EUROPEAN CENTRAL BANK
EUROSYSTEM

Working Paper Series

Anna Matzner, Lea Steininger

Firms' heterogeneous (and unintended) investment response to carbon price increases

No 2958

Abstract

We study the heterogeneous pass-through of carbon pricing on investment across firms. Using balance sheet data of 1.2 million European firms and identified carbon policy shocks, we find that higher carbon prices reduce investment, on average. However, *less* carbon-intensive firms and sectors reduce their investment relatively more compared to otherwise similar firms after a carbon price tightening shock. Following carbon price tightening, firms in demand-sensitive industries see a relative decrease not only in investment but also in sales, employment and cashflow. Moreover, we find no evidence that higher carbon prices incentivise carbon-intensive firms to produce less emission-intensively. Overall, our results are consistent with theories of the growth-hampering features of carbon price increases and suggest that carbon pricing policy operates as a demand shock.

JEL classification: Q54, Q58, D22, H23.

Keywords: Carbon pricing, public policy, climate crisis, corporate finance, economic growth.

1 Non-technical summary

This research explores the impact of carbon pricing on investment behaviors among European (non-financial) firms. Using a dataset of over 1.2 million firms, the study finds that increases in carbon prices generally lead to reduced investment. However, this effect varies significantly across different types of firms. Surprisingly, less carbon-intensive firms and sectors tend to reduce their investments more than their more carbon-intensive counterparts following a carbon price increase. This result is contrary to the policy's objective of incentivizing high emitters to cut emissions.

Industries that are sensitive to demand, such as those dependent on consumer spending such as construction, see a notable decline not only in investment but also in sales, employment, and cash flow after carbon price hikes. Furthermore, there is no substantial evidence that higher carbon prices motivate emission-intensive firms to adopt cleaner production methods. Thus, while the policy increases costs for these firms, it does not significantly drive them to reduce emissions.

The study finds that carbon pricing acts as a demand shock, reducing economic activity by reducing both household consumption and firm investments. This effect is particularly pronounced in firms that are less carbon-intensive, which may not align with the intended environmental goals. The analysis suggests that current carbon pricing policies might need to be re-evaluated to ensure they effectively target emission reductions without excessively hindering economic growth.

The methodology involves leveraging rich firm-level data from the Orbis database, which includes both listed and unlisted firms, providing a broad perspective on the policy's impact. High-frequency data on carbon pricing shocks are used to capture immediate firm responses. By comparing firms within the EU's Emission Trading System (ETS) to similar firms outside it, the study assesses the broader economic impacts of carbon pricing.

Policy-wise, our study points to the need to consider the full toolbox of available instruments to tackle the climate crisis (including anti-trust policy, public infrastructure investments, targeted taxation, regulatory policy). Carbon pricing policies might not be a panacea to facilitate the just transition in a timely manner.

In conclusion, this analysis underscores the complexity as well as potential side-effects of implementing higher carbon prices. While intended to reduce emissions, the actual economic impacts are varied and can sometimes be even counterproductive. Policy makers are advised to carefully consider these heterogeneous effects to design more effective climate policies that achieve environmental objectives while maintaining economic stability and growth.

2 Introduction

At least since the 2015 Paris Agreement, mitigating the climate crisis has been a key policy issue in both advanced and developing economies. The implementation of stringent climate policies and regulations is essential to mitigate the physical risks associated with climate change on our socioeconomic and financial systems. However, climate policy measures themselves can harbor transition risks that may have a real impact on the economy. For this reason, dispute arose early both in the policy arena and the academy as to *how* this goal should and could be achieved. Chief among the questions accompanying the discussion are: Which climate policies are least unfriendly to economic growth? How can corporate investment be channelled into environmentally friendly production? How can climate-related externalities be priced into most effectively, and most efficiently?

Our study answers these questions. Our results show that an increase in carbon prices normalized to a 1% increase in energy prices results in 1,5% stronger decrease in tangible asset stock of energy-*un*intensive compared to energy-intensive production four years after the shock. We build on Känzig (2023) who shows that higher carbon prices through emission trading systems result in a significant increase in headline consumer prices, cause GDP and industrial production to decrease, coupled with an increase in unemployment. This prompts inquiries into why emission trading leads to economic setbacks, especially when compared to other climate measures like carbon taxes, which exhibit far less severe impacts on the economy (Känzig & Konradt, 2023; Metcalf & Stock, 2020; Konradt & Weder di Mauro, 2021). By influencing energy prices, carbon pricing has demonstrated its ability to affect household consumption and therefore reduce demand of energy and non-energy consumption (Känzig, 2023). Additional evidence suggests that factors such as the tax structure, sector-specific pass-through mechanisms and coverage, spillovers and leakage, and monetary policy play a role in explaining the economic consequences of carbon pricing (Känzig & Konradt, 2023). To the best of our knowledge, the role of firms has yet to be investigated.

For the purpose of a granular analysis of firm-level effects of carbon pricing, the European Union (EU) provides an ideal setup as its commitment to carbon-neutrality which was recently renewed with the approval of the European Green Deal.[1] To accomplish carbon-neutrality, the EU in 2005 established, among other, carbon pricing policies in the shape of the European emission trading system (ETS). This trading system functions on the principle of cap and trade, where a limit is set on the total quantity of greenhouse gases permissible for emission; participants within the system are granted allowances that can be traded among them. The idea behind the cap and trade principle is that it allows the system to find the most cost-effective way of reducing emissions without the government significantly intervening. It targets carbon-intense production and aims to reduce primarily emissions from installations in the energy sector, the manufacturing industry, and aircraft operators.

---

[1] In this spirit, the European Commission has put forward a proposal to reduce net greenhouse gas emissions by at least 55% compared to 1990 levels and to increase the share of renewable energy by at least 32% by 2030.

In light of these developments and challenges, the aim of this paper is to provide novel empirical evidence on firm level effects of carbon pricing by exploiting the firm-level information that comes from the `Orbis` database for European firms. We investigate the policy's effect on European firms' investment decisions. Employing a micro-macro approach, we combine the rich dataset of both listed and unlisted firms with high-frequency identified carbon pricing shocks. The `Orbis` database allows us to examine the effect on the whole universe of firms and, importantly, not only those who participate in the ETS. This allows us to capture the broader effect on the macroeconomy as we study the role of energy- and emission-intensity for the shock transmission. We employ the following measures: First, we identify those firms who participate in the ETS to capture the direct effect of carbon pricing. Second, we compare firms in carbon-policy relevant sectors to otherwise similar firms (that is, we benchmark fossil fuels, utilities, energy-intensive, buildings, transportation, and agriculture against a baseline of environmentally inconspicuous production). Third, we employ measures of industry emission-intensity and energy-intensity to study the indirect effects of carbon pricing, i.e. including on non-ETS firms. Overall, this empirical setup facilitates the identification of factors behind the growth-hampering economic impacts of carbon pricing and enables us to assess whether the policy effectively targets not only polluting production but economic growth in general.

Our findings indicate that carbon pricing indeed reduces firms' investment, on average. Interestingly, energy-intensive and emission-intensive production reacts less to a tightening in carbon policy compared to their low-intensity counterparts. Also, firms that are part of the ETS reduce their investment by less than otherwise similar firms. The effect is especially large in the buildings and construction sector. We conclude that our findings emphasize the demand side effects of the carbon policy shocks. We employ a measure of demand sensitivity and find that firms that face high demand sensitivity react more to the shock. This is in line with Känzig (2023) who finds that consumers reduce their consumption of energy and non-energy goods following a tightening of carbon policy. Further, it relates to the broader literature on energy price shocks that more recently focuses on the transmission of such shocks on the demand side of the economy (Chan et al., 2022; Lee & Ni, 2002). Thereby, energy price shocks primarily impact the economy by causing disturbances in the expenditures of both consumers and firms on non-energy related goods and services. The channel undermines our finding that those firms with high emission intensity and energy intensity increase their investment relatively since those firms often face low demand sensitivity. Lastly, we document no discernible effect of carbon-pricing on the emission-intensity of high-polluting firms, further suggesting that the differential response in firms' investment is not operating as intended.

As the EU's carbon pricing system is targeted at carbon-intense companies, its goal is to reduce emissions from certain high-emitting installations in the energy sector, manufacturing industry, as well as aircraft operators. However, there can also be side-effects as well-documented in the energy price literature that may help explain our findinds: carbon pricing might have a wider-reaching effect on production, primarily through higher energy prices since power producers seem to pass through emission costs to a significant extent (Fabra & Reguant, 2014; Joussier et al., 2023). In general, energy price shocks may be transmitted to the economy by adjustments in firms' investment. Kilian (2008) summarizes three main channels of energy-price shocks on firms' investment. First, by increasing the marginal cost of production (Hamilton, 2008). The increase depends on the energy cost share. Additionally, firms might have to pay for the allowances depending on the industry. Second, demand for a firm's output decreases as consumers reduce their expenditures as they experience a decrease in disposable income. Third, changes in energy prices induce uncertainty about future energy prices which causes firms to postpone investment decisions. Consequently, carbon pricing might lower firm profits in all sectors due to the increase in energy prices and reduced demand from the household sector.

2.1 Related literature

We contribute to at least three strands of the economic literature. First, our study adds to the expanding literature that examines the macroeconomic implications of climate policies. Recent empirical contributions have foremost concentrated on the effect of carbon pricing on key macroeconomic aggregates such as GDP, inflation, or employment. Känzig (2023) studies carbon pricing in the EU ETS and finds that while aggregate economic activity falls, consumer price inflation increases. Berthold et al. (2023) provide further evidence on the contractionary and inflationary impact of carbon pricing in the EU ETS and highlight that the magnitude of the effect depends on a country's emission intensity. Konradt & Weder di Mauro (2021) and Metcalf & Stock (2020) study the macroeconomic impact of carbon taxes and conclude that implications of carbon taxes on economic outcomes in Europe and Canada are limited. Känzig & Konradt (2023) compare the effects of carbon pricing under the ETS with European carbon taxes. They highlight that the economic costs associated with the European carbon market are larger than for national carbon taxes supporting the inconclusive findings of the papers mentioned above. They provide evidence for the role of revenue recycling and sectoral coverage for the transmission of these policies and suggest further that that spillovers and leakage, and monetary policy determine the response.

Second, we add to the literature on climate finance. As for carbon pricing, the existing literature has primarily centered around the financial market response to elevated transition risk resulting from climate policies. Various papers have studied the response of stock returns and equity prices following climate policy events. Hengge et al. (2023) and Berthold et al. (2023) focus on the carbon pricing shocks identified by Känzig (2023). The effects on stock returns and equity prices are negative whereby the effects increase with the emission-intensity of the firms. Additionally, higher carbon-intensity of firms and thus higher exposure to climate (transition) risks may lead investors and more specifically banks to ask for higher returns on their loans (Bolton & Kacperczyk, 2021, 2022). Furthermore, climate policies induce firms to reallocate their resources and reduce the value of fossil fuels which might lead to stranded assets (Laeven & Popov, 2023) which is costly for affected firms. As a result, carbon-intensive companies may experience a reduction in their investment opportunities and potentially diminished returns.

Lastly, we contribute to a long strand of literature that studies firms' heterogeneous investment behavior, and exploits cross-sectional variation in doing so (Goolsbee, 1998; House & Shapiro, 2008; Zwick & Mahon, 2017; Barbiero et al., 2020; Ottonello & Winberry, 2020). We deviate from these approaches by (i) focusing on the investment response to carbon pricing shocks, (ii) studying a broader range of both listed and unlisted firms, and (iii) using firms' balance sheet data which is less prone to endogeneity than macroeconomic data while allowing for more granularity in an account of underlying mechanisms.

2.2 Firms in the EU Emission Trading System

In this paper, we use the term carbon pricing to describe the impacts of emission trading. The ETS is considered the cornerstone of the EU's climate policy. The EU was first to establish a carbon trading system and the EU ETS has developed to be the largest carbon trading system worldwide. It covers all EU countries plus Iceland, Liechtenstein and Norway. It limits the volume of greenhouse gas emissions by putting a cap on the number of emission allowances. Each allowance is accompanied with the right to emit a tonne of carbon dioxide or an equivalent amount of other greenhouse gases. It covers approximately 40 percent of emissions in the EU. Firms within the system receive allowances to emit. The allowances are either allocated for free or auctioned at the beginning of each trading period. The participants can then trade allowances. The idea is that emissions are reduced where it is least costly by a market equilibrium. The cap and trade systems sets a financial incentive for firms to reduce emissions. So far, the system took place in four phases. The current fourth phase runs until 2030. The cap on allowances is set on emissions for the EU as whole and decreases annually by a factor of 2.2 percent.

It covers emissions from around 10,000 installations from specific activities where emissions can be accurately measured, reported and verified. More specifically, it covers emissions from electricity and heat generation, energy-intensive industry sectors, including oil refineries, steel works, and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals. It further covers aircraft operators that are flying within the EU. It will cover emissions from maritime transport from 2024. Firms that undergo the listed activities have to participate in the ETS. In some sectors participation depends on the size of the installation.

There are no NACE codes available to identify firms that are covered by the ETS. In our sample, most firms covered are in sectors C (Manufacturing), D (Electricity, gas and steam and air conditioning supply), G (Wholesale and retail trade, repair of motor vehicles and motorcycles), H (Transportation and storage), M (Professional, scientific and technical activities), F (Construction) and B (Mining and quarrying). Relative to the overall number of firms in the sector, sector D comprises the largest share of firms that are covered by the ETS, namely 14.4 percent of all firms in sector D.

Roadmap. The remainder of the paper is structured as follows. Section 3 discusses the firm-level data used for our analysis as well as the dimension of heterogeneity explored to uncover channels of carbon policy on investment. Section 4 elaborates on the high frequency approach used to identify carbon policy surprises. It further summarizes the local projection framework for impulse response calculation. In Section 5, we summarize the average investment response in our sample and continue with a discussion of firm heterogeneity. A final section concludes.

