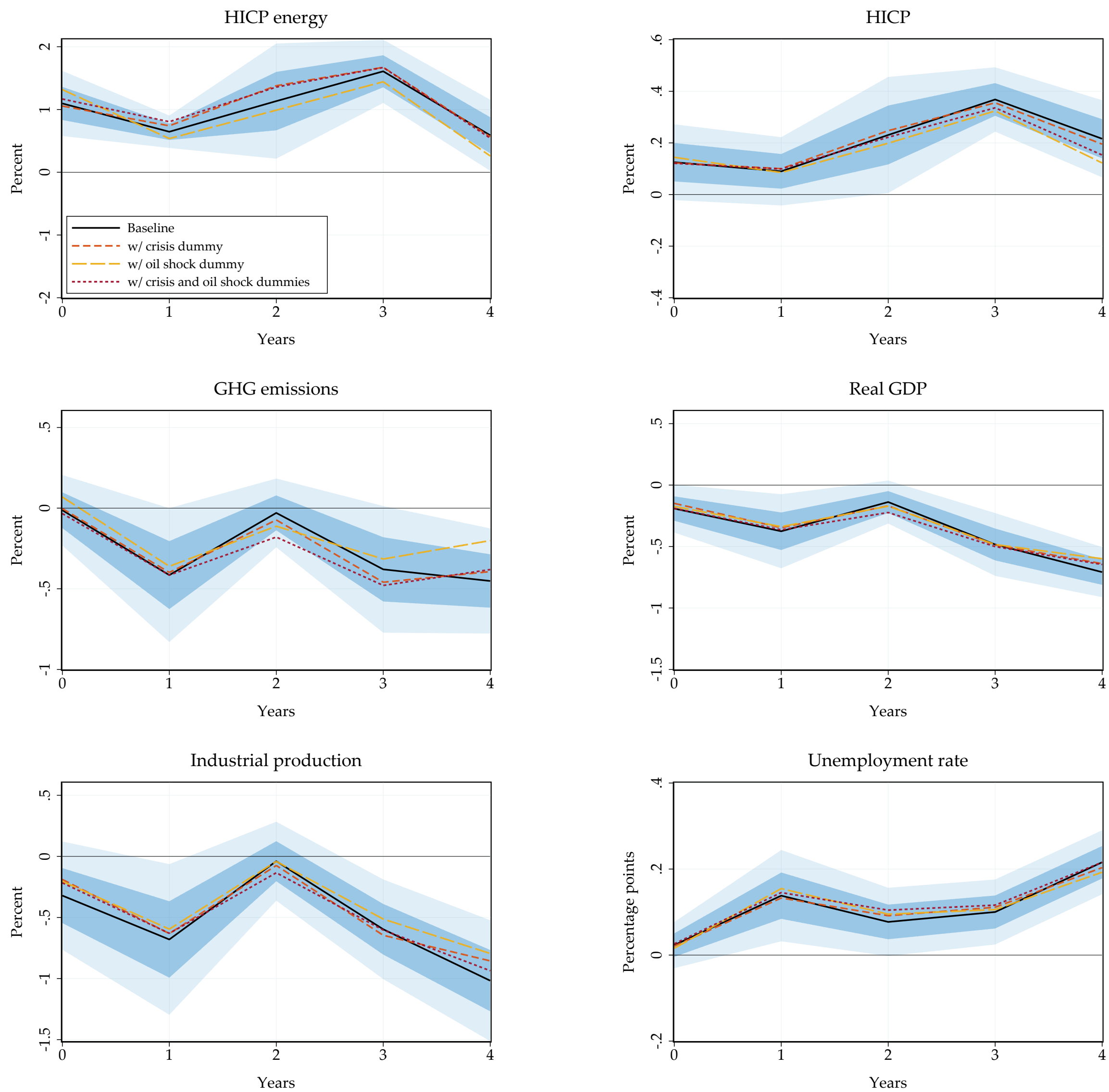

Figure A.2: The Effects of Carbon Price Innovations Controlling for Economic Events

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (1a-IV), conditional on country- and EU-level controls as well as dummies for major crises and the 2014 oil shock. The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively. The dashed lines show impulse responses (point estimates) from the same model including different selections of dummy variables.

As we can see from Figure A.2, the respective point estimates including the dummy variables are very similar to those obtained from the baseline model. This suggests that our results are likely not confounded by big shocks such as the Great Recession or the 2014 oil shock.

A.3. Carbon taxes in North-Western and South-Eastern Europe

Figure A.3 contrasts the evolution of carbon tax rates in Western and Northern European countries to Southern and Eastern European countries. Over the 20-year span, we observe considerable variation of carbon tax rates in the Western and Northern European sample. By contrast, carbon taxes in Southern and Eastern Europe are a more recent phenomenon and the tax rates display little variation. Only Slovenia and Poland had a carbon tax in place over the entire sample we consider and the level of the Polish tax is negligible. The Slovenian tax rate is more binding but also has not changed much over time, leaving little variation for identification.

