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EUROPEAN UNION'S EMISSIONS TRADING SYSTEM AND PRODUCTIVITY: FIRM-LEVEL EVIDENCE FOR FRANCE, ITALY AND SPAIN

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Ce document de travail n’engage que ses auteurs. L’objet de sa diffusion est de stimuler le débat et d’appeler commentaires et critiques.

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Résumé

Le système européen d'échange de quotas d'émission (SEQE) a été introduit en 2005 afin d'inciter les entreprises industrielles à réduire leurs émissions de carbone de la manière la plus efficace possible. Malgré le faible prix du carbone durant les premières phases du système, le SEQE a permis de réduire les émissions industrielles. Une question clé, cependant, est de savoir si ces réductions sont allées de pair avec une baisse de la productivité, puisque le système a contraint les processus de production. Nous étudions l'effet du SEQE sur la productivité globale des facteurs (PGF) au niveau des entreprises manufacturière en France, en Italie et en Espagne, de 2000 à 2017. Le SEQE est ici considéré comme une expérience quasi-naturelle, que nous étudions à l'aide d'une méthode de différence en différence. Nous étudions si les entreprises ont réagi différemment en fonction de leur productivité initiale, de leur taille, de leurs contraintes financières, de leur secteur ou de leur pays d'appartenance; et également au cours des différentes phases de mise en œuvre du système. Les résultats suggèrent que, dans l'ensemble, le SEQE n'a pas nui à la productivité des entreprises, à l'exception des petites entreprises, des entreprises initialement éloignées de la frontière technologique et des entreprises ayant des contraintes financières. La réforme a eu un impact positif sur la PGF des grandes entreprises et des entreprises plus efficaces ou moins contraintes financièrement. L'impact du SEQE est très hétérogène selon les secteurs, les principaux bénéficiaires étant les industries alimentaire, chimique et métallurgique. Il est également plus positif en France qu'en Italie et en Espagne.

Mots-clés: productivité totale des facteurs, données au niveau entreprise, système d'échange de quotas d'émission, méthode des différences de différences, effet d'anticipation.

Classification JEL: D240, Q500, Q580.

Abstract

The European Union Emissions Trading System (EU ETS) was introduced in 2005 in order to incentivize a reduction in carbon emissions in industrial firms in the most efficient way. Despite a low carbon price during the initial phases of the scheme, the EU ETS did foster a reduction in industrial emissions. A key question, though, is whether these reductions came together with lower productivity, as the scheme has constrained production processes. We study the effect of the EU ETS on total factor productivity (TFP) for manufacturing firms in France, Italy and Spain, from 2000 to 2017. The EU ETS is here considered as a quasi-natural experiment and we apply a difference-in-difference framework. We study whether firms reacted differently depending on their initial efficiency, size, financial constraints, sector, and country; or across the different phases of the implementation. The results suggest that the instrument overall was not detrimental to firms' productivity, except for smaller firms, firms initially far from the technological frontier, and financially-constrained ones. The reform had a positive impact on TFP for larger firms and more efficient or less financially-constrained ones. The impact of the EU ETS is found to be very heterogeneous across sectors, the major beneficiaries being the food, chemicals and metallurgy industries. It is also more positive in France than in Italy and Spain.

Keywords: total factor productivity, firm-level data, emissions trading system, difference-in-differences method, anticipation effect.

JEL Classification Numbers: D240, Q500, Q580.

Introduction

The European Union Emissions Trading System (EU ETS) is the major instrument of the European Union to reach its greenhouse gas (GHG) reduction targets. It was introduced in 2005 and has effectively contributed to reduce GHG emissions of installations covered by the system, from 2.38 billion $tCO_2(e)$ in 2005 to 1.81 billion $tCO_2(e)$ in 2014[1], equivalent to an annual average reduction of 2.95%. Obviously, not all of these emission reductions can be attributed to the EU ETS. Hoffmann (2007) shows that the 2008 global financial crisis had a greater role in this reduction than the EU ETS. Other events, such as the mild winter of 2014, have also been mentioned as mitigating factors of emissions.

Here we focus on the impact of the EU ETS on firm productivity – a key issue for European governments, as the EU is accelerating its transition to low carbon[2]. Estimating the impact of the cornerstone instrument of decarbonization of the EU is key to calibrate accompanying policies and to design a multiyear growth trajectory that is compatible with the green transition.

There are traditionally two competing hypotheses on the impact of environmental regulations on competitiveness. The "pollution haven" hypothesis (McGuire, 1982) states that, in the case of asymmetric regulation between countries, firms that are more constrained by environmental standards will suffer lower cost-competitiveness and hence face a strong incentive to relocate. Alternatively, the Porter hypothesis (PH) introduced by Porter (1991) and Porter and Van der Linde (1995) postulates that environmental regulations could encourage firms to innovate in order to reduce their emissions (weak PH); this will ultimately result in productivity gains that will offset the costs of regulation (strong PH).