3 Data

3.1 Firm-level data

Our firm-level data come from the `Bureau van Dijk's` (`BvD`) `Orbis` commercial database for European firms. The dataset contains listed and unlisted firms' balance sheet reporting of annual frequency. Importantly, we include all firms in our dataset and not only those who participate in the EU ETS. This rich database comprises employment statistics, detailed asset and liability information as well as industry affiliation for SMEs and large firms. Our sample consist of 1,233,824 firms over the time period 2000 to 2017. Our baseline sample includes 8 countries: Austria, Belgium, Germany, Spain, Finland, France, Italy, and Portugal.

For our sample selection and to clean the data, we closely follow the steps outlined by Kalemli-Özcan et al. (2023), Durante et al. (2022) and Gopinath et al. (2017). We keep only unconsolidated data from corporate industry firms. We drop firms that report negative total assets, negative employment, employment larger than than 2 million employees, negative sales, or negative tangible fixed assets. We omit firm-year observations if total assets equals zero, firm age is negative, and fixed assets is missing, negative, or zero. Moreover, observations are discarded when tangible fixed assets is missing or negative, and intangible fixed assets is negative. Observations with simultaneously missing data on total assets, operating revenue, sales and employment are also dropped. We implement steps according to Gopinath et al. (2017) to correct for basic reporting mistakes and drop firm-year observations that have missing data on their industry of activity. To avoid distortions from outliers, we winsorize the main variables at the 1% and 99% level. We follow Durante et al. (2022) and keep only firms with at least 5 consecutive years of observations since we focus on the dynamic response to carbon policy shocks and use lags in our local projection framework. Appendix A.1 describes the steps in more detail. After applying all data cleaning process, we are left with 11,013,831 firm-year observations for the sample period.

Our main variable of interest is firm-level investment. We use tangible fixed assets as our measure of firm level investment. Our results are robust if we instead use total assets as dependent variable. We further use the following firm-specific variables as control variables: number of employees, total assets, working capital, cash holdings, and loan information. Table 3 in the appendix displays the summary statistics of all firm level variables.

We are able to identify those firms that participate in the EU ETS by matching data from the `European Union's Transaction Log` with the Orbis database. This allows us to determine the direct effect of participation in the EU ETS. We identify approximately 37,465 firms in our sample that participate in the ETS. Country-specific controls are taken from `Eurostat` and the `World Bank Group`. We employ data on country-level (energy) inflation, GDP growth and the unemployment rate.

3.2 Firm heterogeneity

We are interested in identifying how firm heterogeneity influences the transmission of a carbon policy shock to the economy. Thereby, we plan to identify channels of carbon policy on firm level investment and shed light on effects that might be obscured by the average response.

The EU ETS aims to reduce emissions from production. We analyze how the investment response varies according to a firm's emission intensity and/or a firm's energy share in production. Unfortunately, data on both emissions and energy usage is difficult to obtain on firm level. We obtain different measures of emission- and energy-intensity of firms on industry and sector level to get an idea of how the effect varies with the above. First, we analyze differences between firms who participate in the EU ETS and those who do not participate. Firms are identified by matching the Orbis data with the `European Union Transaction Log`. Second, we classify firms into climate policy relevant sectors (CPRS). CPRS are identified considering i) technology (i.e. the role in the energy value chain), ii) the GHG emissions chain, iii) dominant business models (input substitutability of fossil fuel) as well as iv) the specific policy processes. The main sectors relevant for climate transition risk are fossil-fuel, utilities, energy-intensive, transportation, buildings and agriculture. Third, we calculate a measure of industry-level energy intensity. We employ industry-level data on gross energy use by Timmer et al. (2015) and relate it to industry production. Fourth, we employ a measure of emission intensity on the industry level. More specifically, we use a measure of air emissions intensities by NACE Rev. 2 activity provided by `Eurostat`. It relates emissions of greenhouse gases and air pollutants in 64 industries to value added. We group firms according to their emission intensity in 2017. To explore heterogeneity, we group firms according to their industries' energy- and emission intensity. We use the following percentiles as thresholds to sort our data into groups: $p10$, $p25$, $p50$, $p75$, and $p90$ (pn denotes the n^{th} percentile).

4 Empirical strategy & identification

4.1 Identification

The key difficulty lies in identifying the causal effects of carbon pricing. There are two reasons for potential endogeneity of the effect. First, there is the possibility of simultaneity. In times of economic downturn, governments might be reluctant to increase the carbon price or even reduce it. Second, economic or financial shocks that affect carbon prices and the economy might act as confounding factors. In order to address this challenge, we use the carbon policy shocks as identified in Känzig (2023) where he exploits high-frequency data on EU ETS carbon policy news events. The approach draws upon the literature on high-frequency identification, which was originally formulated in the context of monetary policy (Gertler & Karadi, 2015; Nakamura & Steinsson, 2018).

Policy surprises are identified looking at carbon price expectation revisions caused by regulatory news about the EU ETS in a tight window around the announcement event. More precisely, we calculate the percentage change in EU emission allowances (EUA) future prices on the day of the regulatory event as $CPSurprise_{t,m,d} = (F_{t,m,d} - F_{t,m,d-1})/F_{t,m,d-1}$. Here, $F_{t,m,d}$ is the EUA future price in year t, month m and on day d and $CPSurprise_{t,m,d}$ is the carbon policy surprise in year t, month m and on day d. Känzig (2023) aggregates the daily surprises to obtain a monthly series $CPSurprise_{t,m}$. An allowance gives the right to emit one ton of carbon dioxide equivalent gas. Since price changes are measured within a tight window around the event, future prices likely already factor in all information accessible to investors. With the surprise series, we capture all surges unexpected by the investors. It is crucial that we do not capture the response to any other policy announcements or economic or political events that coincide with the carbon policy news events. Also, Känzig (2023) has specifically chosen regulatory events that concern the supply of emission allowances within the European carbon market. Examples for the regulatory events are decisions of the European Commission, votes of the European Parliament or judgment of a European court that concern the supply of allowances.

Stock & Watson (2018) highlight that high-frequency surprises should be used as instruments rather than shock measures since they capture only part of the shock or are measured with error. Therefore, we employ the carbon policy shock series in our empirical framework as estimated in Känzig (2023). The monthly shock series $CP_{t,m}$ is constructed using the surprise series as instrument for the carbon policy shocks within a monthly external instrument VAR as follows. A priori, the shocks are unobserved. In the external instrument VAR, without loss of generality we thus denote the shock of interest as the first shock in a vector of structural shocks. In a two-stage procedure, the surprises are used as an instrument for the shock. Here, the carbon policy surprises are used as instrument for carbon policy shocks. The carbon policy surprises fulfill the conditions necessary for a valid instrument. The surprises are relevant in explaining structural carbon policy shocks but exogenous with respect to other structural shocks. Since the shock is unobserved, the scale of the shock is indeterminate. To enable interpretation of the effect, the shock is usually normalized such that a one unit increase in the shock measure increases the first variable in the VAR by one. In his external VAR setup of the European economy, Känzig (2023) normalizes the shock such that it increases energy prices by 1 percent. Therefore, we can interpret a one percentage point increase in our shock measure CP_t as a carbon policy shock that increases energy prices in the European economy by one *percent*.

Since our firm-level data is annual, we sum over the monthly shocks in year t to retrieve a yearly shock series (as in, for instance, Holm et al. 2021): $CP_t = \sum_{m=1}^{12} CP_{t,m}$. Figure 1 displays the resulting shock series, CP_t. Our local projection framework allows us to include the shock series directly in the regression.

Figure 1: Annual Carbon Policy Shocks.

4.2 Estimation framework

Our goal is to study the dynamic causal effect of carbon policy on firm investment. We employ a state-of-the-art local projection framework in panel data settings introduced by Jordà (2023) and Jordà et al. (2015). Local projections allow us to estimate how a firm over horizon $h > 0$ responds to carbon policy shocks and to compute the corresponding impulse responses. Each impulse response coefficient is estimated directly with a different regression which makes it less sensitive to misspecification. The baseline specification of the local projection is

$$\Delta_h y_{i,t-1} = \alpha_i^h + \beta^h CP_t + \sum_{p=1}^{P} \theta_p^h \Delta y_{i,t-p} + \sum_{p=0}^{P} \mathbf{X}_{i,t-p} \mathbf{\Gamma}_p^h + \epsilon_{i,t+h}. \tag{1}$$

Time is denoted by t and runs at an annual frequency. The index i denotes the firm. $\Delta_h y_{i,t-1} = y_{i,t+h} - y_{i,t-1}$ denotes the long difference of the response variable of interest, the change in investment (measured as the log difference of the respective variable), from the base year $t-1$ up to year $t+h$ with $h = 0, 1, ..., H$. β^h capture the dynamic effects at horizon h for a percentage point increase in the carbon policy shock measure CP_t. An increase in the shock measure corresponds to a tightening in carbon policy and is normalized to increase energy prices in the European Union by one percent.

Given the exogeneity of the carbon policy shock, we do not need to include controls for identification. We do, however, add fixed effects and some country- and firm- level controls to improve precision. Since the external instrument VAR estimations underlying the shock estimate do already control for any European or global factors, those are not included in the estimation (see Känzig, 2023). The firm fixed effects α_i^h control for heterogeneity across firms for each horizon h. We further add lagged changes in investment, $\Delta y_{i,t-p}$ to our model. $\mathbf{X}_{i,t-p}$ is a vector of additional controls. We add a set of country- and firm-specific controls such as (energy) inflation, GDP growth, the local unemployment rate, total assets, working capital, cash holdings, and leverage. Total assets enter our model in log differences while all other controls enter in differences. We set the lag length $P = 2$ (see, i.e., Jordà et al., 2015; Durante et al., 2022). $\epsilon_{i,t+h}$ denotes the idiosyncratic error term. In all application, standard errors are clustered at the firm level. The treatment of the standard errors accounts for potential correlation within a firm.

The main focus of our paper is how firm heterogeneity affects the transmission of carbon policy to the economy. To test for differences among firms, we interact our shock variable with group specific indicators D_t^g. This allows us to test whether the response of a specific group is statistically significantly different from the baseline group. The specification writes as follows:

$$\Delta_h y_{i,t-1} = \alpha_i^h + \gamma_t^h + \sum_{g=2}^{G} \beta_g^h CP_t D_t^g + \sum_{p=1}^{P} \theta_p^h \Delta y_{i,t-p} + \sum_{p=0}^{P} \mathbf{X}_{i,t-p} \mathbf{\Gamma}_p^h + \epsilon_{i,t+h}, \tag{2}$$

where $\Delta_h y_{i,t-1} = y_{i,g,t+h} - y_{i,g,t-1}$ denotes the long difference in investment and β_g^h captures the dynamic effects at horizon h of group g relative to the baseline group. G is the number of bins per group. For instance, the framework allows us to test whether firms who participate in the ETS react differently to the shock compared to firms who do not participate. We include the same control variables as before. Additionally, the specification now allows us to include time fixed effects which are denoted by γ_t^h. In Equation 1, we are not able to include time fixed effects since our shock measure only varies with time and would therefore be absorbed when including time fixed effects. The group-specific interaction, however, introduces additional variation in our variable of interest and thus allows us to control for time fixed effects.

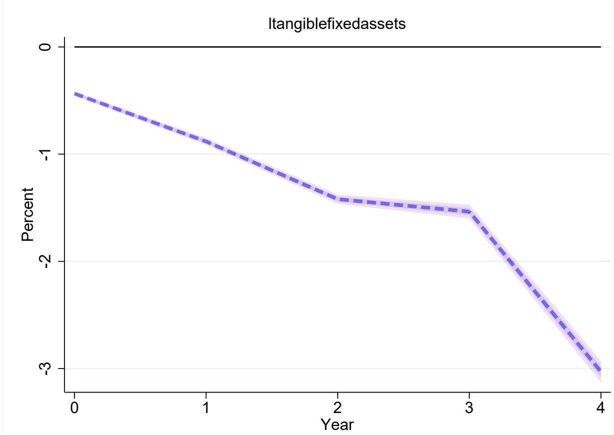
5 Empirical results

This section investigates the relation between carbon pricing and firm investment, with average (aggregate) results in Section 5.1, sector-level effects 5.2 and differential (heterogeneous firm-level) effects in Section 5.3.

5.1 Carbon pricing and investment: Aggregate effects

Before looking into the findings for different channels of heterogeneous transmission, we compute the average response of investment to changes in carbon policy. The estimation includes all firms regardless of whether they do or do not participate in the EU ETS. The goal is to obtain a benchmark against which we can assess the differential responses. This setup permits us to determine the aggregate response of investment to carbon policy surprises using micro data. Our response variables are specified as the log-difference denoted $\Delta_h y_{i,t-1} = y_{i,t+h} - y_{i,t-1}$ (see Equ. 1). Given that our variables are log-transformed, the difference may be interpreted as the approximate overall percentage change in the variable from $t-1$ to h periods in the future since the surprise.

Figure 2: Average investment response



Notes: The graph displays the average firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 2 reports the impulse response function of corporate sector investment up to four years after the carbon policy shock which is normalized to increase energy prices by 1 percent in the European Union. It shows the cumulative log-change between period $t-1$ and $t+h$ after the carbon policy surprise. The results suggest that investments fall in response to the carbon policy shock. After four years the cumulative effect amounts to approximately 3 percent. Our findings suggest that firms react by reducing investment after the policy shock. Firms react already on impact.

To get an idea of the magnitude of the shock for our sample countries and to compare our results to findings in the literature, we estimate the average response of energy inflation, inflation and GDP in our sample countries. The corresponding IRFs are shown in Figure 3: on impact, energy prices increase by about 0.6 percent in our sample following a shock in our carbon policy shock measure. Power producers seem to pass through higher emission costs to energy prices. This is in line with findings in the literature (see, for instance, Fabra & Reguant 2014). Energy prices remain elevated within three years following the shock. Overall, prices increase by about 0.1 percent on impact and remain elevated for the same time period. The peak inflation response are 0.2 percent. Since the shape of inflation follows the shape of the energy component, the responses suggests that inflation is mainly driven by energy price increases. GDP reacts with a lag. Two years after the shock, GDP is approximately 0.3 percent lower than before the shock. Unemployment has a peak response of 0.15 percentage points and reacts with a lag, similarly to GDP.