Panel A: Western and Northern Europe

Panel B: Southern and Eastern Europe

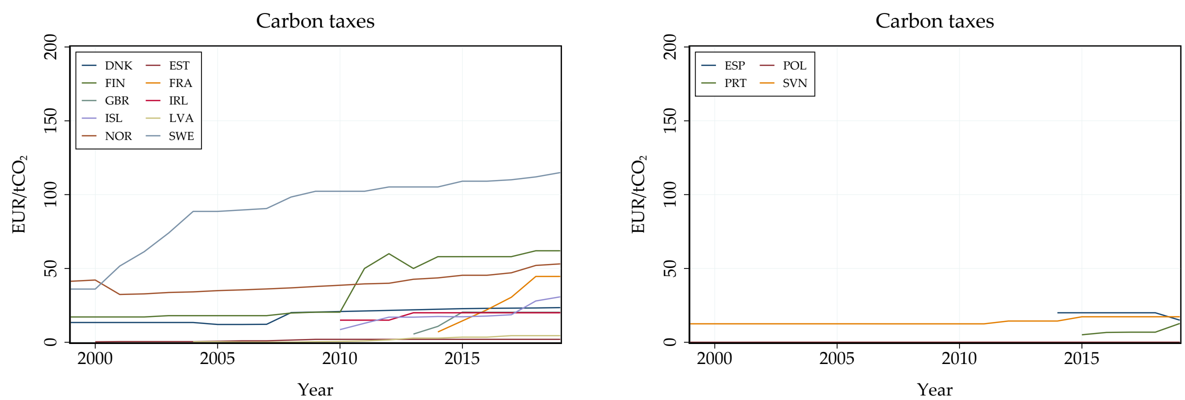

Figure A.3: Carbon Taxes in European Regions

For these reasons, the estimated effects for Southern and Eastern European countries should be interpreted with a grain of salt. Figure A.4 shows that the responses based on this sample are imprecisely estimated and some of the effects are counterintuitive. For instance, the emissions response tends to be positive on impact following an increase in the effective tax, albeit not significantly so.

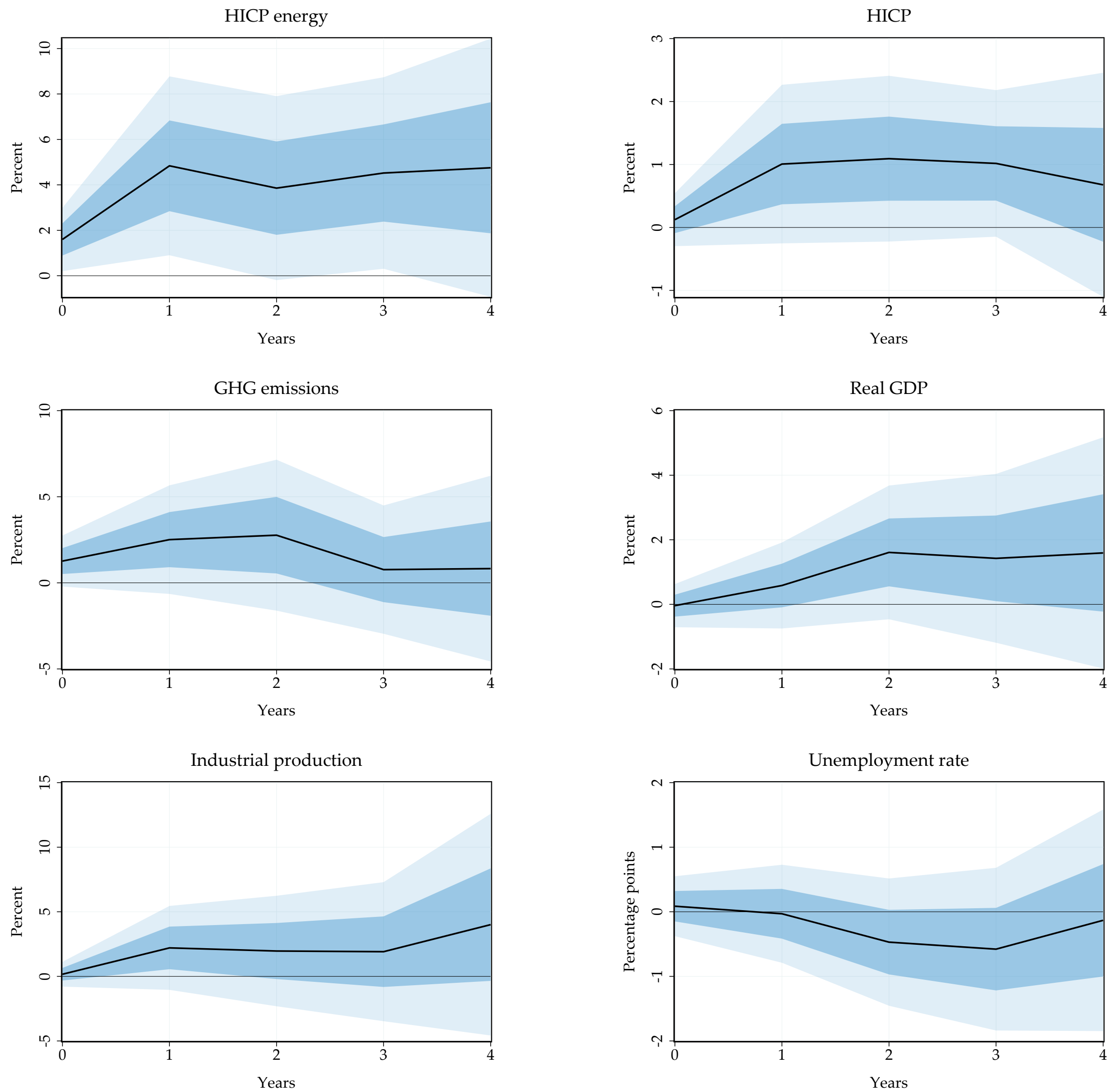

Figure A.4: The Effects of an Innovation in Carbon Taxes in Southern and Eastern Europe

Notes: Impulse responses to a carbon tax increase by one euro in real coverage-weighted terms in Southern and Eastern European countries, estimated based on the specification with time fixed effects (1b). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on standard errors clustered at the country level, respectively.

A.4. ETS prices in North-Western and South-Eastern Europe

Unlike national carbon taxes, ETS prices affect European countries more uniformly. To illustrate, Figures A.5-A.6 present the responses to a carbon price innovation in the North-Western and South-Eastern European subsamples, respectively. We see that the responses are qualitatively comparable, but the magnitudes tend to be more pronounced in Southern and Eastern European countries. In Section 3.5, we discuss different explanations for the heterogeneous impacts of EU ETS prices.