The existing empirical literature tends to validate the weak version of the PH: environmental regulations do incentivize innovation. As for the strong version of the PH, empirical evidence is much weaker. Several authors have studied the impact of the EU ETS on productivity, and the results are mostly insignificant (Di Maria and Jaraité, 2011) or pointing to opposite directions depending on countries and periods. Here, we estimate the impact of the introduction of the EU ETS on firm-level productivity for three large euro-area economies: France, Italy and Spain, using a propensity score matching difference in difference (PSM-DID) method. We study the impact of both the existence of the EU ETS, through a dummy variable, and of its intensity, through interacting the dummy variable with the ETS price. We also study whether firms react differently depending on their initial efficiency, size, financial constraints, sector, and country. Finally, we investigate whether our results are robust across the different phases of the EU ETS implementation and whether their effects were anticipated.

Since (green) capital accumulation is expected to be endogenous to carbon pricing, we focus on total factor productivity (TFP) rather than labor productivity. Even though the carbon prices of the EU ETS were initially very low (in early 2007, during phase 1, permit prices fell below $1), it is a structural reform that is likely to change companies' investment plans in the long run. Indeed, the EU ETS discourages the production of emissions-intensive goods by putting a price on emissions, which in turn encourages both emissions abatement, and investments in technology that lowers abatement costs. Its economic effects are therefore potentially important, despite the fact that allowances were originally allocated free of charge and that supply far exceeded demand.

The results suggest that the EU ETS overall is not detrimental to firms' TFP, except for smaller firms. The EU ETS positively impacts TFP for large firms, especially in France. Firms which are less efficient or financially constrained seem to suffer from the introduction of the EU ETS, whereas TFP benefits from the scheme in unconstrained or frontier firms. One cannot exclude that smaller firms have exited the market following the introduction of the EU ETS, allowing larger firms to reap their market shares and benefit from economies of scale. Such interpretation is supported by our results showing a positive impact of the scheme on the revenue and value added of regulated firms.

[1] According to the evaluation of the EU ETS directive report (Fallmann *et al.*, 2015).
[2] The Fit-for-55 legislative package foresees a reinforcement of the existing ETS market and the creation of a second ETS to cover new sectors, such as building and road transportation (see Fit for 55 - The EU's plan for a green transition - Consilium (europa.eu)).

The overall benign effect of the EU ETS hides heterogenous impacts depending on the sectors. The introduction of the EU ETS has a positive impact on TFP in printing, furniture, metallurgy and food, but a negative one in the paper and wood industries. Finally, the impact of the scheme seems to vary over time, but not in relation to the carbon price. Indeed, TFP reacts negatively only in 2005, when the scheme was introduced.

Our results contribute to the growing literature trying to assess the impact of environmental policies on firm-level performance and ultimately on potential GDP growth. In showing that the EU ETS has a differentiated impact across firm size, initial efficiency, financial constraints and sectors, we suggest that accompanying policies could also be differentiated. Avoiding excessive market concentration could also be an issue.

The remainder of the paper is organized as follows. Section 2 presents the policy background of the EU ETS. Section 3 briefly surveys the related literature. Section 4 describes the dataset. The permanent impact of the EU ETS on TFP is presented in Section 5. We also investigate the different implementation phases of the EU ETS and develop a model with anticipation effect in Section 6. Section 7 concludes.