What are the aggregate implications of these results? We note that, in these specifications, we cannot control for time fixed effects. However, the findings are highly robust and – given the exogeneity of our shocks – likely to change only in terms of precision but not the overall direction. The results thus strongly suggest that across the universe of data splits (that is, along country, firm characteristic and sector dimensions), an increase in carbon prices results in a decline in investment. With these average effects as our benchmark, we are motivated to study the differential responses of different groups in the next section.

5.2 Carbon pricing and investment: Sector-level effects

We next turn to evaluating evidence based on a sector-level analysis. For this purpose, we employ the Climate Policy Relevant Sectors (CPRS) scheme which classifies sectors' economic activities at the NACE Rev2, 4-digit level. The CPRS provides a standardized and actionable classification of sectors primarily with the purpose to assess climate transition risk (Monasterolo & De Angelis, 2020; Battiston et al., 2017) that is widely used by policy makers and academics alike. CPRS are identified considering i) technology (i.e. the role in the energy value chain), ii) the GHG emissions chain, iii) dominant business models (input substitutability of fossil fuel) as well as iv) the specific policy processes. The main sectors relevant for climate transition risk are fossil-fuel, utilities, energy-intensive, transportation, buildings and agriculture. Those sectors are particularly sensitive to climate-related policies (Monasterolo & De Angelis, 2020). The remaining firms are categorized as finance, scientific R&D and other, respectively. Other activities include administrative tasks, telecommunications, educations, wholesale, retail, publishing, and service activities.

In Figure 5, we evaluate model 2 to test the difference in investment behavior by more climate-policy sensitive versus non climate-policy sensitive sectors after a carbon policy shock. Therefore, we summarize the non CPRS sectors and treat them as our baseline group. The responses in Figure 5 thus show the response of CPRS sectors relative to the combined baseline group. The response of firms in the fossil fuel sector is 0.5 percent higher two years after the shock. The difference is insignificant subsequently. Since the average response of firms in our sample is negative – the firms reduce investment after the carbon policy shock – the graph suggests that firms in fossil fuel reduce their investment by less than otherwise similar firms in non climate policy relevant sectors. The response of firms in the utility sector is not significant which suggests that firms in the utility sector do not respond differently compared to non CPRS firms. Energy-intensive firms react stronger within the first year but after four years, their reduction investment is about one percent lower than non-CPRS firms' reduction. Contrary, we see that firms in the building industry react much stronger to the shock compared to non-CPRS firms. The difference increases over time. Four years after the shock, the difference amounts to 1.5 percent. Firms in transportation, react by reducing investment by more than non-CPRS within the first two years but we see rebound effects after. Three years after the shock the response is positive. The largest difference is visible when looking at firms in agriculture. They reduce investment by far less than non-CPRS firms. The difference increases over time and amounts to about four percent after four years.

5.3 Carbon pricing and investment: Firm-level effects

We explore firm heterogeneity with respect to the shock response to identify potential channels of the shock on firms' investment decisions. We estimate Equation 2 for different characteristics. The impulse response functions show the differential impact of a group relative to the respective baseline. The framework allows us to test differences between groups. First, we investigate the effect of participation in the EU ETS. Further, we explore heterogeneities in the response firms according to our measures of emission- and energy-intensity.

The direct effect of participation in the EU ETS. First, we investigate how firms who participate in EU ETS react to the carbon policy shock compared to firms who do not participate. As highlighted above, we can identify firms in our dataset that do participate. Figure 4 suggests that the investment response for firms that do not participate in the ETS is larger than the response of firms that participate. While the difference in response is not large on impact, firms participating in the ETS invest about 1.5 percent more four years after the shock compared to firms who do not participate. The finding is quite striking as one could expect stronger effects for those firms participating in the ETS as those firms are exposed to higher emission costs. While firms participating are subject to emissions costs given their area of economic activity, firms who do not participate suffer more investment losses.

Energy intensity. Figure 6 shows the response of firms according to their energy intensity. We estimate Equation 2 where D_t^g is the respective percentile of the energy intensity distribution. The baseline is the group with the smallest energy intensity ($\leq p10$). Interestingly, we find that firms that are less energy-intensive react much stronger in reducing their investment compared to more energy-intensive firms. Firms in the second group ($p10 <$ energy intensity $\leq p25$) reduce their investment by more within the first two years. Afterwards the difference in response is not significantly different from zero any longer. Investment for firms with higher energy intensity is higher compared to the baseline group and the difference increases with energy-intensity. Firms with the highest energy intensity have 1.5 percent higher investment compared to the baseline four years after the shock. Since the average response is negative, this suggests that they reduce investment by less than the baseline group. This is in line with previous results. Firms with higher energy-intensity are subject to the emission costs, however, they are not those suffering most from the carbon policy shock.

Emission intensity. Figure 7 draws a similar picture. Again, we estimate Equation 2 where D_t^g now is the respective percentile of the emission intensity distribution of production. The baseline is the group with the smallest emission intensity ($\leq p10$). Firms in the second group ($p10 <$ emission intensity $\leq p25$) reduce their investment by more within the first two years. Later their investment increases relative to the baseline group. For the other groups, we see that investment increases with emission intensity. For those firms with high emission intensity in production, the response is 1.5 percent larger compared to the baseline.

Overall, more energy- and emission intensive firms increase their investment relative to otherwise similar firms. The same applies to firms who participate in the ETS compared to those who do not. The result is surprising if we focus on the cost-side of the carbon policy shock. Firms who participate in the ETS and/or are energy- and emission-intense have to meet emission costs. However, those firms reduce their investment less than otherwise similar firms. Two possible explanations arise. First, these results highlights the role of demand side effects of the carbon policy shocks. As emission costs are passed on to firms and consumers, demand for non-energy related goods and services decreases as well. This indicates that carbon policy shocks are mainly transmitted to the economy by demand-side channels. This is in line with Känzig (2023) who shows that households reduce their overall consumption. The demand-side effects explain why investment reduces for all firms. Second, firms participating in the ETS might – while experiencing decreases in demand for products – increase their energy efficiency investment to reduce emissions costs in the future. We discuss these findings further in Section 6 below.

6 The impact of carbon pricing on investment: Channels

The role of demand sensitivity. Firms regulated by the ETS pass on emission costs to energy prices (Fabra & Reguant, 2014). As a consequence, all firms are exposed to higher energy prices following a tightening in carbon policy. Further, firms may experience a drop in consumer demand as energy price shocks are accompanied by disruptions in consumers' spending. Importantly, the disruption occurs primarily in spending on goods and services other than energy (Hamilton, 2008). We, therefore, expect the response to vary with the demand sensitivity of sectors. This naturally raises the question if indeed demand sensitivity determines firm-level responses to carbon pricing and, if so, via which channels it translates into lower investment?

Following the definition in Känzig (2023), we measure demand sensitivity at the sectoral level as the elasticity of sectoral labor income to aggregate labor income. Sectors are classified in sectors with high demand sensitivity (above 0.5 of the elasticity) and low demand sensitivity (below 0.5 of the elasticity). Sectors that are classified as highly demand sensitive are construction, wholesale and retail trade, and accommodation and food service activities.

Figure 8 displays the dynamic response of our investment measure to a tightening in carbon policy in firms in high demand sensitive sectors relative to firms in low demand sensitive sectors. The response of firms in high demand sensitive sectors is significantly larger in all time periods. The peak response amounts to one percent. The finding supports our hypothesis that more energy-intensive and emission-intensive firms react less to the tightening in carbon policy. As discussed above, among the low demand sensitive sectors are activities such as mining and quarrying, manufacturing, electricity, gas, or transport. Those are activities that are more energy- and emission intensive. Firms that have low demand sensitivity are approximately 2.5 times more energy-intensive and 5.4 times more emission-intensive than firms that are have high demand sensitivity in our sample. This is further in line with our sector-level effects in Section 5.2 where we find that firms in the building sector respond more strongly to carbon policy shocks. We conclude that there is evidence of a demand sensitivity channel of carbon pricing on investment. To further explore the role of demand sensitivity for our findings, we investigate how firms' decisions differ with respect to their demand sensitivity after the carbon policy shock. Figure 9 shows how firms adjust their sales, number of employees, cashflow, and long-term debt after the shock of high demand sensitive firms vis-a-vis low demand sensitive firms: firms' sales in demand sensitive sectors reduce by 0.2 percent more on impact. The peak difference amounts to 3 percent three years after the shock. The demand sensitive firms further reduce their number of employees by 0.2 on impact. The difference grows to 1 percent three years after the shock. Expectedly, the strongest difference is visible in terms of cashflow. While on impact, the effect is about 0.4 percent stronger, cashflows are 1.5 percent lower for demand-sensitive firms three years after the shock. A deeper discussion on firm-level dynamics of these differential responses is provided below in Section 6.1.

The role of green investment. We explore the hypothesis that emission-intensive as well as energy-intensive firms increase their investment relative to other types of firms because they are motivated by higher carbon prices to shift their production into less environmentally harmful territory ones as document by our study. Naturally, one would assume that this effect might be to some extent explaining our puzzling finding on the sharper decline of other firms' investment compared to these high-pollutant. We test this hypothesis by estimating the impact of carbon pricing shocks as depicted in Equation 2 and in our usual setup but with emission-intensity growth as a dependent variable. If indeed emission-intensive firms were responding to the carbon price shocks by investing into technology that reduces their emissions in the long-term we would expect to find a relative decline in emission growth rates after the initial short-term effect of the shock. However, as our results indicate in Figures 10 and 11, after four years, the initial emission-intensity growth reducing effect of higher carbon prices is equal to zero in the relevant sectors. We are hence inclined to suggest that the growth-reducing impact of carbon pricing does not channel investment of environmentally conspicuous production into greener technology compared to other firms.

6.1 Interpretation

There is increasing evidence that that carbon pricing via emission trading systems reduces economic growth. We strengthen the empirical base of this prediction by showing that, indeed, across the whole range of firms in our large panel – covering various countries and industries over the period 1999–2017 –, carbon price increases reduce investment both at the aggregate and sector-level. However, we dig deeper to study the differential response as well as the mechanisms of firm investment. That is, as the heart of our analysis we are first to provide evidence on the perhaps surprising impact of carbon pricing shocks on long-term growth *between* firms: we document not only that ETS-firms are affected less but that in general, emission- and energy-intensive firms reduce their investment – and, by extension, growth – by less compared to environmentally inconspicuous production.

This first set of results may be interpreted in light of the growth-hampering effects of carbon pricing type of argument, that higher prices for carbon lead to higher energy prices for *all* firms and that these higher energy prices, in turn, are causal to lower economic growth, on average and at the aggregate. Complementing recent studies by Känzig (2023) and Känzig & Konradt (2023), we argue that the reason is that carbon price shocks are hence economically similar to other energy price shocks: they increase uncertainty and raise operating costs of certain durable goods, which reduces demand for durables and slows down growth, on average (Hamilton, 2008, 2009). The economic literature fairly univocally agrees on both the direction and significance of this effect (Känzig, 2023).

We next consider the mechanisms that underpin our firm-level results as this set of results raise natural questions about the deeper mechanisms at play. Ex-ante, there is no existing economic theory that would suggest that carbon pricing should directly impair the relative performance of *less* carbon- and emission intensive firms compared to high GHG-emitting ones. Rather, our prior is informed by theoretical and empirical work which has implications for the investment decisions of firms whose operations are affected by the introduction of a price of carbon: for instance, the input-cost effect would predict that higher energy cost lowers the usage of energy which in turn lowers productivity of capital and labor. Under these circumstances, energy intensive sectors should be affected more severely (Bohi, 1991; Lee & Ni, 2002) as well as incentivised to channel their investment relatively more in green technology (De Haas & Popov, 2023).

However, there are a number of accounts that could explain our results even in the absence of such a direct effect. One possibility is that carbon-intensive firms are better placed than low emission firms to avoid the contractionary effects of higher carbon (and thus, energy) prices, emphasizing the demand side effects of such shocks. A number of contributions have argued for this link. For instance, Chan et al. (2022) argue that modelling energy price shocks as aggregate supply shocks or as technology shocks in domestic production – as is typically the case – , cannot explain large fluctuations in real output. More recent approaches place the main transmission channel on the demand side of the economy. That is, energy price shocks affect the economy primarily through their effect on consumer expenditures and firm investment expenditures. Similarly, Hamilton (2008) provides empirical evidence that energy price shocks mainly affect the economy through a disruption in consumers' and firms' spending on non-energy goods and services, which is also supported by evidence that documents that firms perceive energy price shocks as shocks to product demand rather than shocks to the cost of production (Lee & Ni, 2002).

We are hence motivated by this prediction to test for the importance of demand-sensitivity. In Section 6.1 we show that, indeed, demand sensitive industries are significantly more affected by carbon pricing compared to less sensitive industries. In Figure 9, we complement this result with evidence on firms' concomitant financial, sales and employment decisions in response to changes in carbon prices. Here, we estimate a variant of Equation 2 where the dependent variable is the year-on-year log difference in firm-level debt, sales, cashflow or employment.

The evidence in Figure 9 points to a nuanced firm response to carbon price shocks depending on sectoral demand sensitivity. Following carbon price tightening, on impact demand sensitive firms see a relative decline in sales, employment, and cashflow compared with insensitive firms. In the case of long-term debt, the point estimate on the interaction of carbon price shocks is only significant after two years, suggesting that firms postpone the decision to reduce their long-term debt compared to less vulnerable firms. The data thus provide some support to the notion that the non-linear response in investment to changes in carbon prices on impact is driven by a mechanism whereby firms in demand sensitive industries adjust employment, reduce their market share in addition to tangible assets. This also leads to a relative decline in cashflow. Why does long-term debt react two years later than other measures? One potential explanation is that if the shock caused by carbon price increases is expected to be of a temporary nature, such a behavior might make sense if it is cheaper to let go of workers than to restructure debt or reduce interest payments at first. Financially constrained firms may be forced to cut back their debt after two years at the latest.