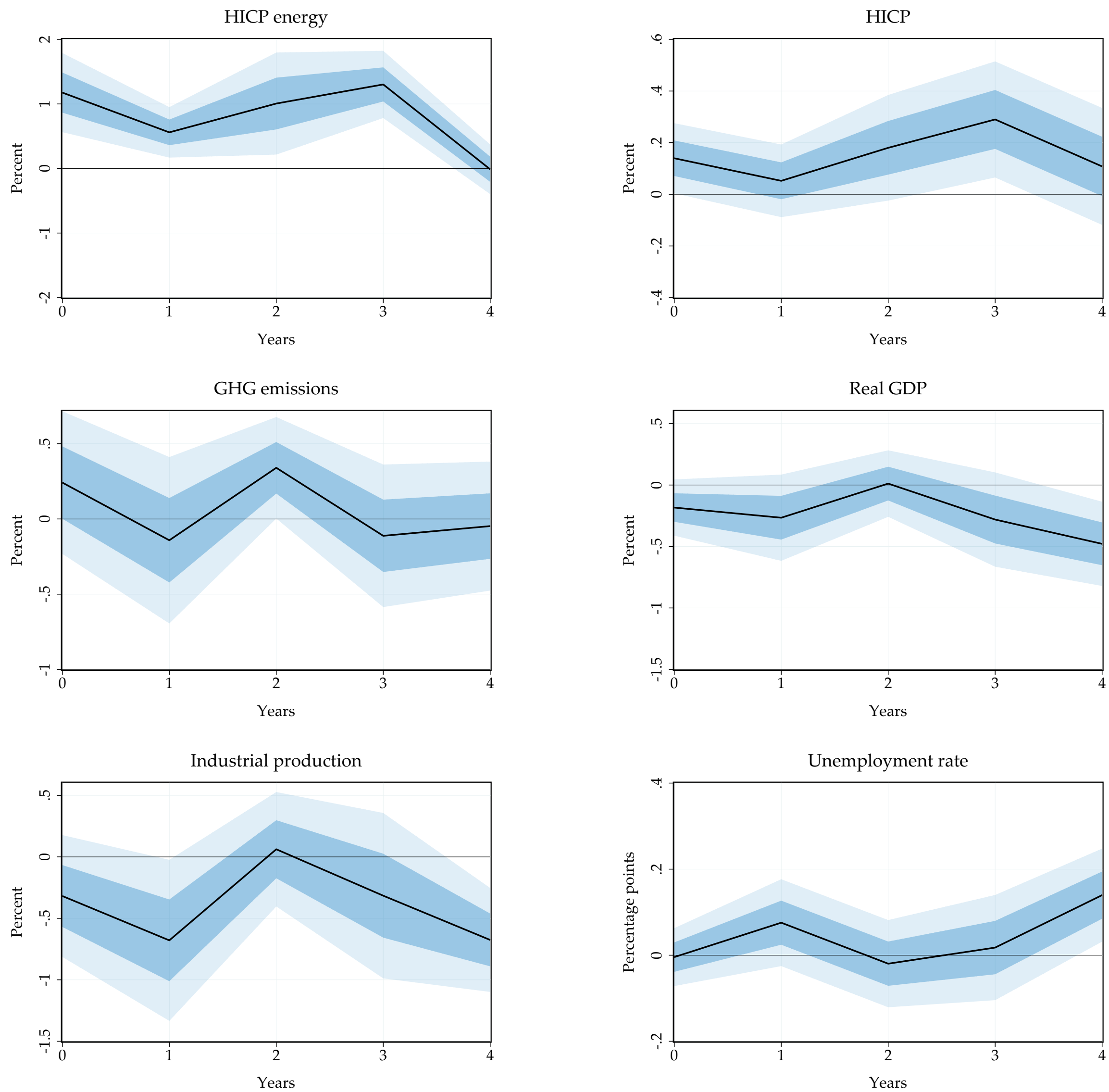

Figure A.5: The Effects of an ETS Price Increase in Western and Northern Europe

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (1a-IV), focusing on Western and Northern European countries. The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

