Carbon Policy and Investment: Evidence from Firm Heterogeneity*

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Abstract

This paper studies how carbon policy shocks affect firms' investment decisions differently, using 3 million firm-level observations on investment from the ORBIS database. The carbon policy shocks are constructed by employing high-frequency data and the structural environment of the European carbon market after replicating Känzig (2021)'s methodology. The impact of the carbon policy shocks on firms' investment is estimated using a local projection approach, specifically, panel OLS local projection, presented by Jordá (2005) and following Cloyne et al. (2018). Firms' investment reactions to carbon policy shocks are heterogeneous. Foremost, firms react to carbon policy shocks contemporaneously. The second finding is that, when considering the firms' age, younger firms have the highest investment reaction to carbon policy shocks. If we consider the firms' size, our third finding shows that small-sized firms are taking the lead in investment response after the carbon policy shocks hit. Further findings show that the high-leveraged firms have a stronger reaction compared to others. However, firms respond similarly at the sectoral level, meaning there is a presence of inter-sectoral input-output linkages after the carbon policy shocks. Finally, industries that produce non-durable goods within the manufacturing sector have much stronger investment reactions than others.

Keywords: Investment, firm heterogeneity, carbon pricing, carbon policy transmission, carbon policy shocks
JEL Classifications: E22, Q43, Q54,

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Contents

1 Introduction

The recent war in Ukraine and its consequences on energy prices have led the green transformation to be one of the highest priorities on the European policy agenda. Policies toward a greener economy were already implemented many years ago. For example, governments have implemented carbon guidelines to ease climate change by using carbon taxes or caps and trade systems before the pandemic. Likewise, carbon taxes were implemented in Europe, with Finland being the pioneer in 1990. After the first carbon tax implementation in the Nordic countries, other European countries followed the carbon taxes practice. Currently, nineteen European countries have carbon taxes.

Existing research has mainly focused on whether carbon policy reduces emissions or not (Martin et al. (2014), Andersson (2019), among others). There are few studies regarding the macroeconomic effects of carbon policy. For instance, Metcalf (2019) and Bernard and Kichian (2021) investigate the effect of British Columbia tax and find the tax does not affect GDP significantly. Also, and Metcalf and Stock (2020) estimates the impacts of carbon taxes on macroeconomic variables, such as GDP and employment growth rates in European countries. According to the results, the impact of the tax is almost zero. Notably, they find no convincing evidence that the tax affects the macroeconomic variables considered negatively. Konradt and di Mauro (2021) discovers that there is no inflationary pressure from implementing carbon taxes in Europe and Canada. On the other hand, McKibbin et al. (2017) and Goulder and Hafstead (2018) exhibit a contraction in the output if theoretical models are employed. Recently Känzig (2021) documents that a rise in carbon prices, driven by regulatory updates, causes a robust and instantaneous increase in energy prices, a decline in output but a persistent fall in overall emissions.

Carbon policy, mainly the regulations regarding carbon emissions, affects the real economy, especially firms' investment decisions. The transmission works through several channels. The most important one is the price channel. An increase in carbon pricing, caused by regulatory updates, transmits into energy prices. The other one is the uncertainty channel which operates through frictions induced by uncertainty. Firms may decrease their investment for precautionary reasons because of the anticipation of future prices.

This paper aims to document the firms' investment heterogeneity in response to carbon policy shocks and seeks to provide answers to the following questions: Is the impact of carbon policy heterogeneous across firms? How long will it take firms to adjust their decisions? What are the firms' characteristics that make them more vulnerable to carbon policy shocks? Which sectors or industries react more to carbon policy shocks? To the best of the authors' knowledge, this paper is the first to exploit regulatory updates regarding carbon emissions to analyze the impacts of carbon policy on firms' dynamic decisions.

For this purpose, this paper uses micro firm-level data from Germany, France, Italy, and Spain, which are the largest economies in Europe. With around 500,000 firms, this paper tracks from 2000 to 2018, a vast and rich dataset that gives around three million firm-level observations for investment. The carbon policy shocks series is constructed by replicating the Känzig (2021)'s methodology. After comprehensive checks, it is established that the shocks series is exogenous. The dynamic impact of carbon policy on firms' investment decisions is estimated by using a local projection framework after Jordá (2005) and following recent work by Cloyne et al. (2018), Jeenas (2019), Ottonello and Winberry (2020) and Crouzet and Mehrotra (2020). The firms' investment response is analyzed until the four-year horizon after the carbon policy shocks. This paper finds that firms lower their investment contemporaneously and continue to invest less up to two years after the carbon policy shocks.

This paper concentrates on various groups of firms to identify the heterogeneous impact of carbon policy shocks. There is adequate statistical power to determine those differences since the data-set is extensive. The firms' size, leverage and age are utilized as proxies for financial constraints. Furthermore, this paper explores the effect of carbon policy shocks on the sector and industry level by grouping firms according to NACE codes into sectors such as service, manufacturing, and construction. In particular, this paper explores that how industries producing durable and non-durable goods in the manufacturing sector respond to carbon policy shocks.

This paper contributes to the literature by analyzing the effects of carbon policy shocks at the firm level. Therefore, this paper explores how carbon policy shocks affect firms with different characteristics. The aim is to draw inferences on the best policies to support firms that are likely to suffer the most from increases in carbon pricing and provide governments with guidelines for supportive policies for vulnerable firms.

The main novel finding of the paper is that firms' investment reactions to carbon policy shocks are heterogeneous. Foremost, firms react to carbon policy shocks contemporaneously. The second finding is that, when considering the firms' age, younger firms have the highest investment reaction to carbon policy shocks. If we consider the firms' size, our third finding shows that small-sized firms are taking the lead in investment response after the carbon policy shocks hit. Further findings show that the high-leverage firms have a stronger reaction compared to others. However, firms respond similarly at the sectoral level, meaning there is a presence of intersectoral input-output linkages due to the rise in energy prices through carbon pricing, the dominant cost in the production network. Also, this paper discovers that industries that produce non-durable goods within the manufacturing sector have much stronger investment reactions than others. Finally, to the best of this author's knowledge, this paper is the first to look into the heterogeneous firm investment responses to carbon policy in the Euro area.

The remainder of the paper proceeds as follows. Section 2 introduces the carbon policy shocks. Section 3.1 describes the data used in this paper. Section 3.2 displays the impact of carbon policy shocks on aggregate investment. Section 3.3 talks about the baseline econometric framework and presents the average effect of carbon policy shocks on firms' investment. Section 3.4 displays and discusses the heterogeneous effects of carbon policy shocks. Section 3.5 introduces robustness checks. Section 4 talks about future work and Section 5 concludes.

2 Carbon policy shocks

The study's first part starts with identifying carbon policy shocks. This paper closely follows Känzig (2021)'s job market paper and replicates Kanzig's results for identifying the shocks. Therefore, all the details regarding this section can be found in Känzig (2021).

The European Union emissions trading system (EU ETS) was established in 2005, and its primary purpose is to fight climate change by reducing greenhouse gas emissions. The EU-ETS functions under the cap and trade system. Regulated firms can trade their emission allowances within the cap according to their needs. They do so in secondary markets such as spot and futures markets. Figure A1 displays the carbon price evolution. The EU-ETS is developed throughout time by constantly updating the regulations to enhance market effectiveness, manage problems across the market, and expand the coverage of the market.

Känzig (2021) puts together 113 regulatory updates in the system by using the event study literature from 2005 - 2018. Following in Känzig's footsteps, this paper identifies the carbon policy surprise series by using high-frequency identification[1]. The carbon surprise series is displayed in Figure A2. It is evident that regulatory updates have a significant effect on carbon prices. Also, some validity checks are conducted, and it is found that the surprise series is not autocorrelated and forecastable by macroeconomic and financial variables. Although the surprise series has good properties, it is only part of the shock of interest because it is impossible to catch all the related regulatory updates Känzig (2021). Therefore, it is used as an external instrument for estimating the dynamic causal effect on variables of interest.[2] After employing the external instrument approach in a VAR setting, this paper performs the weak instrument test by Olea and Pflueger (2013). The heteroskedasticity-robust F-statistic is 17.51, and the corresponding critical value is 15.06. Since the test statistics lie above the critical value, it can be inferred that the instrument is strong and standard inference can be performed.

Figure A3 displays the impulse response functions of the carbon policy shocks. It is evident that the carbon policy causes a strong and immediate rise in the energy prices and there is a lasting reduction in greenhouse gas emissions. Hence, the carbon policy is successful in fighting against climate change. However, there is a cost to reducing the emissions: consumer prices increase, industrial production decreases, and the unemployment rate rises sizeably. According to the results, there is a policy trade-off between improving carbon emissions and economic cost. Also, energy prices seem essential in transmitting carbon policy shocks. In the next section, this paper studies how carbon policy and the resulting rise in energy prices affect the firms' investment decisions. This paper extracts the carbon policy shocks from the monthly VAR as $CPShock_t = s_1' \sum^{-1} u_t$[3]. Finally, throughout the paper, the carbon policy shocks are normalized to increase the HICP energy component by one percent on impact.

[1]For the high-frequency identification, see Känzig (2021).

[2]For the details of an external instrument approach, see Känzig (2021).

[3]For derivation, see Stock and Watson (2018).

3 Investment and firm heterogeneity

The European Commission's intentions to expand the carbon market to buildings and transportation have recently sparked a heated discussion in Euro area on energy poverty and the distributional impacts of carbon pricing European Commission (2021).

In light of this, it is essential to comprehend the EU ETS's distributional effects. The effectiveness of climate policies may ultimately be harmed if some groups are disproportionately affected. This paper searches the impacts of carbon pricing on firms in order to show that this is indeed the case. This will make it easier to understand how carbon pricing affects the real economy. Additionally, investigating potential heterogeneities in firm responses might aid in improving understanding of the transmission channels in operation.

There is a reason to think that there are significant heterogeneities at work. First, as energy expenditure shares vary greatly amongst firms, and the direct impact on energy prices is heavily dependent on this variable, the response will be heterogeneous among the firms. Second, firms would react to changes in aggregate spending differently, due to their differences in financial composition, age, size, and sectors. Likewise, the indirect effects will be heterogeneous.

3.1 Carbon policy shocks and firm level dataset

In this section, this paper presents two main databases: the firm-level database and the carbon policy shocks. Also, there is a summary of statistics for the main variables. Finally, there is an explanation of the matching procedure between the firm-level data and the carbon policy shocks to create the final data for empirical analysis.

3.1.1 Carbon policy shocks

The carbon policy shocks are produced in the previous section. The shocks series is monthly and available from 1999 to 2018. The firm-level data is annual. Therefore, it is necessary to match both frequencies. Consequently, this paper uses 12-month moving sum of the carbon policy shocks and combines it with the firm-level data using a variable from the Orbis database[4].