In conclusion, given that carbon-intensive projects tend to be relatively less sensitive to changes in demand, we strengthen arguments that suggest that carbon pricing shocks should be conceptualized as demand rather than supply-side shocks. While we do not argue that there is no direct effect on the supply side, we support the notion that demand-sided effects outweigh supply-side effects. This argument is also supported by our finding documented in Figures that rules out that 6 and 7 investments are channelled relatively more into green technology by affected firms which a more potent supply-side oriented shock might be able to accomplish.

7 Robustness

In order to make sure our results are not driven by certain empirical choices, we now report a range of robustness checks where we employ i) alternative CP shock proxies, ii) different CP shock frequencies, iii) an alternative measure of investment as well as iv) previous-horizon residuals to test for potential autocorrelation between residuals.

7.1 Robustness I: Instrument

Recall that the carbon policy shock series in our main specification is calculated using carbon policy surprises as an instrument for carbon policy shocks within an external VAR setting. Carbon policy surprises are calculated as the percentage change in EU emission allowances (EUA) future prices on the day of the regulatory event as $CPSurprise_{t,m,d} = (F_{t,m,d} - F_{t,m,d-1})/F_{t,m,d-1}$. $F_{t,m,d}$ is the EUA future price in year t, month m and on day d and $CPSurprise_{t,m,d}$ is the carbon policy surprise in year t, month m and on day d. As robustness check, we employ an alternative shock series from Känzig (2023). More specifically, in the alternative specification the surprises are measured as the EUR change in carbon prices relative to the wholesale electricity price, $P_{t,m,d-1}$, on the day before the event: $CPSurprise_{t,m,d} = (F_{t,m,d} - F_{t,m,d-1})/P_{t,m,d-1}$. Our results are robust to the alternative instrument (see Appendix C.1).

7.2 Robustness II: Alternative shock aggregation

In our main specification, we aggregate the monthly shocks series to obtain a yearly measure of carbon policy: $CP_t = \sum_{m=1}^{12} CP_{t,m}$. To test robustness of our results, we employ another time horizon to compute the relevant carbon policy shocks. We repeat the aggregation over the last six months of the respective year: $CP_t = \sum_{m=6}^{12} CP_{t,m}$. Results are in Appendix C.2. We find that the choice of aggregation period matters economically, but not qualitatively. While the responses regarding emission-intensity, energy-intensity and CPRS are robust to the shock aggregation, the differences in response between ETS firms and non-ETS firms as well as differences between high demand sensitive firms and low demand sensitive firms are smaller. In any case, our results hold that more energy-intensive and emission-intensive firms relatively increase their investment in response to a tightening in carbon policy. They also continue to support the main channel of our analysis – that the response to CP tightening is associated with a firms' demand sensitivity.

7.3 Robustness III: Investment proxy

Our main estimations are based on tangible asset (tangible assets are property, plant, and equipment), which is the standard measure for investment and available for all industries. As a robustness exercise, we follow Feldman et al. (2021) as well as Desai et al. (2009) who alongside many others suggest that the 'gross fixed assets' variable may be employed as an alternative measure for investment at the micro level. In Appendix C.3 we report the results. Based on this dependent variable we still cover all industries in the sample and loose only very few observations. The results are in line with the main findings reported in Section 5. The results differ regarding the effects of ETS firms relative to non-ETS firms. While the direction of the effect is in line with previous findings, the difference is not significant at the five percent level.

7.4 Robustness IV: Residual autocorrelation

Local projections are often subject to residual autocorrelation (Lusompa, 2023). To test robustness of our results, we employ an additional specification. More specifically, for $h > 1$, we add the residuals of the previous regression at $t + h - 1$, as additional regressors. Adjusting the model this way allows us to account for potential autocorrelation in the residuals. We show the results in Section C.4. The results are in line with the main findings reported in Section 5.

8 Conclusion

Theorists and empirical economists are increasingly studying the interconnected dynamics between economic growth and climate change mitigation strategies. However, numerous questions remain unresolved, and economic research has not kept pace with the rapid development of climate policies. We are first to provide evidence on the effect of carbon pricing on firm-level investment in Europe. Our findings show that firm investment is reduced after carbon pricing shocks, on average. Perhaps unexpectedly, we further document that energy-intensive and emission-intensive firms react less to a tightening of carbon policy: Our results suggest that an increase in carbon prices (normalized to normalized to a 1% increase in energy prices) results in 1,5% stronger decrease in tangible asset stock of emission-*un*intensive compared to highest emission-intensive production four years after the shock.

Moreover, the largest average effects is found in the construction and real estate sectors. Our findings indicate that the primary transmission channel to carbon policy shocks to the economy lies in their demand-side effects. When carbon policies are tightened, energy prices rise within our sample. Consequently, all firms experience heightened input costs in the short term, compounded by reduced demand as households curtail their consumption of energy and non-energy goods. This scenario may prompt some firms to defer investment decisions due to increased uncertainty surrounding economic trends.

Our results suggest that, to the extent that such policies indeed move firms towards greener investments, they will also have important growth-hampering side-effects by slowing down demand while, at the same time, not managing to green the production processes of highest polluting firms compared to others.

References

Barbiero, F., Popov, A., & Wolski, M. (2020). Debt overhang, global growth opportunities, and investment. *Journal of Banking & Finance*, 120, 105950.

Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7(4), 283–288.

Berthold, B., Cesa-Bianchi, A., Di Pace, F., & Haberis, A. (2023). The heterogeneous effects of carbon pricing: Macro and micro evidence.

Bohi, D. R. (1991). On the macroeconomic effects of energy price shocks. *Resources and Energy*, 13(2), 145–162.

Bolton, P. & Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, 142(2), 517–549.

Bolton, P. & Kacperczyk, M. (2022). Global pricing of carbon-transition risk. *Journal of Finance forthcoming*.

Chan, J., Diz, S., & Kanngiesser, D. (2022). Energy prices and household heterogeneity: Monetary policy in a gas-tank. *Available at SSRN 4255158*.

De Haas, R. & Popov, A. (2023). Finance and green growth. *The Economic Journal*, 133(650), 637–668.

Desai, M. A., Foley, C. F., & Hines Jr, J. R. (2009). Domestic effects of the foreign activities of us multinationals. *American Economic Journal: Economic Policy*, 1(1), 181–203.

Durante, E., Ferrando, A., & Vermeulen, P. (2022). Monetary policy, investment and firm heterogeneity. *European Economic Review*, 148, 104251.

Fabra, N. & Reguant, M. (2014). Pass-through of emissions costs in electricity markets. *American Economic Review*, 104(9), 2872–2899.

Feldman, N., Kawano, L., Patel, E., Rao, N., Stevens, M., & Edgerton, J. (2021). Investment differences between public and private firms: Evidence from us tax returns. *Journal of Public Economics*, 196, 104370.

Gertler, M. & Karadi, P. (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, 7(1), 44–76.

Goolsbee, A. (1998). Investment tax incentives, prices, and the supply of capital goods. *The Quarterly Journal of Economics*, 113(1), 121–148.

Gopinath, G., Kalemli-Özcan, S., Karabarbounis, L., & Villegas-Sanchez, C. (2017). Capital allocation and productivity in south europe. *The Quarterly Journal of Economics*, 132(4), 1915–1967.

Hamilton, J. D. (2008). Oil and the macroeconomy. *The new Palgrave dictionary of economics*, 2, 1–7.

Hamilton, J. D. (2009). *Causes and Consequences of the Oil Shock of 2007-08*. Technical report, National Bureau of Economic Research.

Hengge, M., Panizza, U., & Varghese, R. (2023). Carbon policy surprises and stock returns: Signals from financial markets. *Available at SSRN 4343984*.

Holm, M., Paul, P., & Tischbirek, A. (2021). The transmission of monetary policy under the microscope. *Journal of Political Economy*.

House, C. L. & Shapiro, M. D. (2008). Temporary investment tax incentives: Theory with evidence from bonus depreciation. *American Economic Review*, 98(3), 737–768.

Jordà, Ò. (2023). Local projections for applied economics. *Annual Review of Economics*, 15, 607–631.

Jordà, Ò., Schularick, M., & Taylor, A. M. (2015). Betting the house. *Journal of international economics*, 96, S2–S18.

Joussier, R. L., Martin, J., & Mejean, I. (2023). Energy cost pass-through and the rise of inflation: Evidence from french manufacturing firms.

Kalemli-Özcan, c., Sørensen, B., Villegas-Sanchez, C., Volosovych, V., & Yeşiltaş, S. (2023). How to Construct Nationally Representative Firm Level Data from the Orbis Global Database: New Facts and Aggregate Implications. *American Economic Journal: Macroeconomics (forthcoming)*.

Känzig, D. R. (2023). The unequal economic consequences of carbon pricing. *NBER Working Paper No. w31221*.

Känzig, D. R. & Konradt, M. (2023). Climate policy and the economy: Evidence from europe's carbon pricing initiatives.

Kilian, L. (2008). The economic effects of energy price shocks. *Journal of economic literature*, 46(4), 871–909.

Konradt, M. & Weder di Mauro, B. (2021). Carbon Taxation and Greenflation: Evidence from Europe and Canada. *CEPR Discussion Paper No. DP16396*.

Laeven, L. & Popov, A. A. (2023). Carbon taxes and the geography of fossil lending. *Journal of International Economics (forthcoming)*.

Lee, K. & Ni, S. (2002). On the dynamic effects of oil price shocks: a study using industry level data. *Journal of Monetary economics*, 49(4), 823–852.

Lusompa, A. (2023). Local projections, autocorrelation, and efficiency. *Quantitative Economics*, 14(4), 1199–1220.

Metcalf, G. E. & Stock, J. H. (2020). Measuring the macroeconomic impact of carbon taxes. *AEA Papers and Proceedings*, 110, 101–106.

Monasterolo, I. & De Angelis, L. (2020). Blind to carbon risk? An analysis of stock market reaction to the paris agreement. *Ecological Economics*, 170, 106571.

Nakamura, E. & Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: the information effect. *The Quarterly Journal of Economics*, 133(3), 1283–1330.

Ottonello, P. & Winberry, T. (2020). Financial heterogeneity and the investment channel of monetary policy. *Econometrica*, 88(6), 2473–2502.

Stock, J. H. & Watson, M. W. (2018). Identification and estimation of dynamic causal effects in macroeconomics using external instruments. *The Economic Journal*, 128(610), 917–948.

Timmer, M. P., Dietzenbacher, E., Los, B., Stehrer, R., & De Vries, G. J. (2015). An illustrated user guide to the world input–output database: the case of global automotive production. *Review of International Economics*, 23(3), 575–605.

Zwick, E. & Mahon, J. (2017). Tax policy and heterogeneous investment behavior. *American Economic Review*, 107(1), 217–248.

Appendix A Data

A.1 Sample selection

For data cleaning purposes, we follow the procedures as outlined in Kalemli-Özcan et al. (2023) and Durante et al. (2022):

- We keep only corporate industry firms. By doing so, we drop financial institutions like banks and insurance companies, foundations, funds, private equity and venture capital firms, as well as public authorities, states and governments.
- We keep only unconsolidated company data, i.e. when their consolidation code is U1 or U2.
- We drop observations that have missing information on identifiers and closing dates.
- We identify and drop duplicate entries. If firms report multiple times per year, only their reported data as at 31st of December is kept.
- We drop firms that report negative total assets, negative employment, employment larger than than 2 million employees, negative sales, or negative tangible fixed assets.
- Firm-year observations are omitted if total assets equals zero, firm age is negative, and fixed assets is missing, negative, or zero. Moreover, observations are discarded when tangible fixed assets is missing or negative, and intangible fixed assets is negative. Observations with simultaneously missing data on total assets, operating revenue, sales and employment are also dropped.

We proceed further with the data cleaning process according to Gopinath et al. (2017). The following steps correct for basic reporting mistakes:

- We drop firm-year observations that have missing data on their industry of activity.
- We drop observations if they contain missing values, zero, or negative values on material costs or total assets.
- Next, we construct the following ratios and estimate their distribution by country. We exclude from our analysis extreme values by trimming observations below the 0.1st percentile or above the 99.9th percentile.
  - Sum of tangible fixed assets, intangible fixed assets, and other fixed assets as ratio of total fixed assets.
  - Sum of fixed assets, and current assets as a ratio of total assets.

- Sum of long term debt and other non-current liabilities as a ratio of total non-current liabilities.
- Sum of loans, creditors, and other current liabilities as a ratio of total current liabilities.
- Sum of non current liabilities, current liabilities, and shareholder funds as a ratio of the variable that reports the sum of shareholder funds and total liabilities.

Additionally, we winsorize the following variables at the 1st and 99th percentile: added value, operating revenue, material costs, total assets, shareholders' funds, fixed assets, tangible fixed assets, other fixed assets, total liabilities (defined as total assets minus shareholders' funds), and labor share (defined as costs of employees divided by added value, multiplied by 10). We replace negative values of cash and cash equivalents with missing values. We generate cash-to-total assets ratios (CCE/total assets) and replace them with missing values if they are larger than 1. We generate working capital-to-total assets (WC/total assets) ratios and replace them with missing values if they are smaller than -1 and larger than 1. We generate leverage ratios by dividing total liabilities by total assets. We generate profitability ratios by dividing EBITDA by operating revenue. We only keep firms in our dataset that report for at least 5 consecutive years. We create a variable for the labor share by dividing costs of employees by added value and then multiplying by 100. Before that, we replace zeros and missing values in added value and costs of employees with 0.1. We drop observations if labor share is negative.

A.2 Data description

Variable	Description	Source	Coverage
GDP growth	Annual growth rate of GDP at market price.	World Bank, OECD	1999-2017
HICP	HICP all items	Eurostat	1999-2017
HICP Energy	HICP energy	Eurostat	1999-2017
Unemployment rate	% of total labor force (ILO estimate)	ILO	1999-2017

Table 1: Data description country-level controls.