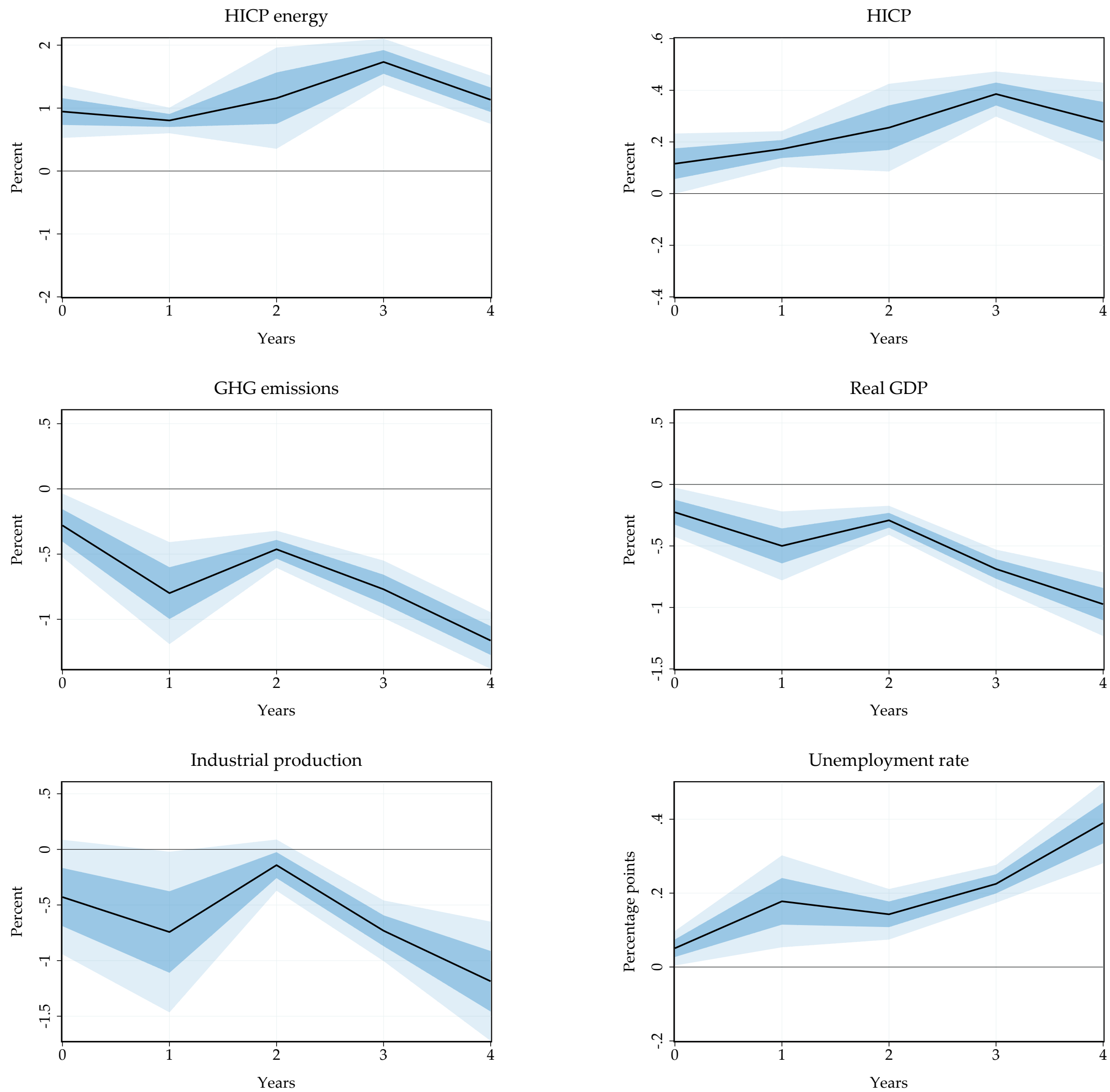

Figure A.6: The Effects of an ETS Price Increase in Southern and Eastern Europe

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (1a-IV), focusing on Southern and Eastern European countries. The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

A.5. Scandinavian carbon taxes

As an additional robustness check, we study the effects of Scandinavian carbon taxes. As Figure A.7 illustrates, these taxes were all implemented in the 1990s, before the start of our sample, which allows us to focus on changes in existing carbon tax rates (i.e. the intensive margin of carbon taxes).

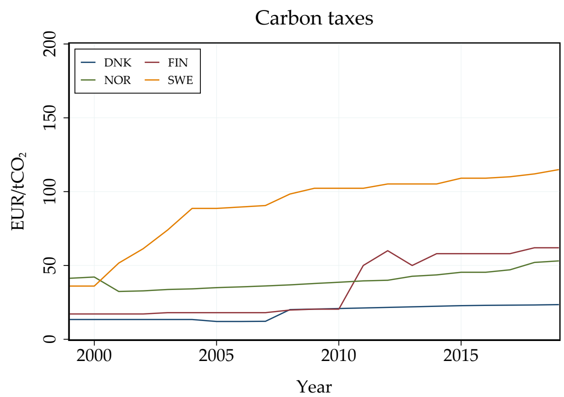

Figure A.7: Carbon Taxes in Scandinavia

To improve estimation efficiency, we also include those Northern and Western European countries without a carbon tax in the panel regressions.[9] Figure A.8 shows the results. We confirm the significant emission reductions but find that the economic consequences tend to be more pronounced for the Scandinavian carbon taxes, consistent with recent evidence in Kapfhammer (2023).

[9] In particular, the control group includes Austria, Belgium, Germany, the Netherlands and Lithuania.