[4]The variable is called "closing month" in the BvD Orbis database and it shows the exact month when a firm closes its account.

This paper utilizes the 12-month moving sum because the impact of the carbon policy shocks on firms' annual investment value is not likely in the month when the account is filled. The following section will explain the merging procedure in more detail between the 12-month moving sum and the firm-level dataset. Figure A4 displays the 12-month moving sum of carbon policy shocks series.

3.1.2 Firm level dataset

The European carbon market includes companies from all over Europe, covering forty percent of the carbon emissions. Many of them display different responses to the regulatory news depending on their characteristics. Hence, firm-level micro-data is the most suitable platform for demonstrating heterogeneous effect of carbon policy.

This paper selects the following countries in Europe which are France, Germany, Spain, and Italy for obtaining granular firm-level data on firms' financial accounts. The sample period starts from 2000 to 2018, and the data is annual. This paper uses Amadeus (soon to be Orbis Europe) / Orbis database which is provided by Bureau Dijk (BvD).

The database details the information regarding firms' balance sheets. Additionally, there is information about the income statements of firms. Furthermore, it contains almost every industry, such as construction, manufacturing, and services. Regarding the coverage of the firms, it has all the corporate world in the countries mentioned before. The distinguishing feature of the database is that it contains listed firms in the stock market while it also has unlisted firms, which are generally very small. Therefore, there is sufficient statistical power to detect differences in a group of firms with different extents, such as age, size, sector, industry, etc.

The focus of this paper is only on non-financial corporations. Thus, the firms in the financial sectors and banks are excluded. Also, the agriculture and mining sectors, sectors that have high government ownership, such as administration, are dropped. Hence, the final sample incorporates the following NACE Rev. 2 sectors: Manufacturing (C), Construction (F), Wholesale and retail trade (G), Transportation and storage (H), Accommodation and food activities (I), information, communication, and R&D (J and M) and other business activities (M and N).

Following Kalemli-Özcan et al. (2015), the nationally firm-level database is attained. Firms are thrown away from the sample if the following variables exhibit negative values: employment, sales, total assets, and tangible fixed assets. Lastly, if firms report more than 2 million employment status, they are also dropped since this is a misreport.

There are outliers in the dataset. Therefore, all the ratios calculated using the balance sheet are winsorized to decrease the effect of outliers. Following Kalemli-Özcan et al. (2018), this paper winsorizes each variable. So, each variable's distribution has a kurtosis below ten. Finally, firms may not have five years of observations consecutively. In that case, they are dropped from the dataset because this paper focuses on the dynamic effect of carbon policy shocks with lags in the regressions. The final sample includes 500,000 firms and around 3 million observations. Table 1 displays the summary statistics.

Table 1. Summary statistics.

	Germany	France	Italy	Spain	Pooled
Tangible net investment (percent)					
mean	2.31	6.40	5.05	2.82	3.95
std	18.04	45.85	42.40	34.85	38.68
min	-24.15	-45.25	-42.94	-40.35	-45.25
max	48.92	150.12	139.16	114.20	150.12
Total Assets (log euro)					
mean	17.84	15.09	14.10	13.39	13.83
std	1.51	2.21	1.54	1.62	1.71
min	9.09	8.95	6.56	5.46	5.46
max	26.80	25.45	25.10	25.60	26.80
Age (years)					
mean	46.78	32.71	26.28	25.55	26.35
std	37.88	17.95	13.51	10.10	13.18
min	3	10	4	9	4
max	691	212	158	151	691
N. firms	9,432	8,146	249,117	251,274	517,969
Obs	44,783	35,758	1,322,879	1,315,607	2,719,027

Notes: The period is from 2000 to 2018 for firms with at least 5 consecutive years of observations.

Following Durante et al. (2022), the benchmark variable is the *tangible* net investment rate $I_{i,t}$. It is calculated by the net investment in tangible assets of firm i at year t, divided by the net capital stock at the end of year t-1.

[4]Year t refers to the firms' accounts' closing date, which shows the firms' accounting year.

Looking through the Table 1, It is evident that there is a vast variation in the firm-level data, which shows the heterogeneous firm landscape. The average net investment rate (pooled) is 3.95 percent, with a standard deviation of 38.68 percent. Also, the average log of the total asset is 13.83 percent, with a standard deviation of 1.71 percent. The average firm is 26 years old (with a standard deviation of 13). The minimum firms' age is four years because this paper employs lags in the model.

The dataset has remarkable characteristics. It is observable in the dataset in which month firms report their accounts during the year. Therefore, if firms close their account in various months of the same year, they experience the past shocks differently. As mentioned before, the 12-month moving sum of the carbon policy shocks is constructed to match the frequencies. The corresponding month in the moving sum series is matched with the variable "closing date" of each firm in each country. The aim is to capture time variation by any means necessary. In detail, let $m_{i,t}$ be the month of closing of the accounts of firm i in year t. Then, the 12-month moving sum of the carbon policy shocks for firm i at year t is described as $\varepsilon_{i,t} = \sum_{k=0}^{11} \varepsilon_{m_{i,t}-k}$ by following the same procedure in Durante et al. (2022).

It is evident from Table 2 that the carbon policy shocks impact the firms in each country differently after the matching procedure. The mean of the shock is -0.02 basis points with a standard deviation of 3.24 after pooling all the countries.

Table 2. The 12-month moving sum of the carbon policy shocks

	Germany	France	Italy	Spain	Pooled
mean	0.07	0.07	-0.04	-0.00	-0.02
std	3.16	3.22	3.25	3.24	3.24

Note: The mean and standard deviations are reported in basis points

3.2 The impact of carbon policy on aggregate investment

This paper studies the reaction of aggregate investment to carbon policy shocks before moving to the main econometric specification. Aggregate investment of country j in quarter q, $GFCF_{j,q}$, is obtainable from the national accounts.[5] Quarters are denoted by using subscript q.

[5]This paper uses the available national accounts series for total investment, which includes government investment and residential investment of households, and in national accounts terminology is called Gross Fixed Capital Formation, chain linked volume.

The carbon policy shocks, which are monthly, are added over each quarter q to match the frequencies. Later, it is combined with the aggregate investment series. Following Jordá (2005)'s local projections method, the impulse response of aggregate investment to carbon policy shocks is estimated. Formally, the model is written as follows:

$$log(GFCF)_{j,q+h} - log(GFCF)_{j,q-1} = \alpha_j^h + \beta^h * \varepsilon_q + u_{j,q+h} \tag{1}$$

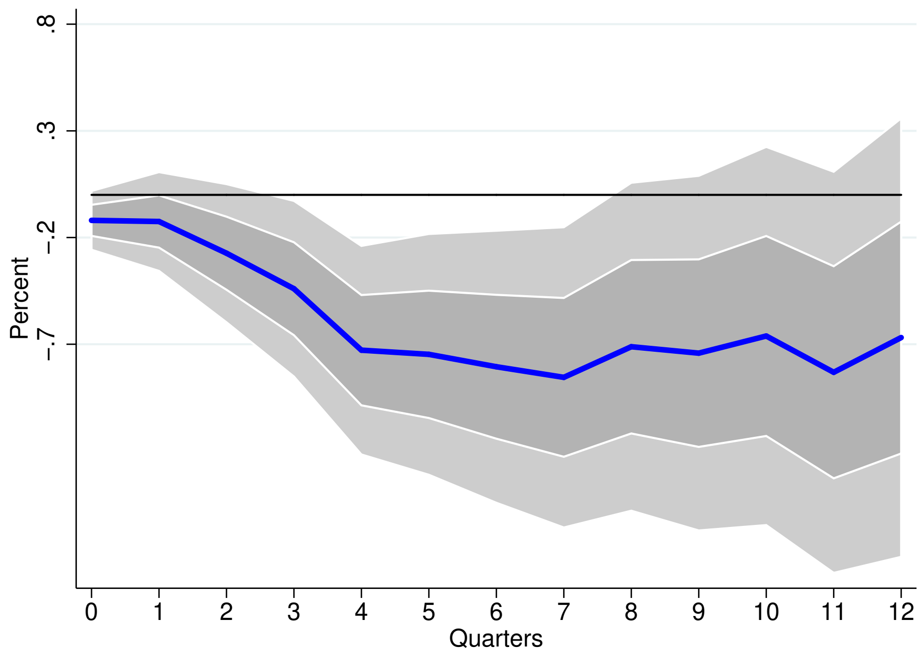
where j denotes the country and h the horizon. The coefficient β^h exhibits the reaction of the aggregate investment after a one basis point change in the carbon policy at horizon h.

$u_{j,q+h}$ is a mean zero error term capturing other shocks, and α_j^h is a country fixed effect. The quarterly carbon policy shocks ε_q do not have the j subscript because the shocks are identical across countries.

The Equation (1) is estimated for each horizon $h \ \epsilon \ (0, 1, ..., 12)$. The impulse response function is provided by the series of estimations of $\hat{\beta}^0, \hat{\beta}^1, \hat{\beta}^2, ..., \hat{\beta}^{12}$. Figure 1 shows the aggregate investment reaction of all the countries considered (Germany, France, Spain, and Italy) by pooling them. Tightening the carbon policy produces a reduction in aggregate investment. Especially, increase in the energy component of the HICP by one percent on impact, produces a decrease of 0.72 percentage points in aggregate investment in the fourth quarter. After the shocks, the effect stays big for almost two years, i.e., in quarters 6 and 7. In the second year's last quarter, point estimates turn statistically insignificant.

The same procedure is followed for each country individually, and the results show matching impulse response functions as in Figure 1 (see Figure A7 in Appendix). Hence, carbon policy shocks affect aggregate investment negatively for the countries evaluated, providing a good benchmark for the subsequent micro-data analysis.

Figure 1. The impact of carbon policy shocks on aggregate investment



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

3.3 Empirical framework

3.3.1 Baseline specification: panel OLS local projection

Following Jordá (2005), the panel local projection approach (OLS-LP) is used in this paper to estimate the dynamic firm investment responses to carbon policy shocks. The dependent variable is defined as $\Delta_h^* I_{i,t-1}$ which is the h-year forward difference in the investment rate, i.e. $\Delta_h^* I_{i,t-1} = I_{i,t+h} - I_{i,t-1}$.