	N	Mean	SD	Min	p5	Median	p95	Max
GDP growth	228	1.91	3.13	-8.4	-3.35	1.95	5.9	24.37
HICP	228	2.06	1.74	-1.7	-0.2	2	4.7	12
HICP Energy	228	3.73	6.6	-14	-7.9	4	13.7	20.1
Unemployment rate	228	9.19	4.24	2.12	4.12	8.45	17.25	26.09

Table 2: Summary statistics country-level data

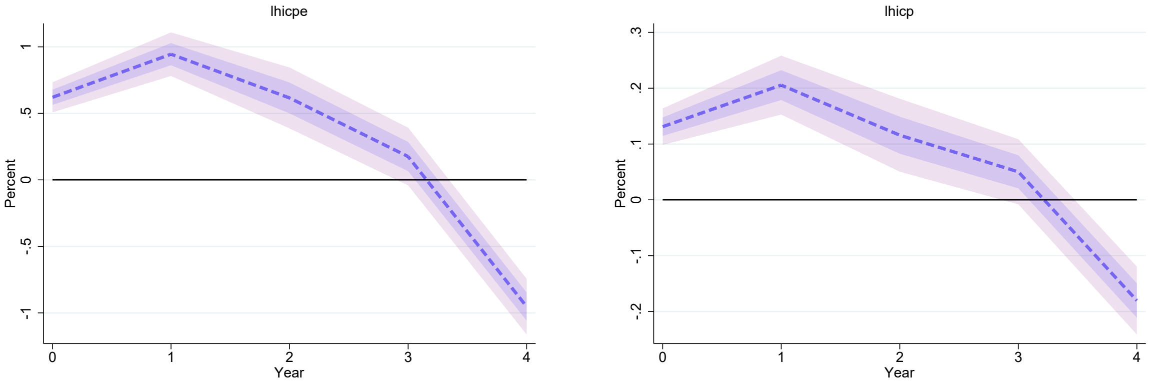
	N	Mean	Median	Std	Min	p5	p95	Max
Tangible fixed assets	11,013,831	916,669	99,790	2,815,110	0	2,820	4,335,238	19,356,291
Total assets	11,013,831	4,366,178	783,000	12,341,421	27,242	84,415	19,613,328	85,029,689
Number of employees	8,283,814	41	7	674	0	1	114	791,678
Cash to total assets	10,721,229	0.13	0.07	0.16	0.00	0.00	0.47	1.00
Working capital to total assets	10,969,549	0.25	0.22	0.26	-1.00	-0.12	0.73	1.00
Firm age	11,009,915	16	13	13	0	2	41	150
Labor share	9,611,523	71.93	73.43	28.69	3.94	26.07	105.77	231.60
Leverage ratio	11,013,831	0.69	0.72	0.22	0.00	0.27	0.97	1.00
Carbon policy shock	11,013,831	-0.05	-0.53	2.55	-4.76	-4.76	3.92	3.92
Oil supply news shock	11,013,831	0.37	0.13	1.91	-3.22	-3.22	4.73	4.73
Emission intensity	10,956,438	0.21	0.05	0.62	0.00	0.01	1.29	17.33
Energy use 2014	11,013,831	103,313	85,330	243,700	0	6,377	208,333	5,661,958
Energy use 2016	11,013,831	99,796	86,181	245,372	0	6,249	202,223	5,558,978
Log(Tangible fixed assets)	10,900,000	1,162	1,154	214	0	819	1,529	1,678
Log(Fixed assets)	11,013,831	1,216	1,209	202	668	894	1,570	1,738
Log(Number of employees)	8,144,048	218	208	141	0	0	475	1,358

Table 3: Summary statistics firm-level data

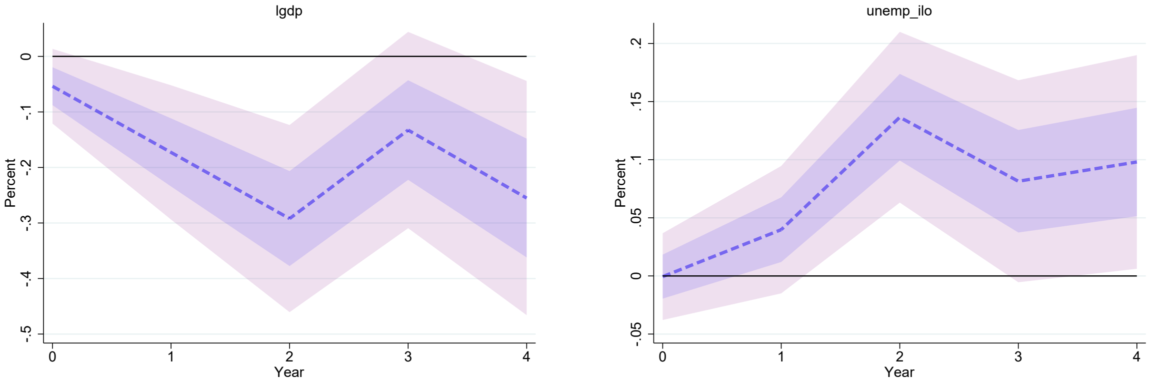
Appendix B Results

B.1 Figures: Macro responses to a carbon policy shock

Figure 3: Average macroeconomic responses



(a) HICPE (b) HICP

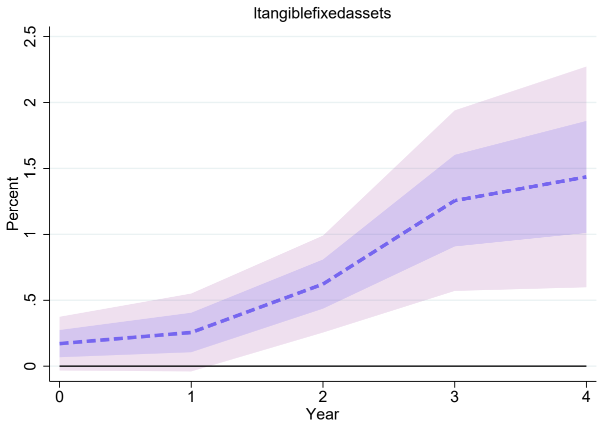


(c) GDP (d) Unemployment rate

Notes: The graph displays macroeconomic responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. It shows the cumulative log-change in HICPE, HICP, GDP and the unemployment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands.

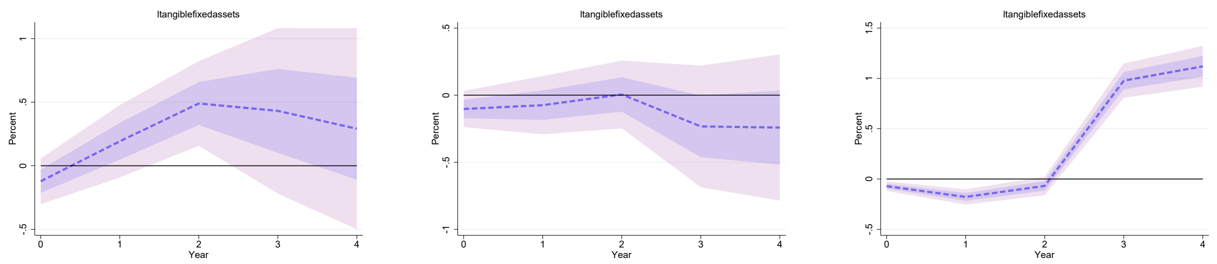
B.2 Figures: Investment response to a carbon policy shock

Figure 4: Investment response of ETS firms relative to non-ETS firms

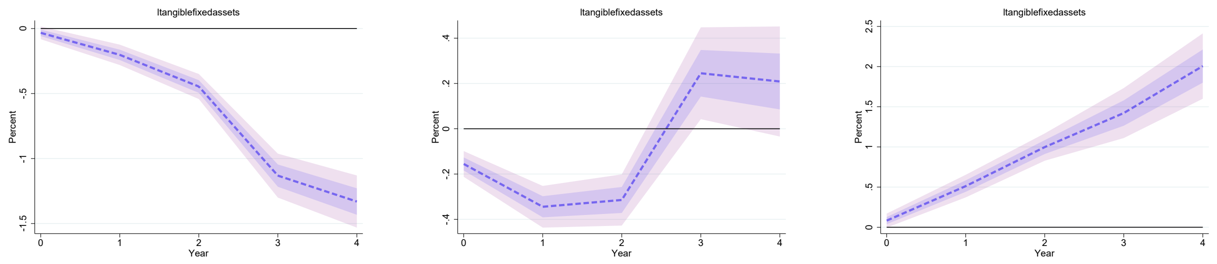


Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms participating in the ETS relative to firms that do not participate in the ETS. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 5: Investment response by climate-policy relevant sector



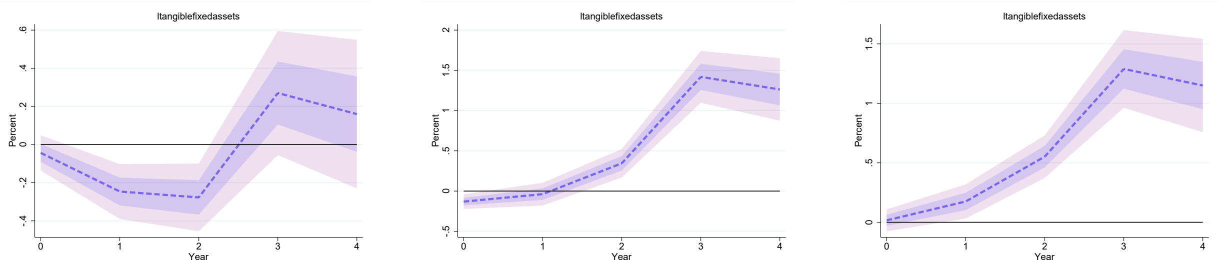
(a) Fossil Fuel (b) Utility (c) Energy-intensive



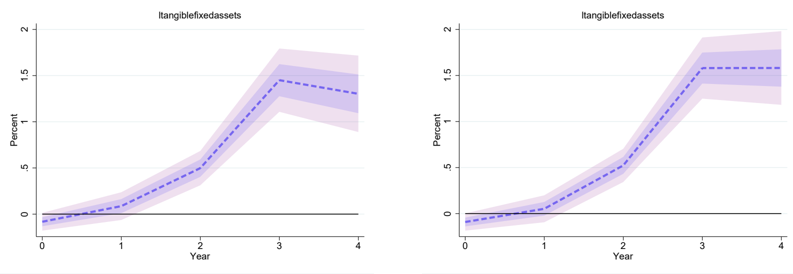
(d) Buildings (e) Transportation (f) Agriculture

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms in carbon-relevant sectors relative to firms in non-carbon-relevant sectors. It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 6: Investment response by energy intensity



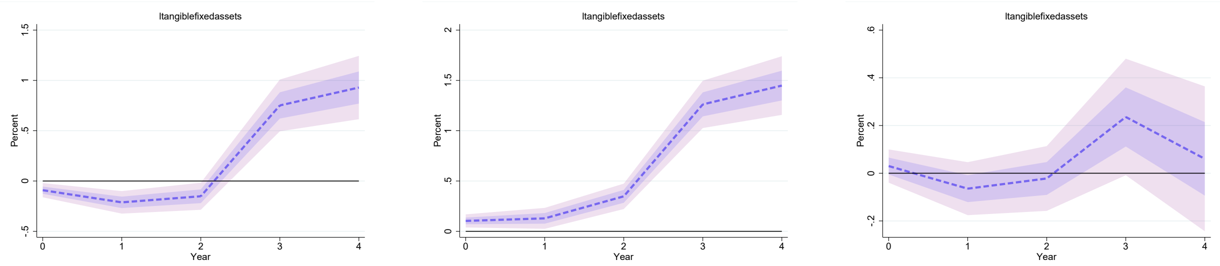
(a) $10 - 25\%$ (b) $25 - 50\%$ (c) $50 - 75\%$



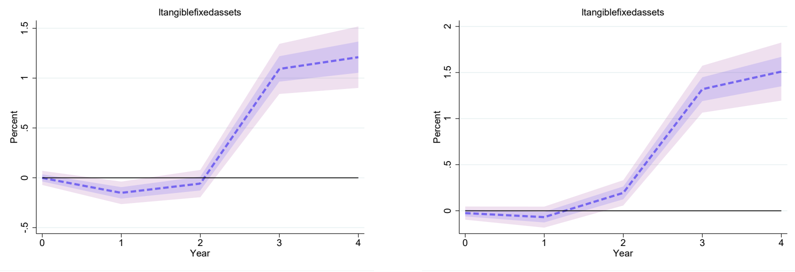
(d) $75 - 90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 7: Investment response by emission intensity



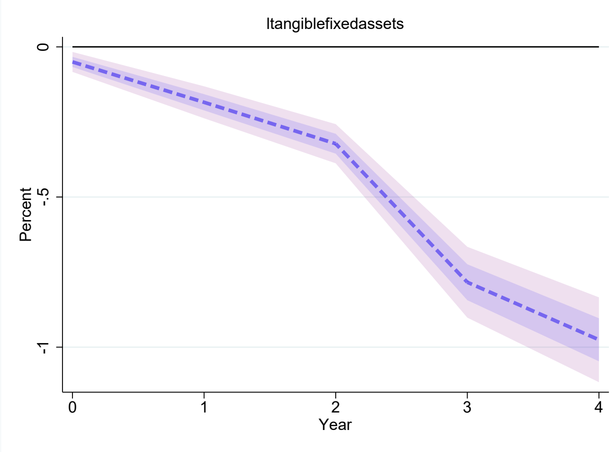
(a) $10 - 25\%$ (b) $25 - 50\%$ (c) $50 - 75\%$