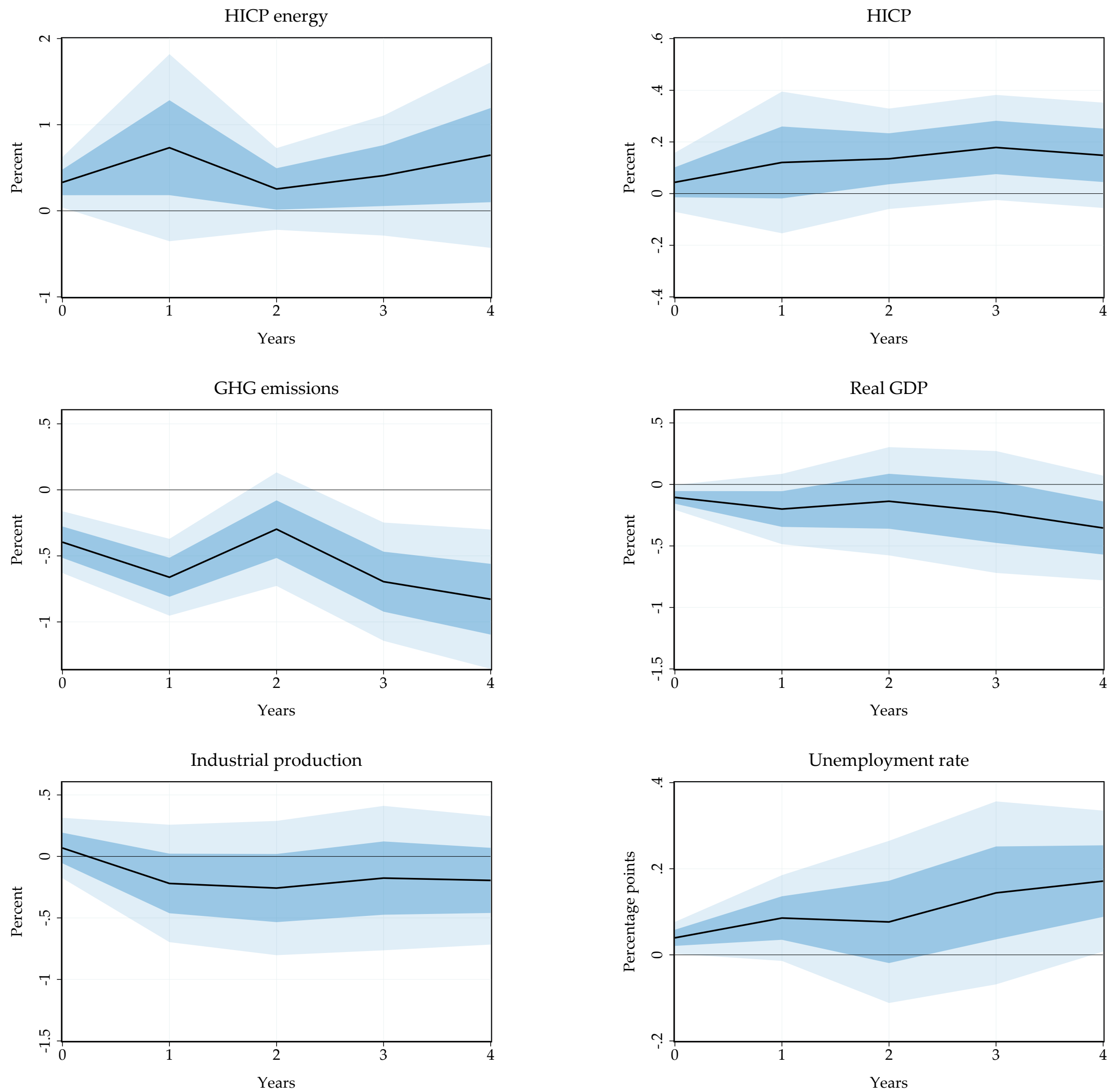

Figure A.8: The Effects of Scandinavian Carbon Taxes

Notes: Impulse responses to a carbon tax increase by one euro in real coverage-weighted terms in Scandinavian countries, estimated based on the specification with time fixed effects (1b). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on standard errors clustered at the country level, respectively.

A.6. Heterogeneity in ETS price impacts

As discussed in the main text, the impacts of carbon policy shocks vary significantly with the share of free allowances countries receive, as well as the concentration in national electricity markets. Figures A.9-A.10 illustrate the regional variation in these variables across Europe, which speaks directly to which regions tend to be more affected by carbon policy shocks.

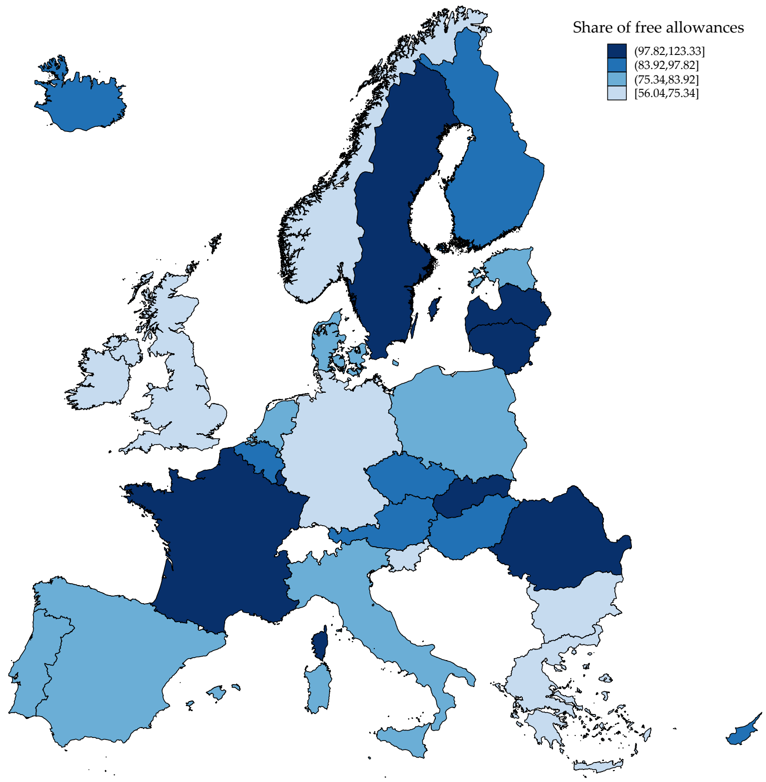

Figure A.9: The Regional Distribution of Free Allowances

Notes: Based on the average share of free allowances relative to total emissions.

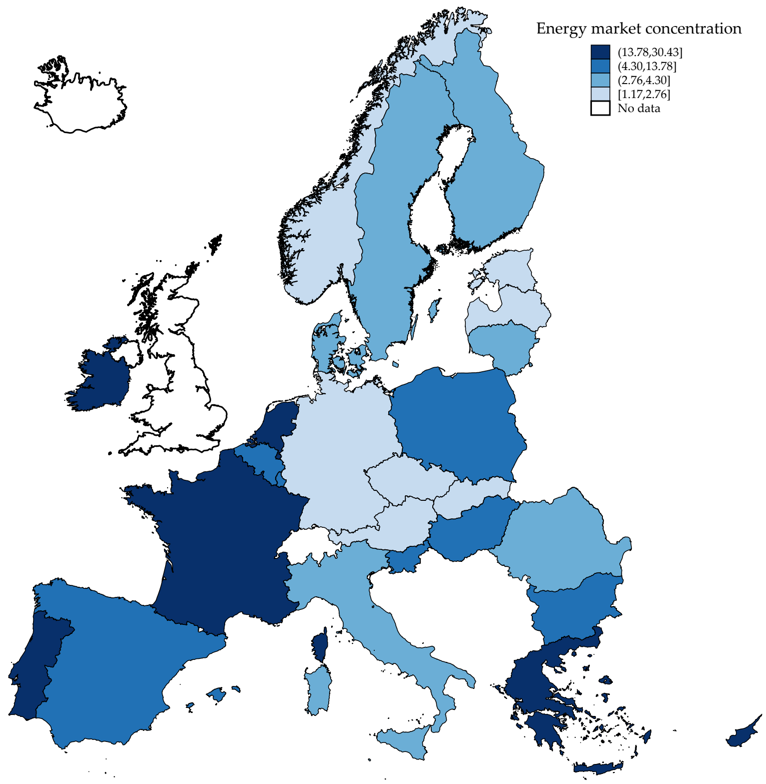

Figure A.10: The Regional Distribution of Electricity Market Concentration

Notes: Based on the average amount of primary energy consumption per electricity retailer. Data for the United Kingdom and Iceland are missing.