The primary interest of this paper is to analyze the effect of a carbon policy shocks in year t (i.e., $\varepsilon_{i,t}$) on the dependent variable at horizons $h \ \epsilon$ (0,1,...,4). Since $I_{i,t-1}$ is predetermined at time t, it is possible to analyze the impact as the reaction of the future investment rate (i.e., the dynamic firm investment response to a causal effect of the carbon policy). The dummy variable is depicted as $D_{i,t-1}^g$, which selects the groups of interest in firms to check whether different groups of firms react to the carbon policy shocks. Particularly, the dummy variable takes the value of one if at time *t-1* the firm i belongs to the group g and 0 otherwise. Lastly, these dummy variables are interacted with the carbon policy shocks $\varepsilon_{i,t}$. The baseline empirical specification follows Cloyne et al. (2018):

$$\Delta_h^* I_{i,t-1} = \alpha_i^h + \sum_{g=1}^{G=1} \beta_g^h * D_{i,t-1}^g * \epsilon_{i,t} + \sum_{g=1}^{G=1} \gamma_g^h * D_{i,t-1}^g + \Gamma^h \Delta X_{i,t-1} + u_{i,t+h} \qquad (2)$$

α_i^h displays the firm fixed effect. It controls for heterogeneity in the investment rate across firms for each horizon h. $\Delta X_{i,t-1}$ is a vector of additional control variables. This flexible specification catches the heterogeneous effects of carbon policy across various groups. Especially, the estimation of the coefficients β_g^h is crucial because they show the impulse response functions for group g at the forecast horizon h ϵ (0,1,...,4). The coefficient γ_g^h controls different level effects of a group membership. However, if it does not change over time, this coefficient drops from the regression since there is a firm fixed effect.

The coefficient of $\Delta X_{i,t-1}$ represents the control vector which includes past shocks ($\varepsilon_{i,t-1}$, $\varepsilon_{i,t-2}$) and firm-specific controls: lagged investment differences ($\Delta I_{i,t-1}, \Delta I_{i,t-2}$), lagged sales growth differences ($\Delta SG_{i-1}, \Delta SG_{i-1}$), lagged cash flow differences ($\Delta CF_{i,t-1}, \Delta CF_{i,t-2}$).

Table A1 in Appendix displays the descriptions of the variables. It is established that the carbon policy surprise series is a strong instrument in the external instrument framework, and the carbon policy shocks are exogenous. Therefore, the control variables are introduced in the regression only to enhance the efficiency of the estimations. In the robustness checks section, the exclusion of the control variables is analyzed. It is anticipated that sales growth influences investment positively because it represents the demand factors and growth opportunities. Also, cash flow should impact the investment positively because it denotes the internal sources of funding. Remark that the carbon policy shocks are measured in basis points, whereas the investment is estimated in percentages. Hence, the coefficients β_g^h illustrate the estimation of the percentage points responses of investment to the identified carbon policy shocks, normalized to increase the HICP energy component by one percent on impact. Finally, standard errors are clustered at firm and time levels.[6]

[6]Cluster at the time level refers to the month-year level, not just year level because firms document their account at any month of the year.

3.3.2 The average effect

In this section, this paper presents the average effect of carbon policy shocks on the investment rate as a benchmark using the whole sample. The group dummy $D^g_{i,t}$ is dropped from Equation (2). Also, the group-specific coefficients β^h_g are replaced with a single parameter β^h at horizon h to calculate the effect. The estimation of the sequence of $\hat{\beta}^0, \hat{\beta}^1, ..., \hat{\beta}^4$ coefficients depicts the impulse response functions. The results are illustrated in Table 3 for each horizon (h=0,...,4). All the available years are incorporated in the regression to raise the number of observations for each horizon. Hence, when a firm joins the sample close to the ending, it is not used in the regression for further horizons. Therefore, the number of observations lessens as the horizon grows. As predicted earlier, the impact of sales growth and cash flows on the investment rate is positive, whereas the lags of investment differences affect the investment rate negatively. The reason is that the investment rate follows a fluctuating cycle; expanding the investment rate in the past is followed by more downward investment today.

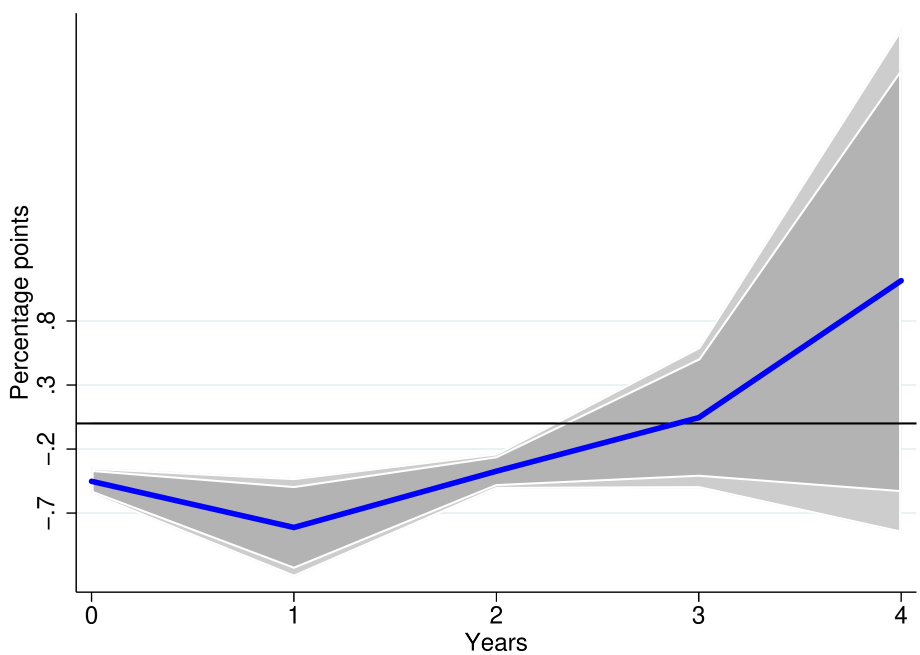
In Figure 2, (Y-axis) represents the percentage points and (X-axis) shows the each horizon h. Accordingly, the impulse response function reports the change in the percentage points of the investment rate after the identified carbon policy shocks, normalized to increase the HICP energy component by one percent on impact.

Surprisingly, there is a statistically significant contemporaneous effect on the investment rate when the carbon policy shocks hit the firms because the carbon policy works through carbon pricing. Change in the carbon pricing immediately transmits into the energy prices. Therefore, firms must adjust their decisions to the rise of an immediate cost accordingly and cut their plans mostly related to the investment. Hence, the impact of the carbon policy is instantaneous.

Firms start to buy emission rights after the change in the regulations towards carbon emission to compile with the new rules. However, there is a lack of uniform, generally accepted principles for carbon allowance accounting, but most firms recognize the allowances on their balance sheets as intangible fixed assets. Therefore, there should be a rise in intangible investment after the regulatory news regarding carbon emissions. Accordingly, It is observable in Figure A5. There is no statistically significant response contemporaneously, but intangible investment increases one year after the shock and continues to do so. The lag in the response could be explained by the fact that these decisions take time in nature. An increase in intangible investment could originate from the rise in greener patents, less carbon-intensive technologies, and revaluation of the previously purchased carbon allowances or newly bought carbon allowances after the news.[7]

The carbon policy shocks impact the investment rate negatively at the horizon h=1 and h=2 (both impacts are statistically significant at one percent level). Numerically, a restrictive carbon policy shock produces a contemporaneous decline in the investment rate of 0.45 percentage points (pp). In the first year after the shocks, the decline intensifies to 0.81 pp; in the second year, the subsequent reduction in investment rate is 0.37 pp. The effect of the carbon policy shocks becomes insignificant in the third and fourth years. It is evident that there is a consistency between both analyses of the firm-level investment data and the aggregate investment data. Both analyses show a v-shaped pattern, and the effect is the highest in the first year. Consequently, there is an important benchmark to analyze the heterogeneity in the reaction of firms with different characteristics to carbon policy.

Figure 2. The impact of carbon policy shocks on average firm-level investment



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

[7]Intangible assets include operational assets that lack physical substance. For example, patents, copyrights, trademarks, franchises, and rights regarding carbon emissions

Table 3. The impact of carbon policy shocks on average firm-level investment.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
ϵ_t	-0.45***	-0.81***	-0.37***	0.05	1.12
	(0.05)	(0.20)	(0.07)	(0.28)	(1.00)
ϵ_{it-1}	-0.42***	-0.55***	0.10**	0.05	7.80
	(0.06)	(0.06)	(0.05)	(0.15)	(5.42)
ϵ_{it-2}	-0.37***	-0.18***	0.10***	-0.81	2.82
	(0.03)	(0.04)	(0.03)	(1.13)	(3.36)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.67***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.26*
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔCF_{it-2}	0.09***	0.02	0.02	-0.03	0.42***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	0.46***	0.05	2.57***	4.72*	-29.90
	(0.10)	(0.46)	(0.27)	(2.52)	(23.90)
Observations	1188079	816489	190461	25893	3310

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Before diving into the firm heterogeneity, the last study is analzying the impulse response function of firms pooled by country level (Spain, Germany, France, and Italy) to carbon policy shocks. Accordingly, the carbon policy shocks $\varepsilon_{i,t}$ is interacted with the country dummy variables, and Equation (2) is computed again. The results are shown in Appendix in Table A2. Also, the impulse response functions are displayed for each country in Figure A7. For each of the countries, there is a u-shaped pattern in the reaction. Also, the impact is the highest in the first or second years after the carbon policy shocks for countries investigated. In absolute value, the effect is more prominent for Spain and Italy compared to France and Germany. Particularly, Spanish firms respond more substantially in the first year after the carbon policy shocks.

The results are not convincing that there is a substantial distinction in the investment reaction to carbon policy shocks across countries. Similarly, Dedola and Lippi (2005) notes that cross-industry differences are significant, whereas cross-country differences are not for the monetary policy shocks. The same reasoning seems to work with the carbon policy shocks. In the next section, this paper investigates firm heterogeneity in response to carbon policy shocks when firms belong to different groups.

3.4 Firm heterogeneity in the response to carbon policy shocks

3.4.1 Proxies for financial constraints

Financial frictions are a possible source of a heterogeneous reaction to carbon policy shocks. Recent studies about financially constrained firms show that the response is sizeable compared to non-financially constrained firms. Nevertheless, there is no clear guidance on measuring financial frictions, but proxies or indicators are in place. There are proxies in various dimensions of information asymmetries that can be employed for financial frictions. For example, Gertler and Gilchrist (1994) utilizes the firms' size suggesting that "the information frictions that add to the cost of finance apply mainly to younger firms, firms with a high degree of idiosyncratic risks, and firms that are not well collateralized. These are, on average, smaller firms."

Ferrando and Mulier (2015) argues that financially restrained firms are more likely to have lower liquidity and more heightened leverage (which is depicted in the total debt to total asset ratio). Also, they have inferior profits and are more undersized. Finally, Gertler (1988) is a pioneer in discussing that age is essential to show whether firms are financially constrained or not, and it is exogenous to any business cycle fluctuations. Furthermore, Hadlock and Pierce (2010) strengthens the idea that age is a significant determinant of the firms' constraint together with firm size. Thus, this paper utilizes the firms' size, leverage, and age as a proxy for financial constraints while being cautious about the firms' size and leverage as proxies because they could act endogenously.