(d) $75 - 90\%$ (e) Top 10%

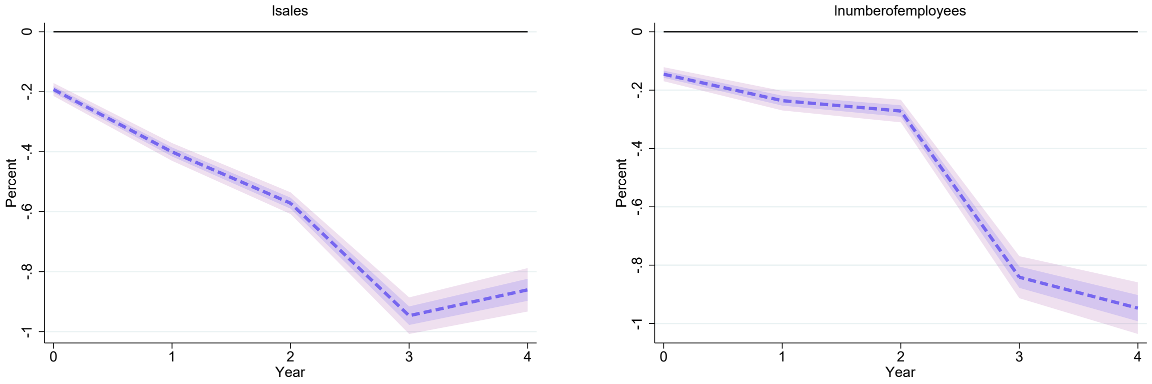
Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 8: Investment response of high demand sensitive firms relative to low demand sensitive firms



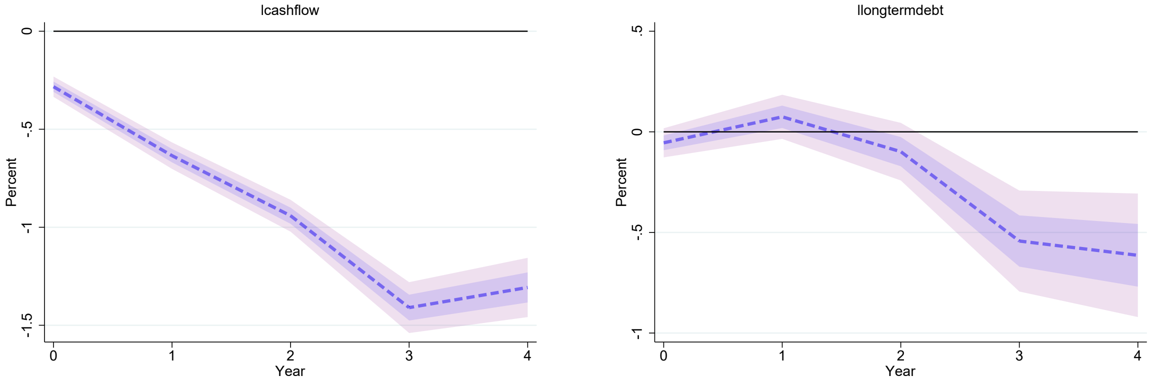
Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 9: Further responses of high demand sensitive firms relative to low demand sensitive firms



(a) Sales

(b) Number of employees



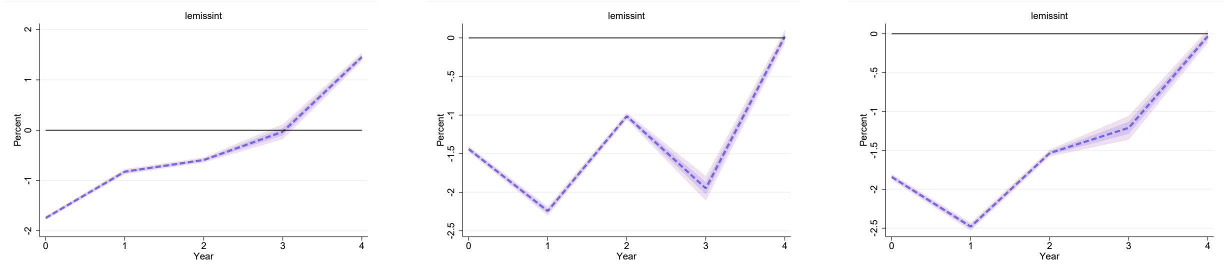
(c) Cashflow

(d) Long-term debt

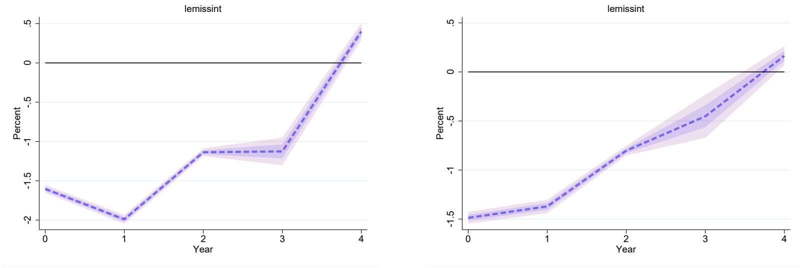
Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of sales, number of employees, cashflow, and long-term debt for high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

B.3 Figures: Emission intensity response to a carbon policy shock

Figure 10: Emission intensity response by energy intensity



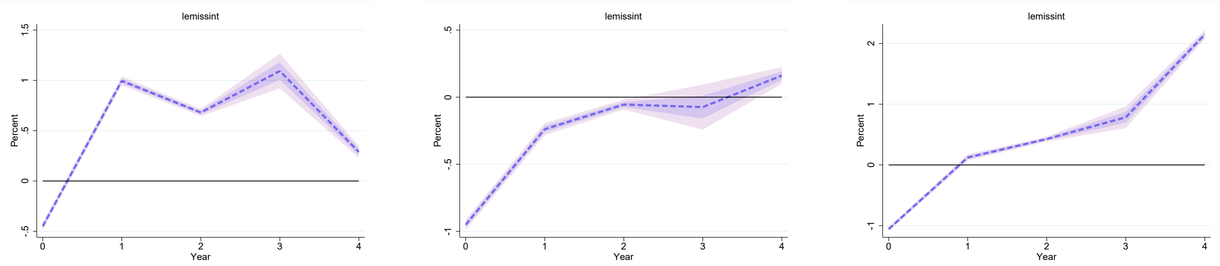
(a) 10 – 25% (b) 25 – 50% (c) 50 – 75%



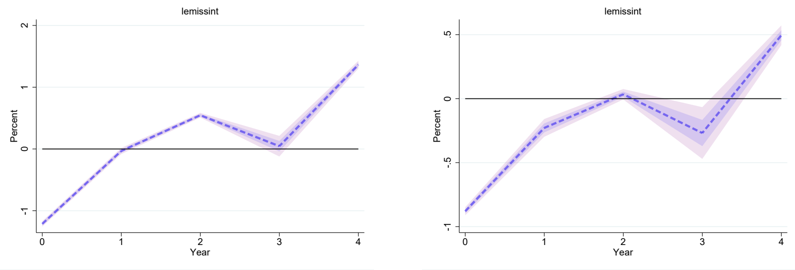
(d) 75 – 90% (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in Emission intensity between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 11: Emission intensity response by emission intensity



(a) $10 - 25\%$ (b) $25 - 50\%$ (c) $50 - 75\%$



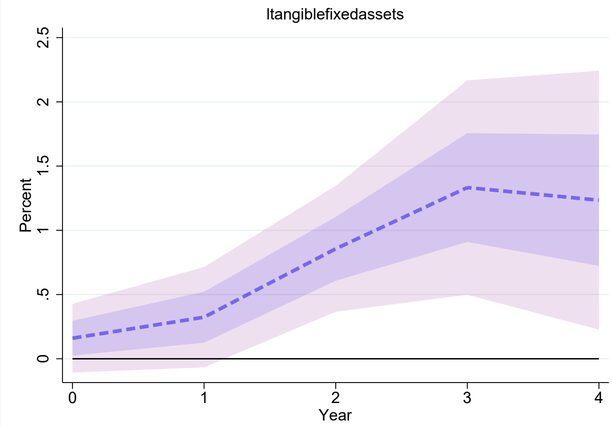
(d) $75 - 90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in Emission intensity between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Appendix C Robustness

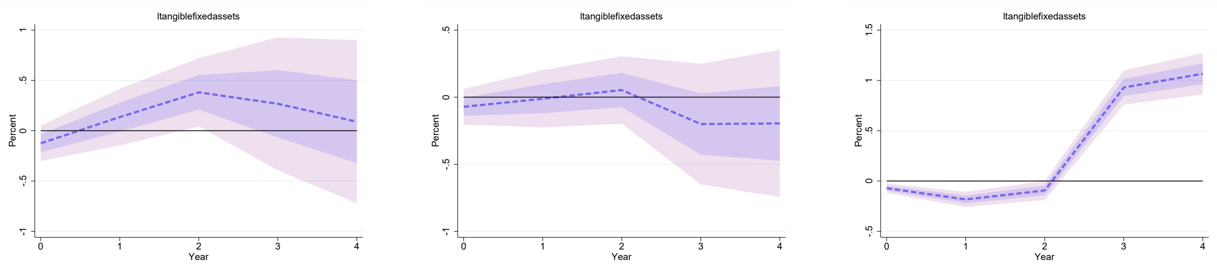
C.1 Robustness I: instrument

Figure 12: Investment response of ETS firms relative to non-ETS firms



Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms participating in the ETS relative to firms that do not participate in the ETS. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

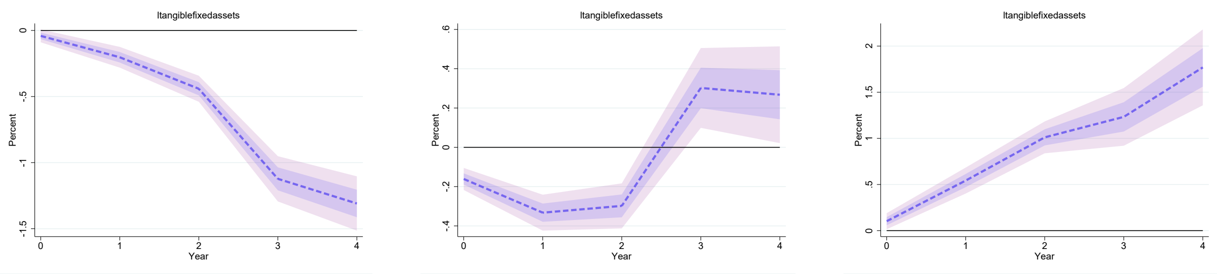
Figure 13: Investment response by climate-policy relevant sector



(a) Fossil Fuel

(b) Utility

(c) Energy-intensive



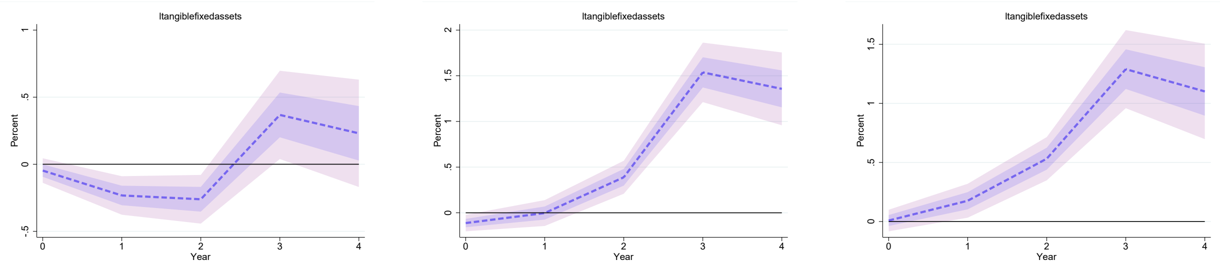
(d) Buildings

(e) Transportation

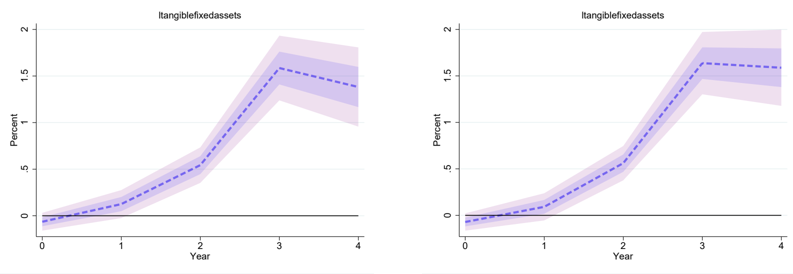
(f) Agriculture

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms in carbon-relevant sectors relative to firms in non-carbon-relevant sectors. It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 14: Investment response by energy intensity



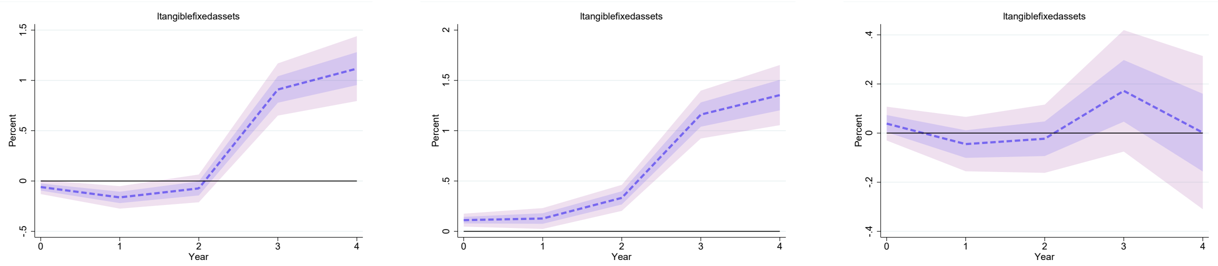
(a) $10-25\%$ (b) $25-50\%$ (c) $50-75\%$



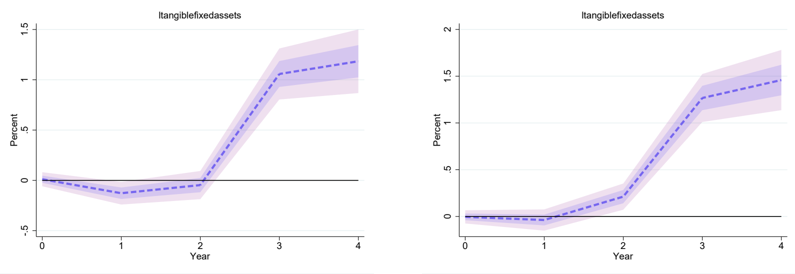
(d) $75-90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 15: Investment response by emission intensity