Figures A.11-A.12 further explore potential drivers of heterogeneity, focusing in particular on the energy mix and the sectoral composition, proxied by the service share, of a given country. It turns out that there is not that much heterogeneity depending on the energy mix of a country. One reason could be that it is important to account for the allocation of free allowances, as countries with a relatively brown energy mix received a disproportionate share of free allowances (see also Table A.1). We do find more meaningful heterogeneity with respect to the service share. Interestingly, countries with a higher service share display a somewhat stronger energy price response as well as larger effects on output and unemployment. The stronger economic impacts are consistent with the notion that some jobs in the service sector tend to be particularly cyclical.

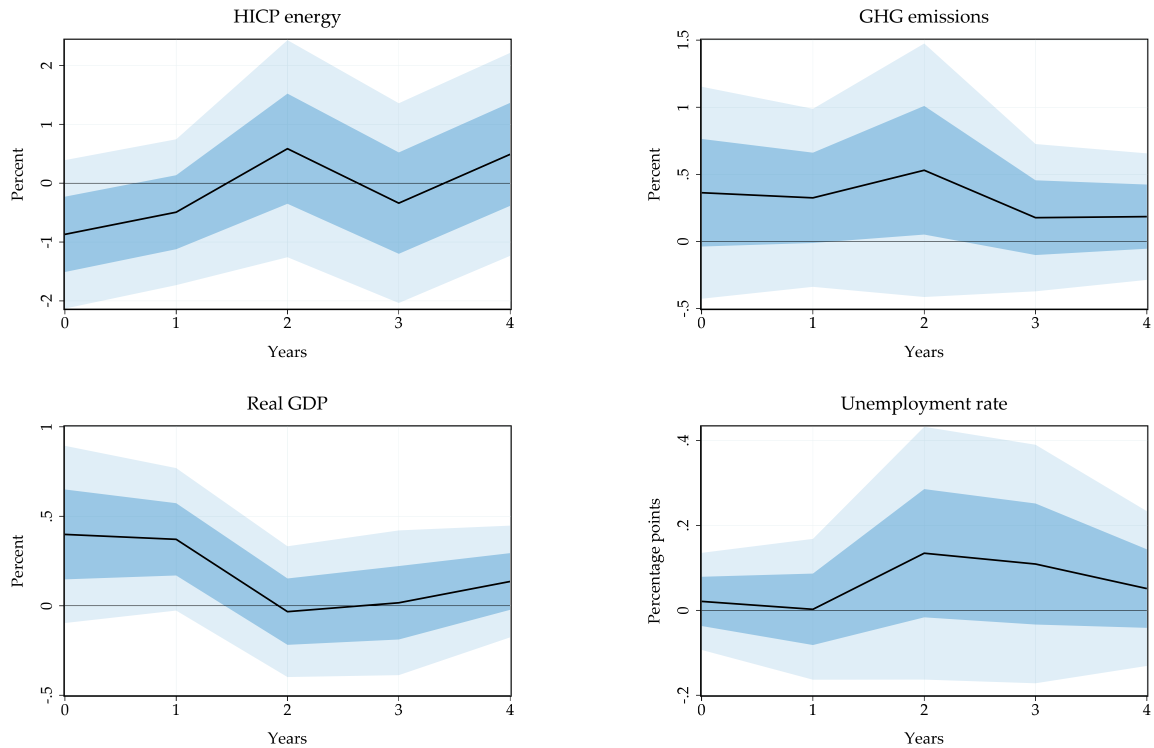

Figure A.11: Heterogeneity by Energy Mix

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for an interaction term with a country's share of non-renewables in primary energy consumption (standardized). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