3.4.2 Results based on the firms' age

This section reports the heterogeneous reaction to carbon policy shocks depending on firms' age. Accordingly, this paper defines two sub-groups: younger and older, and classifies firm age as the number of years of incorporation of the company. For the years of incorporation, this paper uses the 'date of incorporation' variable in the BvD Orbis database. Accordingly, a firm is considered younger if it is lower than 26 years old, which corresponds to the fifty percentile, and older if it is more than the fifty percentile. The Equation (2) is estimated for each horizon h ϵ (0,1,...,4) with employing the defined age groups. Therefore, the generic group dummy $D^{g}_{i,t}$ becomes $D^{younger}_{i,t}$ and $D^{older}_{i,t}$ for the younger and older firms, respectively.

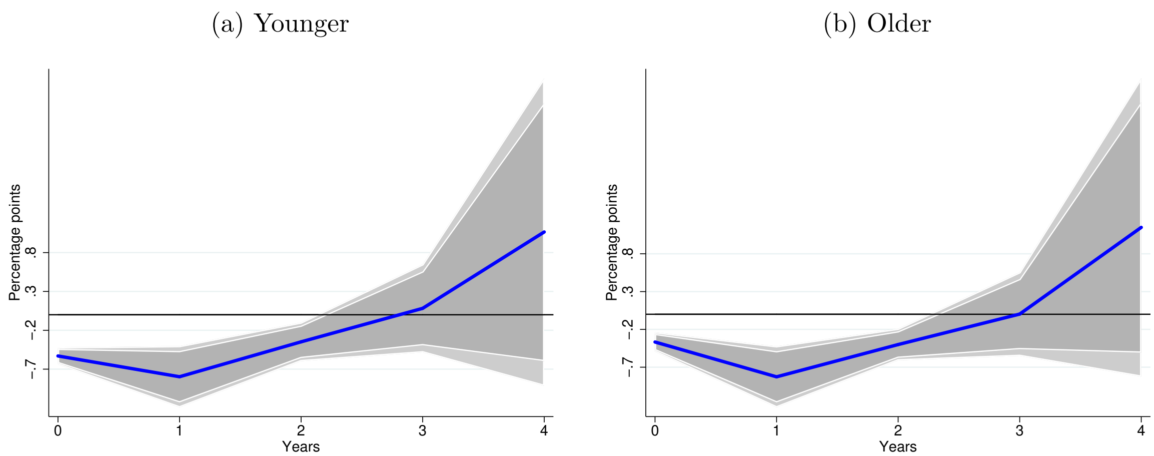
The carbon policy shocks are multiplied by the dummy variables representing the firms' age at year t. Figure 3 displays the corresponding impulse response functions for the younger and older firms and in Appendix, Table A3 represents the results.

As discussed before in the average effect section, each group of firms also has a contemporaneous investment reaction to the carbon policy shocks. The highest reaction to carbon policy shocks is from the younger firms, with a point estimate of -0.53 pp, while the older firms decrease their investment by 0.37 pp. It is reasonable to think that younger firms' reaction is the highest, since they are more financially constrained firms compare to older firms.

In the first year horizon, the impact for each group of firms elaborates, but older firms take the lead slightly. Accordingly, younger firms decreased their investment rate by 0.80 pp compared to the decline of 0.83 pp for older firms. In the second year horizon, the effect of the carbon policy shocks on the younger and older firms is still significant. Investment drops by 0.35 pp for the younger firms while the older firms' investment rate shrinks by 0.39 pp. In the third year horizon, the impact of the carbon policy shocks disappears.

The heterogeneous reactions with respect to age support the existence of cost channels through energy prices due to the effect of carbon policy, i.e., a more robust response of financially constrained firms. This suggests that financial frictions contribute to firms' investment responses to carbon policy heterogeneity. However, the age effect is not that strong. It is only present contemporaneously after the shock. On the other hand, the highest reaction of older firms compared to younger firms since the first year after the shock is another representation of the significant structural change in firms after the carbon policy shocks by regulatory updates. Hence, the older firms react more stronger since the shocks affect firms' structure because of the emission rules and rising uncertainty in the future.

Figure 3. The impact of carbon policy shocks on investment by age



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

3.4.3 Results based on the firms' size

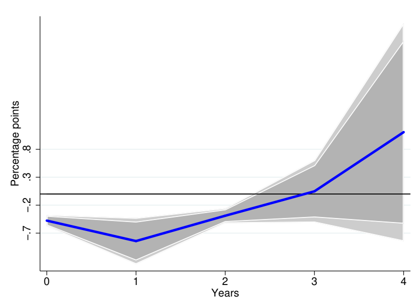
This section represents the results based on the firms' size. Figure 4 displays the corresponding impulse response functions for the small, medium, and large-sized firms and Table A4 represents the results in Appendix. In the figure, panel (d) and panel (e) represent the difference in the impulse response functions of the large-sized firms versus the medium-sized firms and the small-sized firms, respectively. The difference is calculated in the estimates by using the large-sized firms as the reference groups. The results seem enlightening but they should be treated carefully since firms' size can be endogenous, as argued before.

Each group has a contemporaneous investment reaction to the carbon policy shocks. The small-sized firms are taking the lead and decreasing their investment by 0.48 pp, while other groups' responses are statistically insignificant. One plausible interpretation is that the medium-sized and large-sized firms are integrated highly with high carbon emission technology. However, they probably have more resources to change their systems after the carbon policy shocks caused by the regulatory updates, but this is not the same for the small-sized firms. Therefore, the small-sized firms decrease their investment rate extortionately to fund their transformation because of the emission rules compared to other groups.

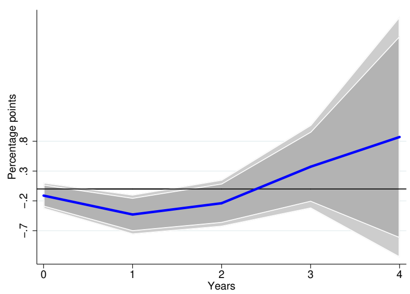
In the first year horizon, the reaction gets more vital for each group, but the small-sized firms' response to the carbon policy shocks turns out to be more extensive compared to other firms. The small-sized firms' investment rate declines by 0.84 pp, whereas the large-sized and medium-sized firms' investment rate, drops by 0.46 and 0.43 pp, respectively, and they are statistically significant this time. Although large-sized and medium-sized firms can mitigate the impact contemporaneously thanks to their vast resources, they still need to decrease their investment one year after the shock since the uncertainty about future energy prices kicks in. Nevertheless, this is different with small-sized firms in which they reduce their investment in both years. In the second year horizon, the reaction of the large-sized and medium-sized firms becomes statistically insignificant, whereas the small-sized firms respond significantly. In the third year horizon, the impact disappears for all firms.

Figure 4. The impact of carbon policy shocks on investment by size

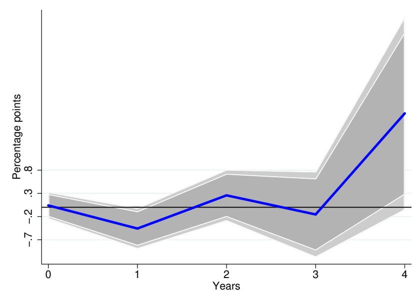
(a) Small



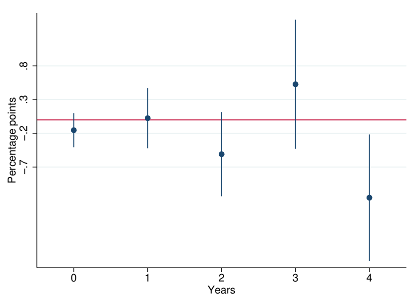
(b) Medium



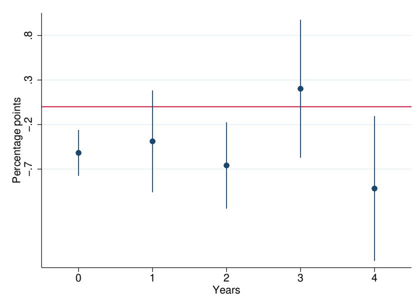
(c) Large



(d) Difference Medium vs Large



(e) Difference Small vs Large



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level. Bars in (d) and (e) represent 95 percent confidence interval of the difference in impulse responses.

3.4.4 Results based on the firms' leverage

This section represents the results based on the firms' leverage. Figure 5 displays the corresponding impulse response functions for the low-leverage, medium-leverage, and high-leverage firms and Table A5 represents the results in Appendix. In the figure, panel (d) and panel (e) represents the difference in the impulse response functions of the low-leverage firms versus the medium-leverage and the high-leverage firms, respectively. The difference is calculated in the estimates by using the low-leverage firms as the reference groups. The results seem informative, but they should be treated carefully since firms' leverage can be endogenous, as discussed earlier.

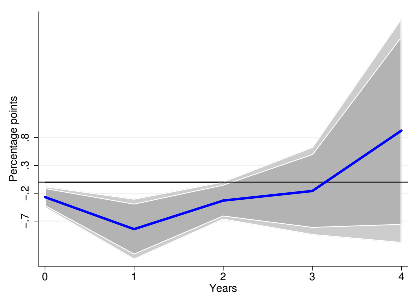
Each group has a contemporaneous investment reaction to the carbon policy shocks. The highest reaction comes from high-leverage firms, and they drop their investment by 0.66 pp. In contrast, medium-leverage firms decrease their investment by 0.31 pp. Finally, the lowest reaction comes from the low-leverage firms, which lower their investment by 0.27 pp.

In the first year horizon, the reactions get more mixed for each group, but the low-leverage firms' response to the carbon policy shocks turns out to be more extensive compared to other firms. The low-leverage firms' investment rate declines by 0.84 pp, whereas the medium-leverage and high-leverage firms' investment rate drops by 0.80 and 0.60 pp, respectively. In the second year horizon, the reaction of the medium-leverage firms becomes the highest compared to others. In the third year horizon, the impact disappears for all firms.

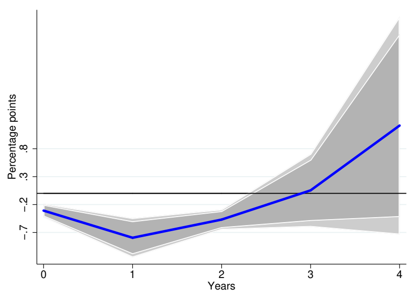
For leverage, the results are in line with Bahaj et al. (2022) and Jeenas (2019) that higher leveraged firms react stronger. This is most visible in the contemporaneous response, where the highest leveraged firms react the strongest while the lowest leverage firms react the least. If high leverage is interpreted as an indication of a higher external finance premium, this result is consistent with the interpretation that firms that are more likely to be financially constrained react more to carbon policy.