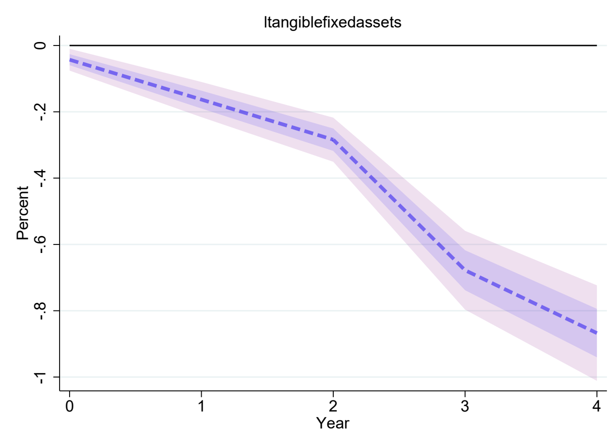
(a) 10 – 25% (b) 25 – 50% (c) 50 – 75%



(d) 75 – 90% (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

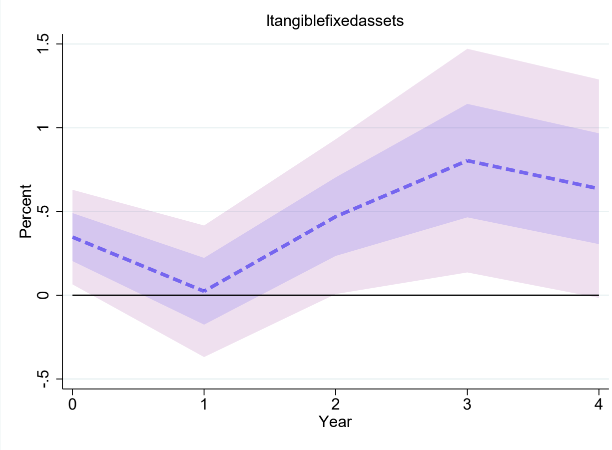
Figure 16: Investment response of high demand sensitive firms relative to low demand sensitive firms



Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

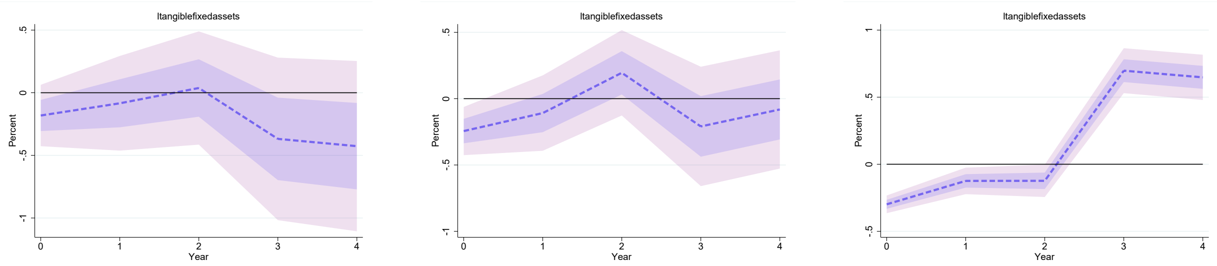
C.2 Robustness II: 6 month shock aggregation

Figure 17: Investment response of ETS firms relative to non-ETS firms

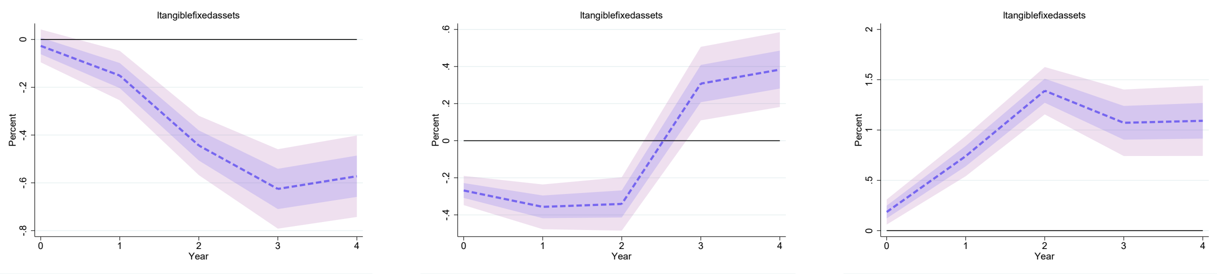


Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms participating in the ETS relative to firms that do not participate in the ETS. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 18: Investment response by climate-policy relevant sector



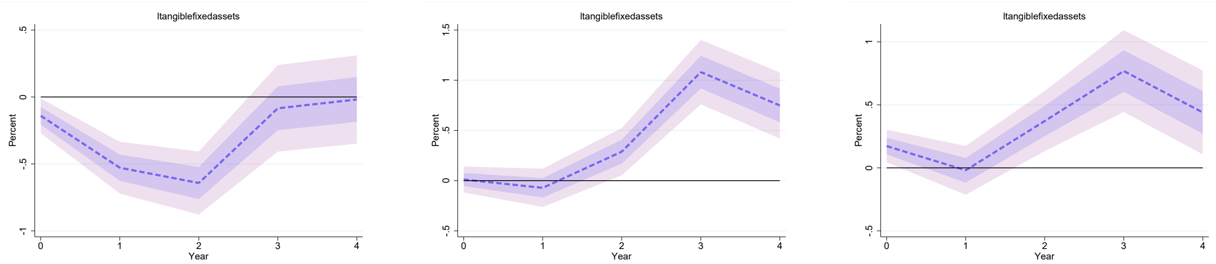
(a) Fossil Fuel (b) Utility (c) Energy-intensive



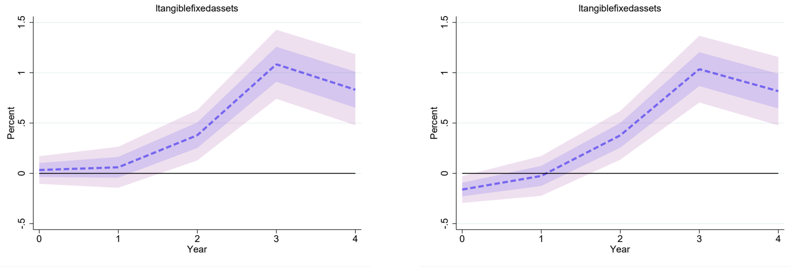
(d) Buildings (e) Transportation (f) Agriculture

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms in carbon-relevant sectors relative to firms in non-carbon-relevant sectors. It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 19: Investment response by energy intensity



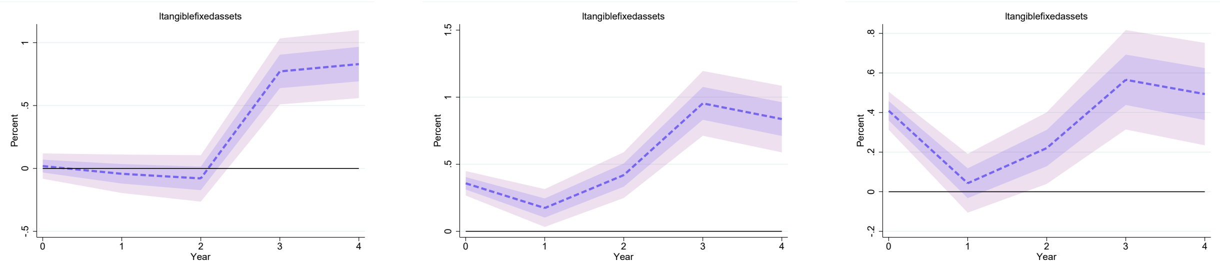
(a) $10-25\%$ (b) $25-50\%$ (c) $50-75\%$



(d) $75-90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

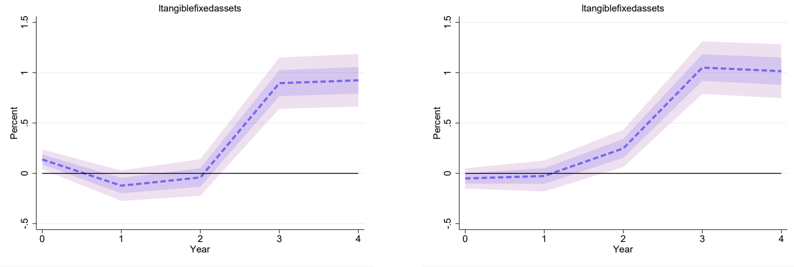
Figure 20: Investment response by emission intensity



(a) 10 − 25%

(b) 25 − 50%

(c) 50 − 75%

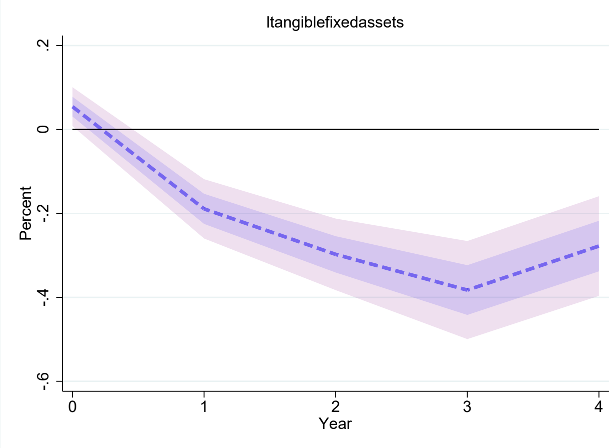


(d) 75 − 90%

(e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

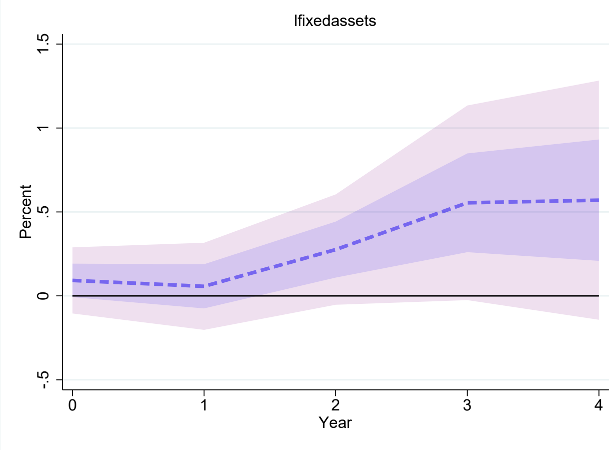
Figure 21: Investment response of high demand sensitive firms relative to low demand sensitive firms



Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

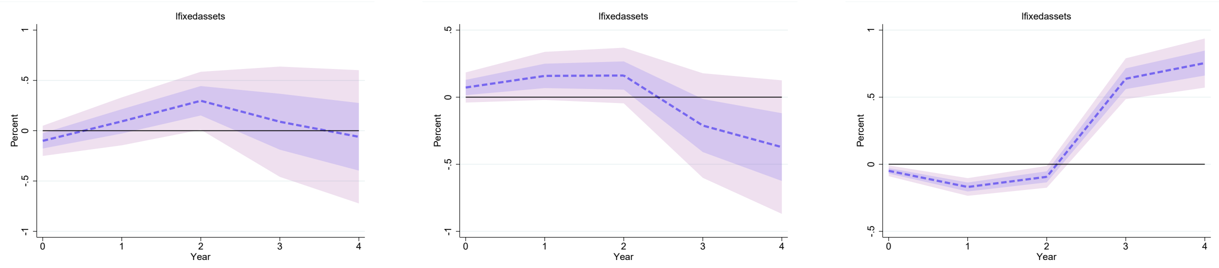
C.3 Robustness III: fixed assets

Figure 22: Investment response of ETS firms relative to non-ETS firms

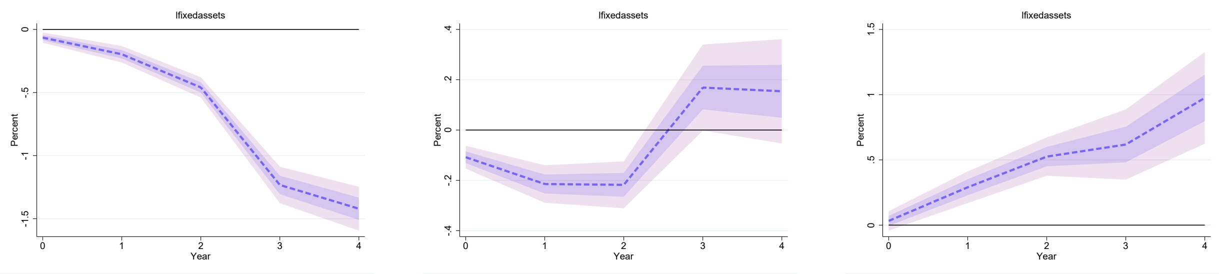


Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms participating in the ETS relative to firms that do not participate in the ETS. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 23: Investment response by climate-policy relevant sector



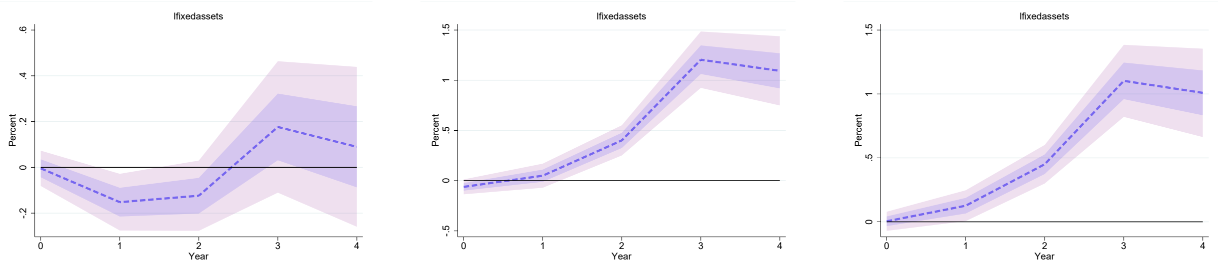
(a) Fossil Fuel (b) Utility (c) Energy-intensive



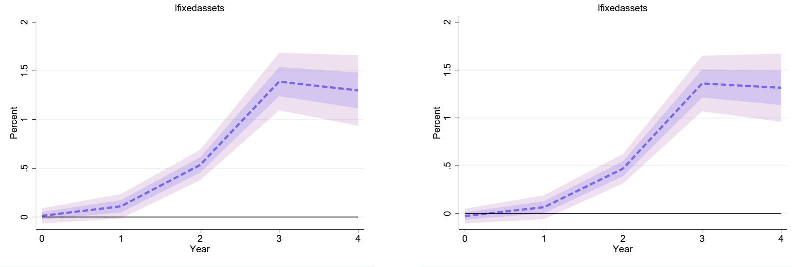
(d) Buildings (e) Transportation (f) Agriculture