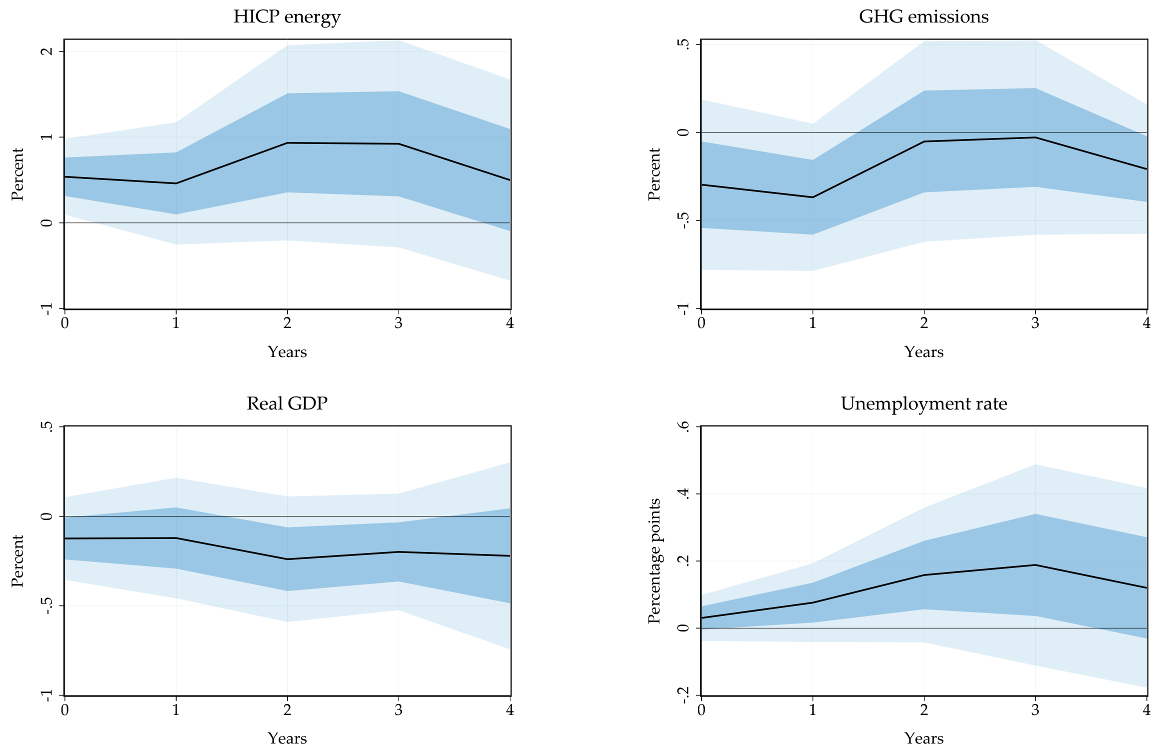

Figure A.12: Heterogeneity by Service Share

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for an interaction term with a country's share of services in value added (standardized). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively.

As we show in Figure 10, the impacts of ETS prices meaningfully depend on the share of freely allocated allowances. Since the allocation of free allowances was determined based on countries' industrial structure (see Martin, De Preux, and Wagner, 2014, for details), we want to ensure that differences in free allowances, and not the underlying industrial structure, are driving the results. To that end, we control for the (lagged) country-level trade and carbon intensity, as well as interaction terms with the carbon price. Trade intensity is defined as total trade to GDP, while carbon intensity corresponds to total emissions to GDP. Figure A.13 displays the corresponding impulse responses, which are comparable to the baseline estimates, especially for GDP and unemployment. In other words, the allocation of free allowances matters for understanding the heterogeneous impacts of ETS prices even when taking initial differences in countries' industrial structure into account.

Finally, we show in Table A.1 that countries in the second income group, which dis-

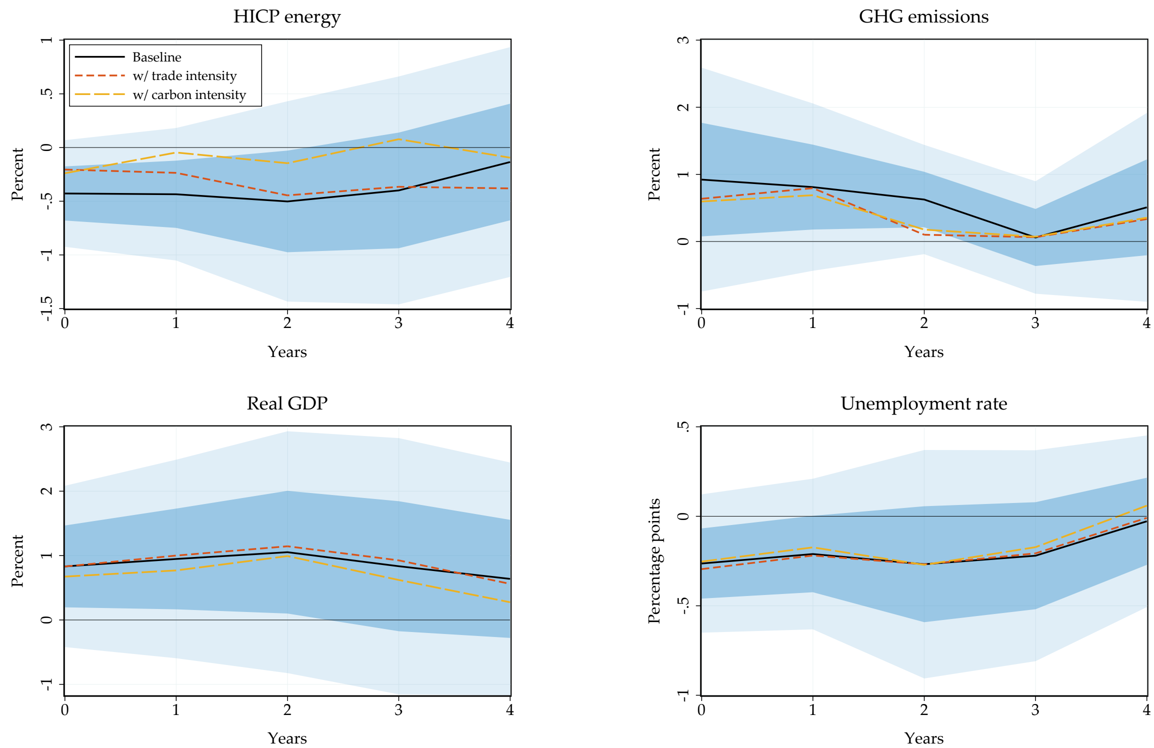

Figure A.13: The Role of Free Allowances Conditional on Industrial Structure

Notes: Impulse responses to an ETS carbon price increase by one euro in real coverage-weighted terms, estimated based on (5), allowing for an interaction term with a country's share of free allowances to total emissions (standardized). The solid line is the point estimate and the dark and light shaded areas are 68 and 95 percent confidence bands based on Driscoll and Kraay (1998) standard errors, respectively. The dashed lines show impulse responses (point estimates) from the same model controlling for country-level trade intensity and carbon intensity, as well as their interaction with carbon prices.

play the strongest response to carbon policy shocks, have received relatively fewer free allowances and tend to have more concentrated electricity markets.