Figure 5. The impact of carbon policy shocks on investment by leverage

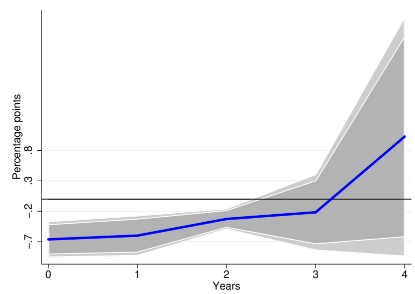
(a) Low leverage



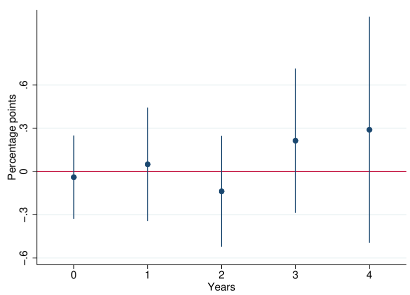
(b) Medium leverage



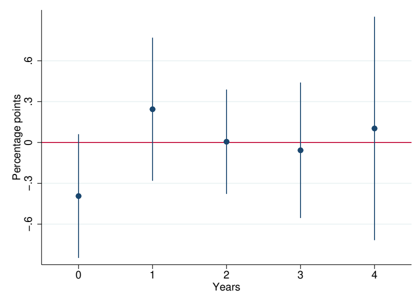
(c) High leverage



(d) Difference Medium vs Low leverage



(e) Difference High vs Low leverage



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level. Bars in (d) and (e) represent 95 percent confidence interval of the difference in impulse responses.

3.4.5 Results based on the firms' sectors and industries

This section analyzes the difference in impulse responses of firms depending on their sectors and industries. This paper starts with the three broad sectors: manufacturing (NACE Section C), construction (NACE Section F), and service. The service sector is obtained by collecting these sectors: wholesale and retail trade (G), transport and storage (H), accommodation and food activities (I), information, communication and R&D (J), and other business activities (M and N).

This paper estimates Equation (2) for each horizon $h \epsilon$ (0,1,...,4) by distributing each firms into the three main sectors. Accordingly, the dummy variable $D^{g}_{i,t}$ becomes ,$D^{ser}_{i,t}$, $D^{con}_{i,t}$ and $D^{man}_{i,t}$ for the firms that operate in service, construction and manufacturing sectors, respectively. In Appendix, Table A6 displays the results, while Figure 6 displays the corresponding impulse response functions for the service, construction, and manufacturing sector firms. In the figure, panel (d) and panel (e) represent the difference in the impulse response functions of the service sector firms versus the manufacturing sector and construction sector firms, respectively. The difference is calculated in the estimates by using the service sector firms as the reference groups.

Each group has a contemporaneous investment reaction to the carbon policy shocks. Using the sector grouping, there is no statistically significant differences between responses. The service sector firms decrease their investment rate by 0.47 pp after the carbon policy shocks, whereas the construction sector firms reduce their investment by 0.46 pp. The drop in the investment rate of the manufacturing sector firms is 0.40 pp. In the first year horizon, the impact of the carbon policy shocks becomes more robust. The service sector firms decrease their investment rate by 0.80 pp, while it is a 0.83 pp decline for manufacturing sector firms and a 0.84 pp reduction for construction sector firms. In the second year horizon, the manufacturing sector firms' response disappears. On the other hand, service and construction sector firms continue to respond significantly to the carbon policy shocks with a reduction in their investment rate by 0.37 pp and 0.63 pp, respectively. In the third year horizon, firm responses in each group become neutral.

Given the impulse response functions shown in Figure 6, one may wonder what is behind the similar reactions of firms in each sector. There may be distortions affecting different industries due to taxes, markups, contracting frictions, and regulations, in our case, regulations regarding carbon emission. Therefore, one plausible explanation is that changes in the carbon price due to regulatory news spread throughout the economy via input-output linkages.

Durante et al. (2022) investigates the heterogeneity in the output reaction to monetary policy and finds that the industries that produce durable goods in the manufacturing sector react more strongly than those that make non-durable goods. The finding is consistent with Dedola and Lippi (2005) and Peersman and Smets

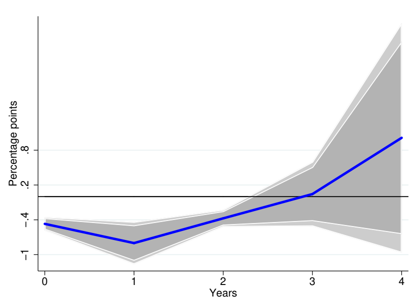
(2005). This paper investigates whether the same mechanism works for carbon policy or not. Accordingly, the new group dummy variables for durables goods, $D_{i,t}^{dman}$, and non-durable goods $D_{i,t}^{ndman}$ within the manufacturing sector are defined. Equation (2) is estimated using the four sector dummies (durables manufacturing, non-durables manufacturing, construction, and services).

In Appendix, Table A7 displays the results and Figure 7 displays the corresponding impulse response functions for the services firms, construction firms, and the firms which operate in durables and non-durables manufacturing industries. The difference is calculated in the estimates by using the services firms as the reference groups.

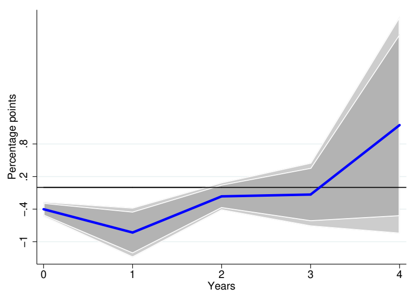
Surprisingly, industries that produce non-durable goods within the manufacturing sector display stronger investment reactions to carbon policy than those that produce durable goods. The contemporaneous investment reaction for the industries that produce non-durables within the manufacturing sector is to decrease their investment rate by 0.46 pp. In contrast, the reaction for those that produce durable goods is around 0.35 pp. The opposite finding for the carbon policy compared to the monetary policy comes from the rise in energy prices through carbon pricing. This is because it is easier for firms to cut their investment for goods that last less than three years after the immediate cost rise due to regulatory updates and adjust themselves for the future. On the other hand, the decision on durable goods is long-term in nature and works through a demand-driven interest rate channel. In the first year horizon, the impact of the carbon policy shocks becomes more vital for both industries and disappears in the second year horizon.

Figure 6. The impact of carbon policy shocks on investment by sector

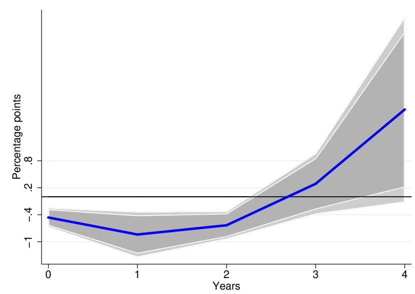
(a) Services



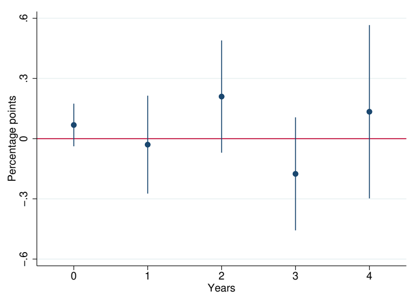
(b) Manufacturing



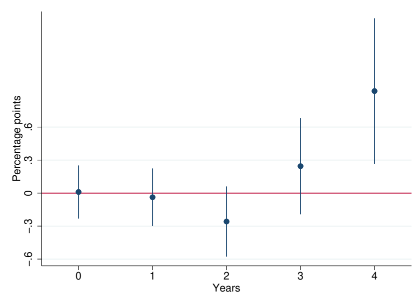
(c) Construction



(d) Difference Manufacturing vs Services



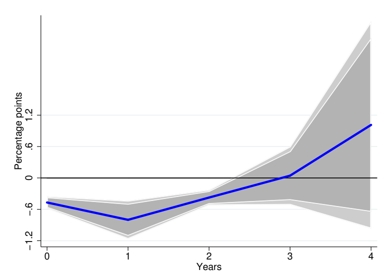
(e) Difference Construction vs Services



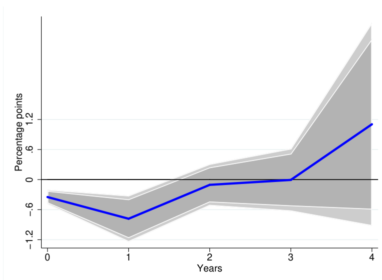
Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level. Bars in (d) and (e) represent 95 percent confidence interval of the difference in impulse responses.

Figure 7. The impact of carbon policy shocks on investment by sector and industry

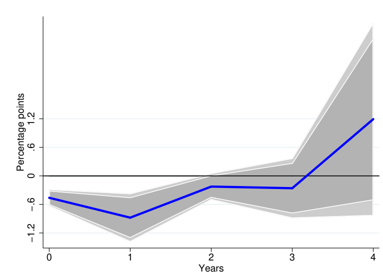
(a) Services



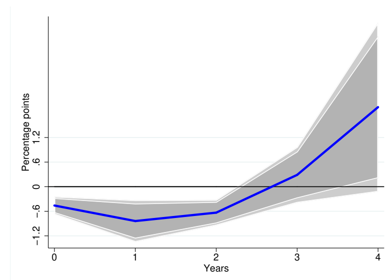
(b) Durables Manufacturing



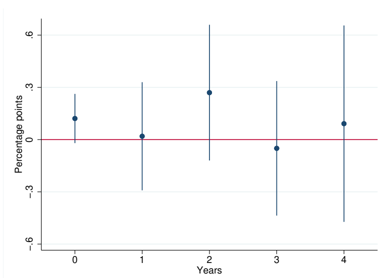
(c) Nondurables Manufacturing



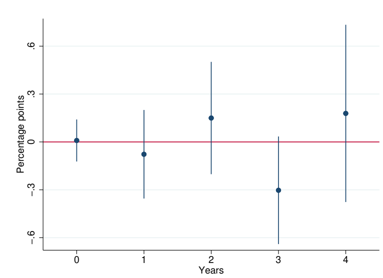
(d) Construction



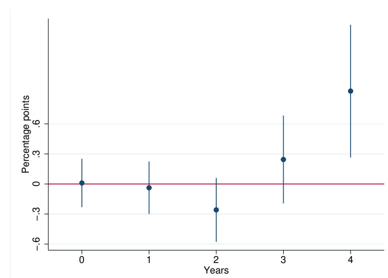
(e) Diff.Durables Man. vs Serv.



(f) Diff.Nondurables Man. vs Serv.



(g) Diff. Construction vs Serv.