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms in carbon-relevant sectors relative to firms in non-carbon-relevant sectors. It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 24: Investment response by energy intensity



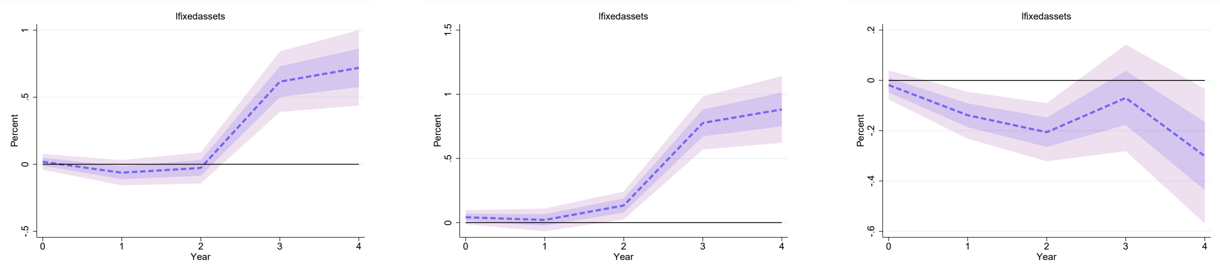
(a) $10-25\%$ (b) $25-50\%$ (c) $50-75\%$



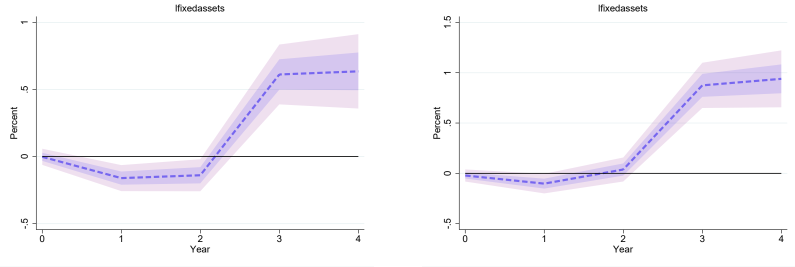
(d) $75-90\%$ (e) Top10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

Figure 25: Investment response by emission intensity



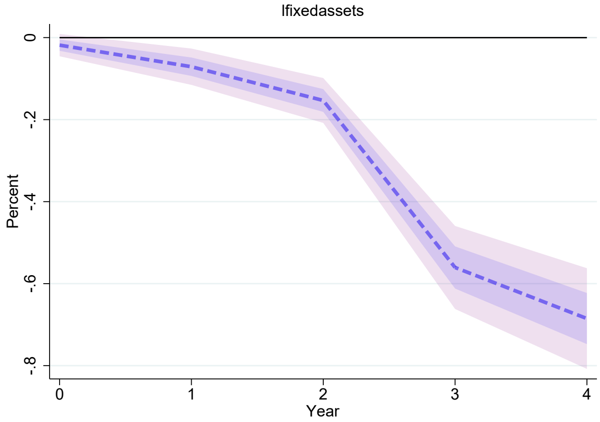
(a) $10-25\%$ (b) $25-50\%$ (c) $50-75\%$



(d) $75-90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

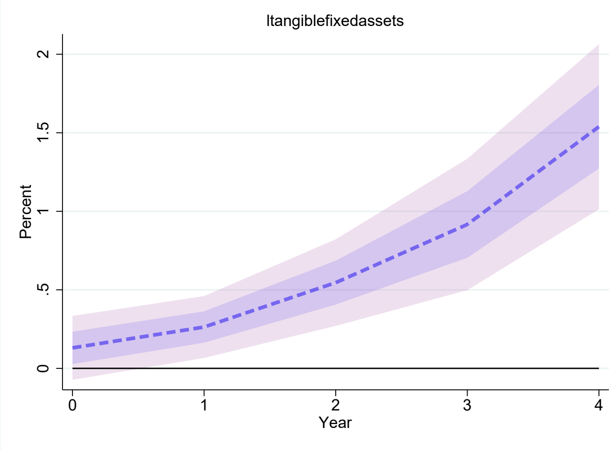
Figure 26: Investment response of high demand sensitive firms relative to low demand sensitive firms



Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm.

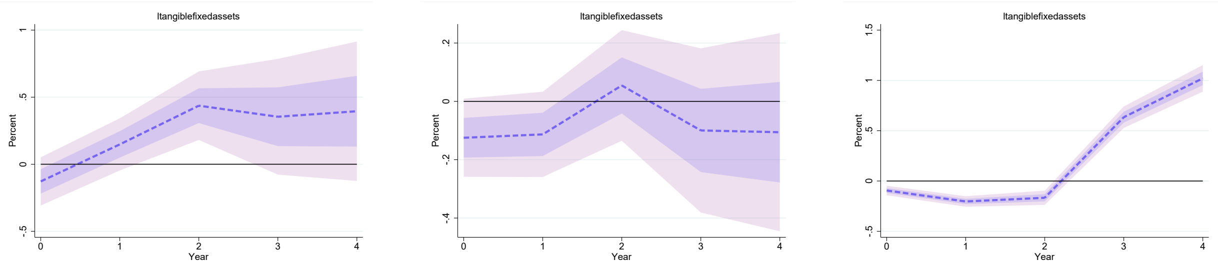
C.4 Robustness IV: Residual autocorrelation

Figure 27: Investment response of ETS firms relative to non-ETS firms

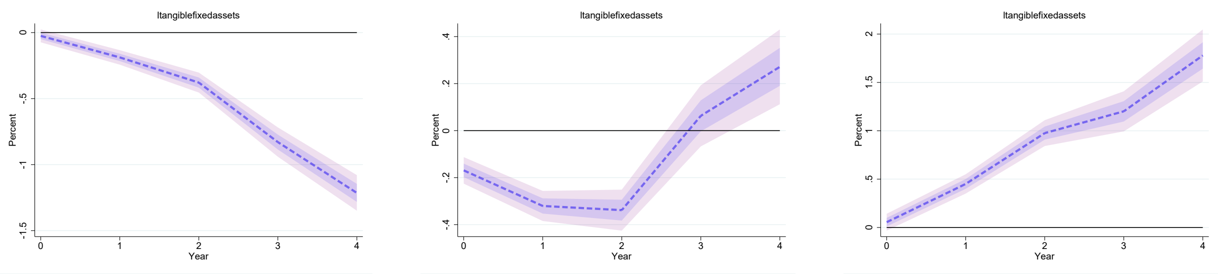


Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms participating in the ETS relative to firms that do not participate in the ETS. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm. We control for potential residual autocorrelation.

Figure 28: Investment response by climate-policy relevant sector



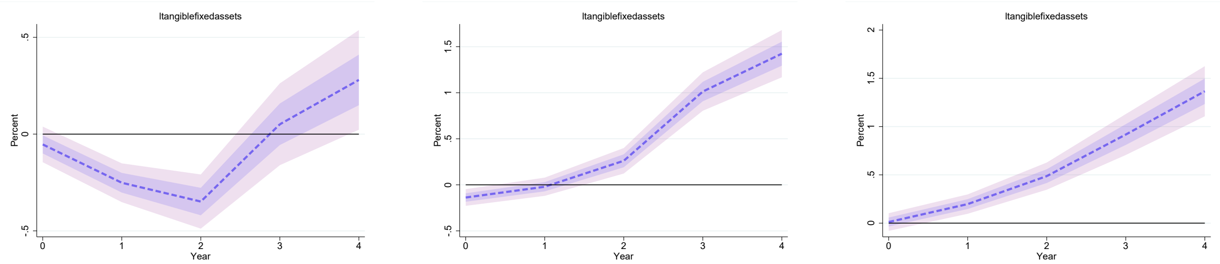
(a) Fossil Fuel (b) Utility (c) Energy-intensive



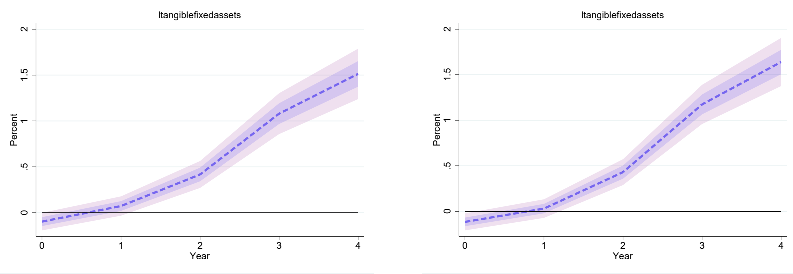
(d) Buildings (e) Transportation (f) Agriculture

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms in carbon-relevant sectors relative to firms in non-carbon-relevant sectors. It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm. We control for potential residual autocorrelation.

Figure 29: Investment response by energy intensity



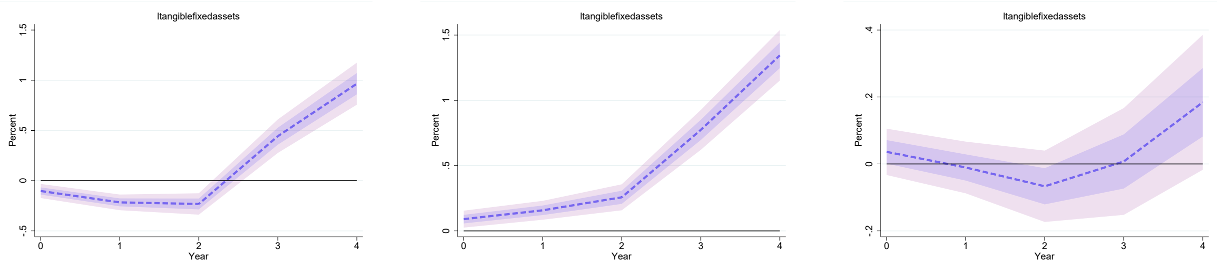
(a) $10 - 25\%$ (b) $25 - 50\%$ (c) $50 - 75\%$



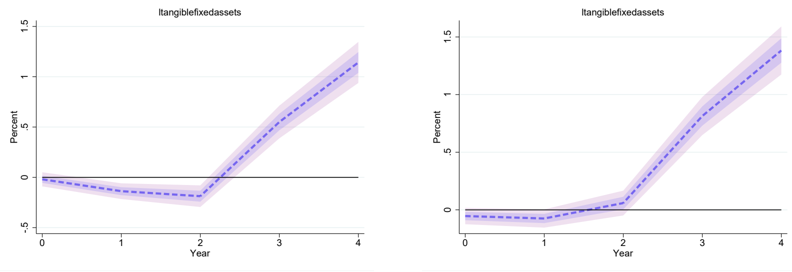
(d) $75 - 90\%$ (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their energy-intensity relative to the baseline (least energy-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm. We control for potential residual autocorrelation.

Figure 30: Investment response by emission intensity



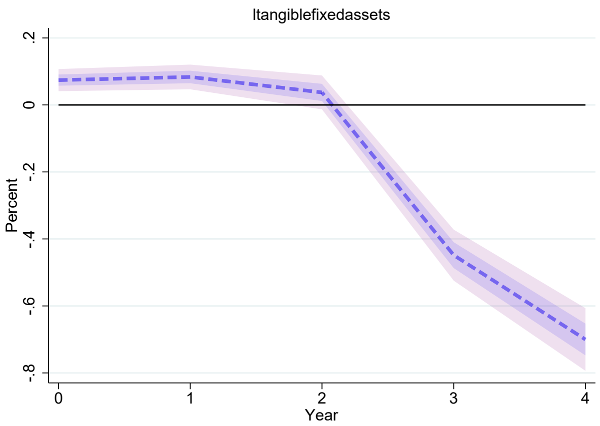
(a) 10 – 25% (b) 25 – 50% (c) 50 – 75%



(d) 75 – 90% (e) Top 10%

Notes: Firm level responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of firms according to their emission-intensity relative to the baseline (least emission-intensive firms). It shows the cumulative log-change in investment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm. We control for potential residual autocorrelation.

Figure 31: Investment response of high demand sensitive firms relative to low demand sensitive firms



Notes: The graph displays responses to a carbon policy shock, normalized to increase energy prices by one percent on impact. The graph shows the response of high demand sensitive firms relative to low demand sensitive firms. It shows the cumulative log-change in investment and employment between period $t-1$ and $t+h$ with the carbon policy shock dated at t. The time periods are years. Shaded (dark) purple areas represent 95 (68) percent confidence bands. The confidence bands are based on clustered standard errors by firm. We control for potential residual autocorrelation.

Acknowledgements

We thank Michael Pfarrhofer and Francesco Scarazzato for extensive discussion. We also gratefully acknowledge helpful comments from Brigitte Roth Tran, Jon Steinsson, Reed Walker, Joseph Shapiro, Ishan Nath, Emily Martell, Marcos Demetry, Antoine Germain, Clair Brown and Michael Baltensperger as well as seminar participants at the UC Berkeley IRLE Seminar, the Vienna Economics PhD Workshop, EENR and the CESifo Junior Workshop on Energy and Climate Economics. We thank Clemens Kuess for excellent research assistance. We also thank WU Vienna's cloud services for generously supporting this research. Lastly, we gratefully acknowledge funding for this work by the *Austrian Economic Society* (NOeG) and the *University Anniversary Fund* of the City of Vienna.
The opinions expressed herein are those of the authors and do not necessarily reflect those of the ECB or the Eurosystem. All remaining errors are naturally our own.

Anna Matzner
University of Economics and Business, Vienna, Austria; email: anna.matzner@wu.ac.at

Lea Steininger
European Central Bank, Frankfurt am Main, Germany; email: lea.steininger@ecb.europa.eu

Postal address 60640 Frankfurt am Main, Germany
Telephone +49 69 1344 0
Website www.ecb.europa.eu

PDF ISBN 978-92-899-6768-6 ISSN 1725-2806 doi:10.2866/671995 QB-AR-24-075-EN-N