Table A.1: Summary Statistics of Interaction Variables by Income

Variable	GDP per capita groups First	Second	Third
Share of free allowances to total emissions	98.95 (40.40)	81.79 (32.73)	86.46 (30.05)
Primary energy per electricity retailer	3.79 (2.03)	9.11 (8.06)	8.11 (7.30)
Share of non-renewables in primary energy	93.82 (6.15)	89.28 (6.30)	78.02 (21.09)
Share of services in value added	66.64 (3.76)	71.70 (5.82)	72.69 (7.95)

Notes: All variables are expressed as sample averages per income group, with standard deviations in parentheses. Groups are constructed based on 1998 real GDP per capita, with cutoffs at the 30th and 70th percentile. First group: Bulgaria, Estonia, Hungary, Lithuania, Latvia, Poland, Romania, Slovakia; second group: Belgium, Cyprus, Czechia, Finland, France, Germany, Greece, Italy, Portugal, Slovenia, Spain, United Kingdom; third group: Austria, Denmark, Ireland, Iceland, Luxembourg, the Netherlands, Norway, Sweden.

B. Data

In this appendix, we provide more detailed information on the data sources as well as some descriptive statistics on our main variables of interest. Table B.1 shows the definitions, sources and coverage of all variables we use in our analyses, at the country and EU level. Table B.2 presents descriptive statistics on the main variables of interest. Finally, Table B.3 provides information on the sectoral coverage of European carbon pricing policies.

Table B.1: Data Description

Variable	Description	Source	Coverage
Panel A: Country variables			
Carbon tax rate	Tax rates in USD	World Bank Group	1999–2019
Carbon tax coverage	In percent of total emissions	World Bank Group	2019
ETS emissions	Verified emissions, incl. aviation	EU Transaction Log	2005–2019
ETS allowances	Freely allocated allowances, adj. for corrections	EU Transaction Log	2005–2019
Total emissions	Total GHG excl. LULUCF incl. aviation	Eurostat	1999–2019
Real GDP	Real gross domestic product	World Bank Group	1999–2019
Industrial production	Excl. construction	Eurostat	1999–2019
Unemployment rate	ILO estimate	World Bank Group	1999–2019
HICP Energy	HICP energy	Eurostat	1999–2019
HICP	HICP all items	Eurostat	1999–2019
PPI	Industrial producer prices, domestic market	Eurostat	1999–2019
PPI Energy	Electricity, gas, steam and air conditioning producer prices, domestic market	Eurostat	1999–2019
Long term interest rate	10-year government bond rate	OECD, ECB	1999–2019
Policy rate	Monetary policy interest rate	BIS	1999–2019
Primary energy consumption	Total primary energy consumption	BP & OWID	1999–2019
Non-renewable share	Share of non-renewables in primary energy	BP & OWID	1999–2019
Electricity retailers	Number of electricity retail companies	Eurostat	2013–2019
Service share	Share of services in value added	OECD	1999–2019
Trade intensity	Merchandise trade to GDP	WTO	1999–2019
Panel B: EU variables			
Carbon policy shock		Känzig (2022)	1999–2019
ETS price	EUA front contract	Datastream	2005–2019
Real GDP	EU Real GDP	Datastream	1999–2019
Share price index	Euro STOXX	Datastream	1999–2019
Panel C: Global variables			
Oil price	Brent crude spot price	FRED	1999–2019

Table B.2: Descriptive Statistics

Variable	Observations	Mean	Median	St. Dev.
Panel A: Country variables				
Carbon tax rate (in €)	206	27.98	19.17	31.59
Carbon tax coverage (in %)	294	0.28	0.29	0.17
ETS emissions (in mn. tCO2)	420	68.08	28.23	96.98
ETS allowances (in mn. tCO2)	419	54.22	23.99	79.49
Total emissions (in mn. tCO2)	588	176.93	72.05	233.97
Real GDP (in bn. €)	588	512.69	199.13	761.96
Industrial production (index)	552	97.28	100.00	19.66
Unemployment rate (in %)	588	8.25	7.24	4.39
HICP Energy (index)	582	84.98	90.34	21.77
HICP (index)	588	88.27	91.47	14.24
PPI Energy (index)	503	88.82	93.20	24.04
PPI (index)	540	90.81	95.80	15.04
Long term interest rate (in %)	541	4.03	4.13	2.46
Policy rate (in %)	563	2.50	2.00	2.81
Primary energy consumption (in TWh)	588	730.10	341.54	948.81
Non-renewable share (in %)	588	86.45	93.10	17.95
Electricity retailers (number)	182	159.78	53.50	275.15
Service share (in %)	525	70.01	69.94	6.42
Trade intensity (in %)	588	81.18	68.88	38.48
Panel B: EU variables				
Carbon policy shock (in %)	588	-0.00	0.03	1.83
ETS price (in €)	420	12.13	13.04	7.11
Real GDP (in tn. €)	588	10.06	10.18	0.70
Share price index (in €)	588	307.86	309.50	57.59
Panel C: Global variables				
Oil price (in €)	588	62.36	61.74	29.47

Table B.3: Main Sectors Covered by Carbon Pricing

Jurisdiction	Sectors
Panel A: EU ETS	
EU	Power sector, energy-intensive industry, aviation
Panel B: Carbon taxes	
Finland	Transportation, heating
Poland	
Norway	Transportation, industry, agriculture
Sweden	Transportation, heating, industry
Denmark	Transportation, heating
Slovenia	Buildings, transportation
Estonia	Transportation, industry
Latvia	Industry, power sector
Ireland	Industry, transportation
Iceland	Transportation
United Kingdom	Power sector
Spain	Industry
France	Industry, transportation
Portugal	Transportation, road and construction

Notes: Based on Sumner, Bird, and Dobos (2011), Carl and Fedor (2016), Andersson (2019), Marten and Van Dender (2019), Metcalf and Stock (2023), Konradt and Weder di Mauro (2023). No data is available for Poland.