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level. Bars in (e), (f) and (g) represent 95 percent confidence interval of the difference in impulse responses.

3.5 Robustness checks

In this section, this paper analyzes the robustness of the results in different settings that can avert potential concerns. Two robustness checks are conducted. The first one is related to sample size. The sample size of the analysis is finite, especially in terms of time extent. In the previous paragraphs, it is established that carbon policy shocks are exogenous. However, the paper incorporates two years of lagged control variables in the analysis to increase the precision of the estimates. Accordingly, the sample size decreases even more after adding control variables. Therefore, the control variables are omitted to improve the sample size in terms of time extent. The analysis is performed again to determine if the exclusion of control variables affects the results. Table A8 in Appendix displays the robustness check. As it can be seen, it has a negligible impact on the results.

The second one is affiliated with the firm fixed effect. The sample period starts from 2000 to 2018, but some firms are inactive throughout the period. Therefore, the period occasionally is small for regressor variables, leading to doubt on the firms' fixed effect estimation, especially about the accuracy. According to Nickell (1981), there is also a possibility of standard Nickell bias using the firm fixed effect. Thus, the analysis is conducted again with the exclusion of the firm fixed effect. Table A9 in Appendix demonstrates the robustness check. The estimation results are barely impacted after excluding the firm fixed effects.

4 Future work

The plan is to investigate the international production networks and their role in creating cross-border spillovers of carbon policy shocks by using multi-sector New Keynesian models with asymmetric input-output linkages. Furthermore, another plan is to analyze how the number of patents for low-carbon technology is affected by looking at the European Patent Office. A tag for climate change mitigation technologies was introduced for investment plans that tackle the impact of emission reduction by adapting new technologies. Likewise, the same analysis will be done with the unemployment rate and R&D expenditures. Also, combined with the firm-level data, the plan is to investigate whether media coverage affects firms' investment and energy usage decisions. Similarly, incorporated with the firm-level data, the intent is to study whether political fragmentation, measured using the manifesto data, population aging, and voters' impatience in the country impact firms' green plans.

Furthermore, the regulatory news related to carbon emissions can be extended to 2022 and see the corresponding effects. The integration of the electricity sector and the percentage of the firms in each country subject to the European carbon market are significant determinants of the transmission of carbon pricing. Therefore, integrating this information into the analysis will be crucial.

5 Concluding remarks

The analysis has revealed that carbon policy has a significant heterogeneous effect on firms' investment. This paper sheds new light on the relative importance of carbon pricing through which carbon policy affects investment.

Foremost, there is a contemporaneous firm investment response to carbon policy shocks. Furthermore, this paper finds that younger firms respond more to carbon policy shocks in comparison with the others when the ages of the firms are considered. Moreover, the paper demonstrates that the firms' size is a helpful characteristic when explaining the reaction of firms to carbon policy shocks. Accordingly, the findings of the paper suggest that small-sized firms have the highest level of reaction to carbon policy shocks. Also, this paper finds that high-leverage firms respond more to carbon policy shocks in comparison with others if the leverage of the firm is in question. Surprisingly, by investigating firm heterogeneity within the sectoral level, this paper discovers that firms react similarly to carbon policy shocks irrespective of their sectors. This indicates that there is a presence of inter-sectoral input-output linkages due to the rise in energy prices through carbon pricing, the dominant cost in the production network. Finally, comparing the firms according to their products, industries that produce non-durable goods within the manufacturing sector react more to carbon policy shocks than those that produce durable goods.

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A Appendix Tables and Figures

A.1 The carbon price evolution

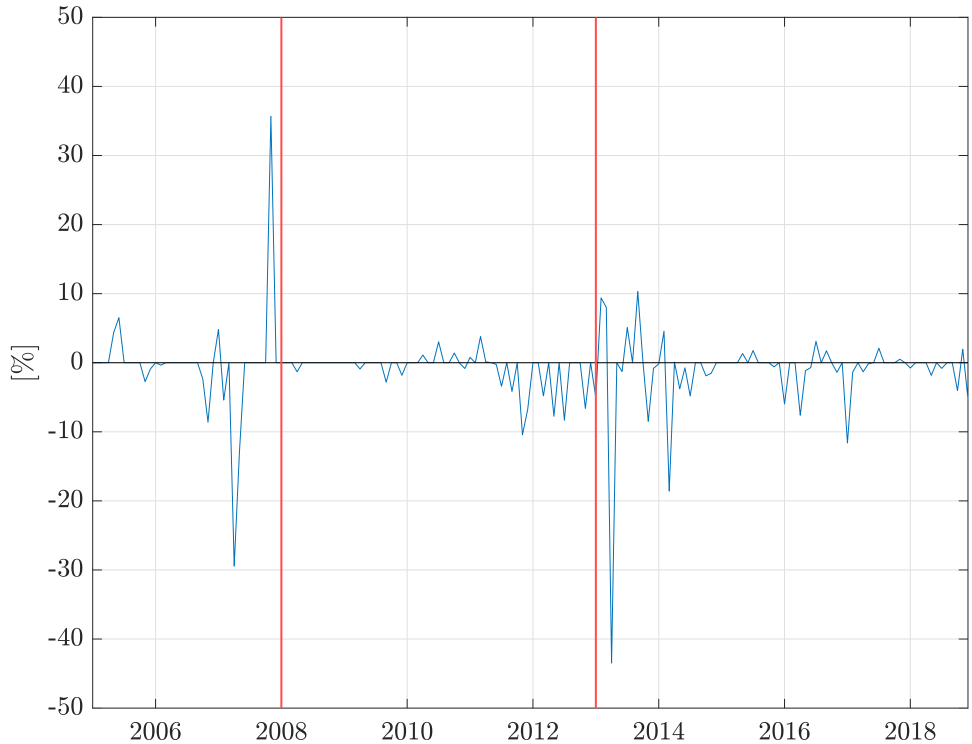
Figure A1 is calculated by following the paper of Känzig (2021).

Appendix Figure A1. The carbon price evolution

A.2 The carbon policy surprise series

Figure A2 is identified by replicating Känzig (2021).

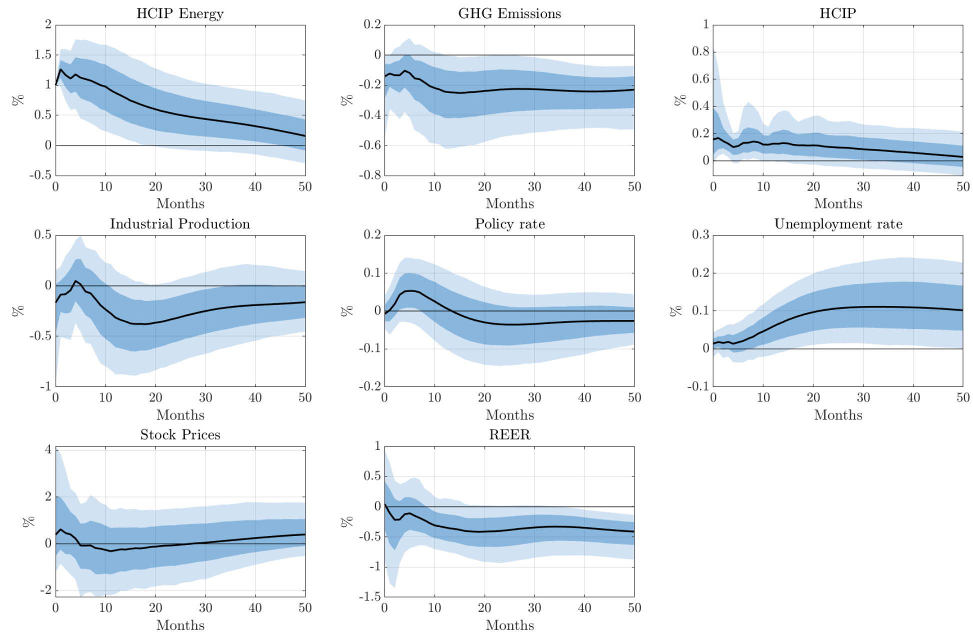
Appendix Figure A2. The carbon policy surprise series



A.3 The impact of carbon policy shocks on aggregate variables

Figure A3 is calculated by replicating Känzig (2021).

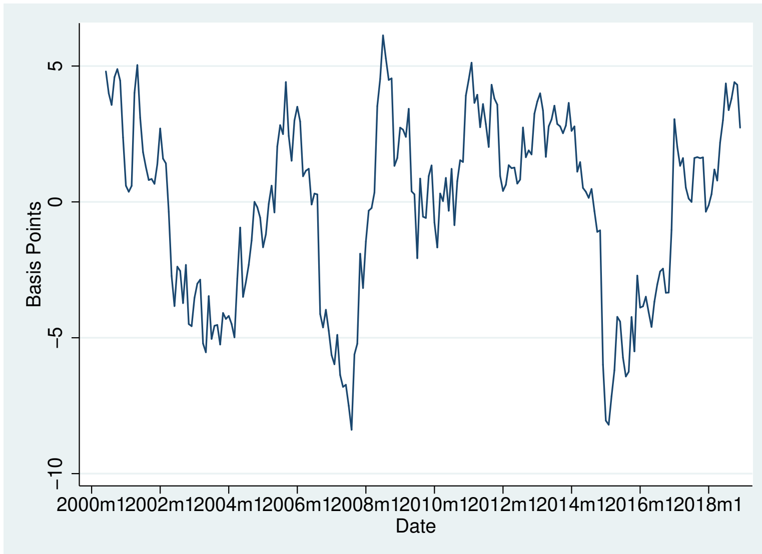
Appendix Figure A3. Impulse responses to carbon policy shocks



First stage regression: F: 17.51, R^2: 3.93%

A.4 The 12 month moving sum of the carbon policy shocks

Appendix Figure A4. 12 month moving sum of carbon policy shocks



A.5 Firm-level data

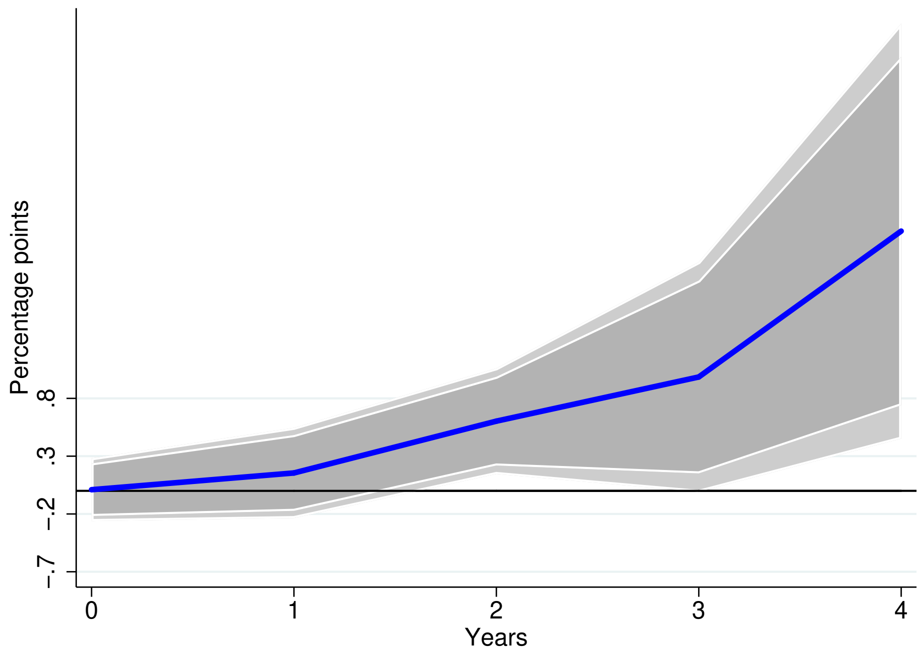
Table A1 represents the description of the variables in detail for the firm level analysis.

Appendix Table A1. Description of the variables.

Variables	Description
$I_{i,t}$	(**Tangible fixed assets**$_t$ -**Tangible fixed assets**$_{t-1}$) / **Tangible fixed assets**$_{t-1}$
$\epsilon_{i,t}$	12-month moving sum of the carbon policy shock
Age	Years since corporation
$SG_{i,t}$	ln **Sales**$_t$ - ln **Sales**$_{t-1}$
$CF_{i,t}$	**Cash flow**$_t$ / **Total Assets**$_t$
$Size_t$	**Number of Employees**
Small size	**10 to 49 Employees**
Medium size	**50 to 249 Employees**
Large size	**250 or more Employees**
lev_t	(**Loans**$_t$ + **Long term debt**$_t$) / **Total assets**$_t$
$shdebt_t$	**Loans**$_t$ / **Total assets**$_t$

A.6 The impact of carbon policy shocks on average firm-level intangible investment

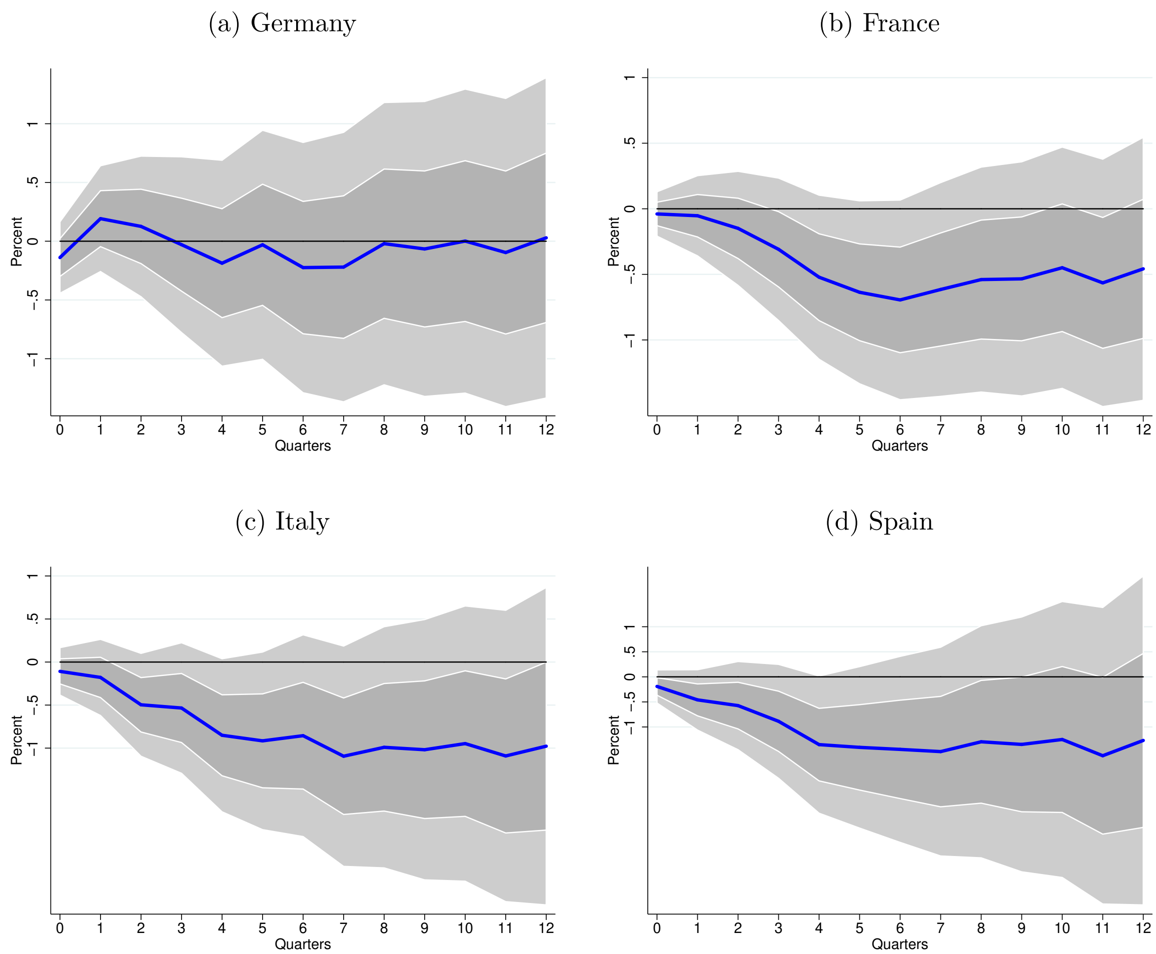
Appendix Figure A5. The impact of carbon policy shocks on average firm-level intangible investment



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

A.7 Country level tables and figures

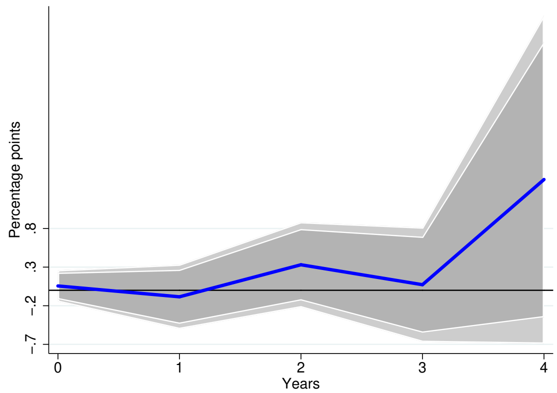
Appendix Figure A6. The impact of carbon policy shocks on aggregate investment by country



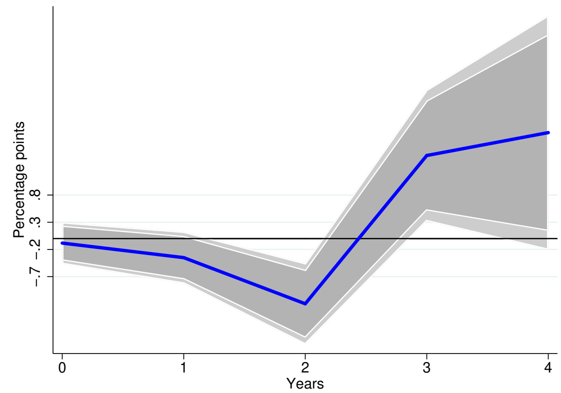
Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

Appendix Figure A7. The impact of carbon policy shocks on average firm-level investment by country

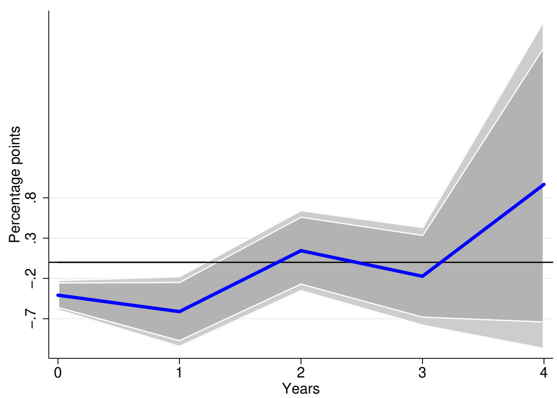
(a) Germany



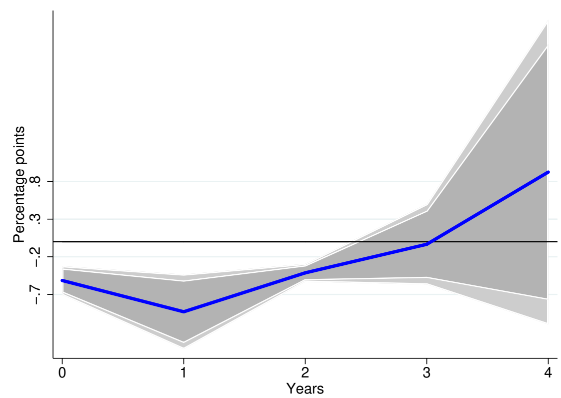
(b) France



(c) Italy



(d) Spain



Note: 90 and 95 percent confidence intervals are displayed in grey areas. Standard errors are clustered at firm and time level.

Appendix Table A2. The impact of carbon policy shocks on investment by country.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{DE}_{it}$	0.06	-0.08	0.33	0.07	1.43
	(0.10)	(0.21)	(0.28)	(0.38)	(1.08)
$\epsilon_{it} D^{ES}_{it}$	-0.51***	-0.93***	-0.41***	-0.03	0.92
	(0.10)	(0.25)	(0.06)	(0.27)	(1.03)
$\epsilon_{it} D^{FR}_{it}$	-0.08	-0.35	-1.20***	1.53**	1.95*
	(0.19)	(0.24)	(0.38)	(0.62)	(1.10)
$\epsilon_{it} D^{IT}_{it}$	-0.41***	-0.61***	0.14	-0.17	0.97
	(0.10)	(0.22)	(0.26)	(0.31)	(1.04)
ϵ_{it-1}	-0.43***	-0.57***	0.11**	0.01	7.37
	(0.06)	(0.06)	(0.04)	(0.14)	(5.52)
ϵ_{it-2}	-0.37***	-0.17***	0.14***	-0.98	2.47
	(0.03)	(0.04)	(0.04)	(1.10)	(3.44)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.67***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.26*
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔCF_{it-2}	0.09***	0.02	0.02	-0.03	0.43***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	0.44***	0.07	2.96***	5.02**	-27.81
	(0.10)	(0.48)	(0.34)	(2.46)	(24.37)
Observations	1188079	816489	190461	25893	3310

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.8 Investment responses to carbon policy shock by age, size and leverage: Tables

Appendix Table A3. The impact of carbon policy shocks on investment by age.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{younger}_{it}$	-0.53***	-0.80***	-0.35***	0.08	1.07
	(0.06)	(0.20)	(0.13)	(0.29)	(1.01)
$\epsilon_{it} D^{older}_{it}$	-0.37***	-0.83***	-0.40***	0.00	1.15
	(0.07)	(0.21)	(0.11)	(0.28)	(1.01)
ϵ_{it-1}	-0.42***	-0.55***	0.10**	0.05	7.77
	(0.06)	(0.06)	(0.05)	(0.15)	(5.42)
ϵ_{it-2}	-0.37***	-0.18***	0.10***	-0.82	2.79
	(0.03)	(0.04)	(0.03)	(1.13)	(3.36)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.67***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.26*
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔCF_{it-2}	0.09***	0.02	0.02	-0.03	0.42***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	-0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	0.46***	0.05	2.57***	4.72*	-29.73
	(0.10)	(0.46)	(0.27)	(2.52)	(23.88)
Observations	1188079	816489	190461	25893	3310

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix Table A4. The impact of carbon policy shocks on investment by size.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{sm}_{it}$	-0.48***	-0.84***	-0.39***	0.05	1.11
	(0.05)	(0.21)	(0.07)	(0.28)	(1.00)
$\epsilon_{it} D^{me}_{it}$	-0.11	-0.43**	-0.24	0.37	0.87
	(0.11)	(0.17)	(0.20)	(0.36)	(1.03)
$\epsilon_{it} D^{la}_{it}$	0.04	-0.46**	0.26	-0.15	2.02*
	(0.15)	(0.23)	(0.28)	(0.47)	(1.06)
ϵ_{it-1}	-0.41***	-0.55***	0.10**	0.05	7.77
	(0.06)	(0.05)	(0.05)	(0.15)	(5.39)
ϵ_{it-2}	-0.37***	-0.17***	0.10***	-0.78	2.77
	(0.03)	(0.04)	(0.03)	(1.13)	(3.33)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.66***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.23
	(0.01)	(0.01)	(0.02)	(0.04)	(0.13)
ΔCF_{it-2}	0.08***	0.02	0.02	-0.03	0.42***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	-17.02***	-11.54***	-2.52	-13.79***	-52.34*
	(1.29)	(2.57)	(2.54)	(4.89)	(25.42)
Observations	1185459	813926	189898	25836	3292

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix Table A5. The impact of carbon policy shocks on investment by leverage.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{ll}_{it}$	-0.27***	-0.84***	-0.33*	-0.16	0.93
	(0.10)	(0.28)	(0.17)	(0.40)	(1.03)
$\epsilon_{it} D^{ml}_{it}$	-0.31***	-0.80***	-0.47***	0.05	1.22
	(0.06)	(0.18)	(0.09)	(0.33)	(1.00)
$\epsilon_{it} D^{hl}_{it}$	-0.66***	-0.60***	-0.33***	-0.22	1.03
	(0.15)	(0.17)	(0.09)	(0.32)	(1.01)
ϵ_{it-1}	-0.44***	-0.59***	0.09*	-0.04	8.45
	(0.05)	(0.05)	(0.05)	(0.17)	(5.82)
ϵ_{it-2}	-0.43***	-0.21***	0.06**	-1.01	2.77
	(0.02)	(0.03)	(0.03)	(1.28)	(3.24)
ΔI_{it-1}	-0.78***	-0.75***	-0.70***	-0.69***	-0.65***
	(0.12)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.35***	-0.31***	-0.29***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03	0.04*	0.04	0.21
	(0.01)	(0.02)	(0.02)	(0.06)	(0.20)
ΔCF_{it-2}	0.09***	0.02	0.04*	-0.02	0.48**
	(0.01)	(0.02)	(0.02)	(0.06)	(0.20)
ΔSG_{it-1}	0.04***	0.01**	0.01***	-0.00	-0.02
	(0.00)	(0.00)	(0.00)	(0.01)	(0.03)
ΔSG_{it-2}	0.03***	0.01**	0.01**	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.03)
Constant	-8.50***	-3.07***	0.27	2.69	-36.37
	(0.56)	(0.80)	(0.54)	(3.03)	(25.13)
Observations	959794	647786	141037	15856	2044

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.9 Investment responses to carbon policy shock by sectors and industries: Tables

Appendix Table A6. The impact of carbon policy shocks on investment by sector.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{man}_{it}$	-0.40***	-0.83***	-0.16	-0.13	1.15
	(0.07)	(0.23)	(0.13)	(0.30)	(1.02)
$\epsilon_{it} D^{con}_{it}$	-0.46***	-0.84***	-0.63***	0.29	1.94*
	(0.11)	(0.26)	(0.16)	(0.35)	(1.05)
$\epsilon_{it} D^{ser}_{it}$	-0.47***	-0.80***	-0.37***	0.04	1.01
	(0.06)	(0.19)	(0.07)	(0.28)	(1.01)
ϵ_{it-1}	-0.42***	-0.55***	0.10**	0.05	7.93
	(0.06)	(0.06)	(0.05)	(0.15)	(5.43)
ϵ_{it-2}	-0.37***	-0.18***	0.10***	-0.82	2.92
	(0.03)	(0.04)	(0.03)	(1.12)	(3.37)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.67***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.24*
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔCF_{it-2}	0.09***	0.02	0.02	-0.03	0.42***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	0.45***	0.05	2.59***	4.73*	-30.50
	(0.10)	(0.46)	(0.27)	(2.51)	(23.95)
Observations	1188079	816489	190461	25893	3310

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix Table A7. The impact of carbon policy shocks on investment by sector and industry.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
$\epsilon_{it} D^{dman}_{it}$	-0.35***	-0.78***	-0.10	-0.01	1.11
	(0.07)	(0.24)	(0.21)	(0.32)	(1.04)
$\epsilon_{it} D^{ndman}_{it}$	-0.46***	-0.88***	-0.22	-0.26	1.19
	(0.09)	(0.26)	(0.14)	(0.32)	(1.04)
$\epsilon_{it} D^{con}_{it}$	-0.46***	-0.84***	-0.63***	0.29	1.94*
	(0.11)	(0.26)	(0.16)	(0.35)	(1.05)
$\epsilon_{it} D^{ser}_{it}$	-0.47***	-0.80***	-0.37***	0.04	1.01
	(0.06)	(0.19)	(0.07)	(0.28)	(1.01)
ϵ_{it-1}	-0.42***	-0.55***	0.10**	0.05	7.93
	(0.06)	(0.06)	(0.05)	(0.15)	(5.43)
ϵ_{it-2}	-0.37***	-0.18***	0.10***	-0.82	2.92
	(0.03)	(0.04)	(0.03)	(1.13)	(3.37)
ΔI_{it-1}	-0.78***	-0.75***	-0.71***	-0.70***	-0.67***
	(0.11)	(0.02)	(0.00)	(0.01)	(0.02)
ΔI_{it-2}	-0.45***	-0.36***	-0.32***	-0.28***	-0.31***
	(0.03)	(0.02)	(0.00)	(0.01)	(0.02)
ΔCF_{it-1}	0.10***	0.03**	0.02	0.01	0.24*
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔCF_{it-2}	0.09***	0.02	0.02	-0.03	0.42***
	(0.01)	(0.01)	(0.02)	(0.04)	(0.14)
ΔSG_{it-1}	0.04***	0.01***	0.02***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
ΔSG_{it-2}	0.03***	0.01***	0.01***	-0.01	0.00
	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	0.45***	0.05	2.59***	4.72*	-30.51
	(0.10)	(0.46)	(0.27)	(2.51)	(23.95)
Observations	1188079	816489	190461	25893	3310

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.10 Robustness checks

Appendix Table A8. Robustness checks for carbon policy: Omitted control variables case.

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
ϵ_{it}	-0.37***	-0.68***	-0.66***	-0.21	-0.14***
	(0.07)	(0.18)	(0.22)	(0.14)	(0.02)
$\epsilon_{it} D^{dy}_{it}$	1.49*	3.11***	2.94**	1.96	-2.73**
	(0.83)	(0.78)	(1.14)	(1.26)	(1.36)
$\epsilon_{it} D^{dmo}_{it}$	0.03	0.08*	0.01	-0.02	-0.01
	(0.03)	(0.04)	(0.04)	(0.08)	(0.05)
$\epsilon_{it} D^{ndy}_{it}$	1.68***	2.67***	2.43**	1.85	-2.21***
	(0.49)	(0.79)	(1.06)	(1.48)	(0.57)
Constant	0.40	0.61	1.68*	3.49***	3.16***
	(0.39)	(0.89)	(0.95)	(0.74)	(0.00)
Observations	1965575	1588849	1204536	830384	196861

Non-durables and not-young firms are chosen as the reference group

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix Table A9. Robustness checks for carbon policy: Omitted fixed effect case

	ΔI^*_{it0}	ΔI^*_{it1}	ΔI^*_{it2}	ΔI^*_{it3}	ΔI^*_{it4}
ϵ_{it}	-0.40***	-0.69***	-0.54**	0.43*	0.30
	(0.06)	(0.16)	(0.21)	(0.26)	(0.18)
$\epsilon_{it}D^{dy}_{it}$	0.75	3.19***	3.66**	5.69***	0.00
	(0.99)	(0.75)	(1.61)	(0.04)	(0.00)
$\epsilon_{it}D^{dmo}_{it}$	0.21	-0.62**	-0.69	-0.37***	-0.07
	(0.16)	(0.31)	(0.45)	(0.11)	(0.17)
$\epsilon_{it}D^{ndy}_{it}$	1.56***	4.86***	0.06	4.16	0.00
	(0.36)	(1.35)	(0.92)	(4.39)	(0.00)
Constant	0.12	-0.03	1.20	-1.77	-5.56*
	(0.19)	(0.44)	(0.81)	(1.99)	(3.10)
Observations	1197258	824958	460212	105312	16687

Non-durables and not-young firms are chosen as the reference group

Standard errors are clustered at firm and time levels in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

A.11 Summary statistics

Appendix Table A10. Summary statistics for age

	Younger	Older
Obs	1,423,027	1,296,000
Percent	52.34	47.66

Appendix Table A11. Summary statistics for size

	Small	Medium	Large
Obs	2,488,009	167,997	57,505
Percent	91.68	6.18	2.11

Appendix Table A12. Summary statistics for leverage

	Low	Medium	Large
Obs	626,662	1,151,131	586,672
Percent	26.50	58.68	24.81

Appendix Table A13. Summary statistics for sector

	Manufacturing	Services	Construction
Obs	716,173	1,624,943	377,911
Percent	26.34	59.76	13.90

Appendix Table A14. Summary statistics for country

	Germany	France	Italy	Spain
Obs	44,783	35,758	1,322,879	1,315,607
Percent	1.65	1.32	48.65	48.39