1. The EU ETS

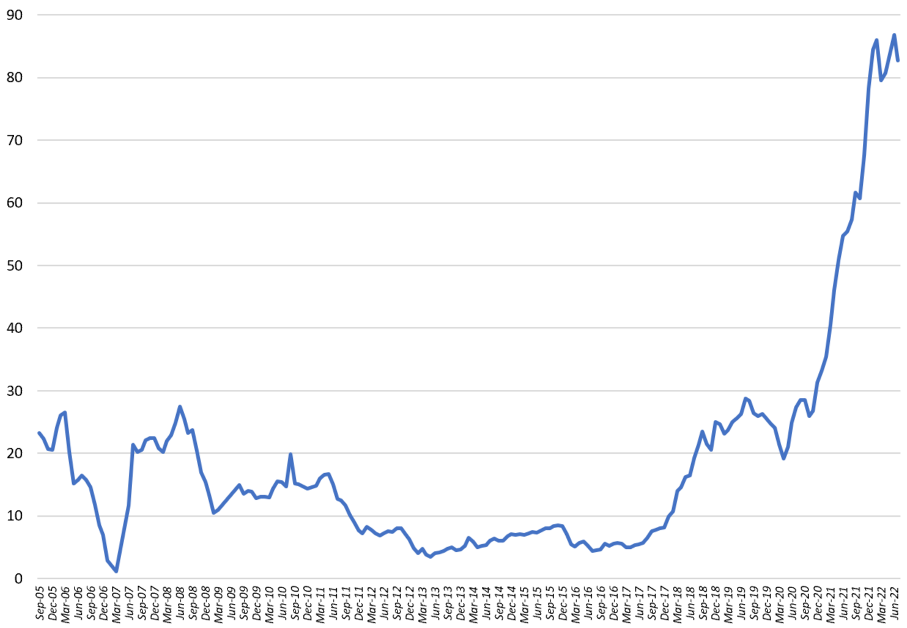
The EU ETS is a cornerstone of the EU's policy to combat climate change. Set up in 2005, it is the world's first major carbon market and it remains the biggest one to date. The first steps were made at the 1997 Kyoto Protocol, setting for the first time legally-binding emissions reduction targets for 37 industrialized countries. In 2000, the European Commission presented a green paper with a first design of the EU ETS. The Directive was adopted in 2003 and the system was launched in 2005. To date, it operates in all EU countries plus Iceland, Liechtenstein and Norway. It includes around 12,000 industrial installations and covers around 45% of Europe's GHG emissions. It is the key tool of the EU's policy for reaching its ambitious GHG reduction targets under the 2030 framework for climate and energy policies.

The EU ETS is a *cap and trade* system. First, the overall volume of GHG that can be emitted by power plants, industry factories and aviation sector covered by the EU ETS is limited by a *cap* on the number of emission allowances. Each allowance gives the holder the right to emit a certain amount of CO_2, or the equivalent amount of other powerful GHG: nitrous oxide (N_2O) and perfluorocarbons (PFCs). The cap decreases every year, ensuring that total emissions fall. Firms must cover their emissions by the allowances; otherwise, they face heavy fines for every ton of CO_2 emissions not covered. Second, the *trade* permits are sold by the firms that have an excess of them, compared to their level of emissions; they are bought by firms whose initial allocation falls short of their emissions. The price of permits adjusts to clear the market.

Four phases succeeded one another: 2005-07, 2008-12, 2013-20, and 2021-30. In each phase, the scope of activities that are subject to the EU ETS was broadened, and the total amount of allowances was reduced. In phase 1 (2005-07), the cap on allowances was set at national level, on the basis of estimates (given the absence of emissions data). The key objective was to cover only CO_2 emissions from power generators and energy-intensive industries. Almost all allowances were given to enterprises for free, and the penalty for non-compliance was 40 euros per ton. As a result, the total amount of allowances issued significantly exceeded emissions, and the price of allowances fell to zero in 2007. This phase of *learning by doing* succeeded in establishing the infrastructure needed to monitor emissions and the trading of the permits. Phase 2 (2008-12) coincided with the first commitment period of the Kyoto protocol, with concrete emissions reduction targets. The cap on allowances was decreased (6.5% lower compared to 2005), the N_2O emissions from the production of nitric acid were included by several countries, the proportion of free allocation fell to 90%, and the aviation sector was included in January 2012. Even though the cap on allowances was reduced, the 2008 global financial crisis led to emissions reductions that were greater than expected. This led once again to a large surplus of allowances, hence a falling price. Phase 3 (2013-20) has changed the system considerably. National caps were replaced by a single EU-wide cap on emissions, free allowances were replaced by auctioning, and new sectors were included. Under phase 4 (2021-30), it is planned to reduce the overall number of emission allowances at an annual rate of 2.2%, to include even more sectors, and to restrict free allowances to those sectors that are at the highest risk of relocating their production outside of the EU.

Figure 1 reports the evolution of the price of EU ETS allowances over 2005-22. Up to recent years, the EU ETS has suffered from a surplus of emission allowances. The ETS price started to pick up in 2019 and even more in 2021, reaching 83 €/tCO_2 in June 2022.

Figure 1: Price of EU ETS allowances 2005-22 (euro per ton of CO2)



Source: Investing.com and Tradingeconomics.com

The scope of an ETS refers to the sources of emissions and types of GHG covered by the system. It is a critical design element of an ETS (Partnership, 2021). A broader scope allows to encompass a greater portion of emissions, to lower the overall cost of emissions reductions, and to reduce compliance costs for entities. On the other hand, a broader scope can involve higher administrative costs. The choice of the scope needs to consider this trade-off. Directive 2003/87/EC defined the categories of activities to be initially covered by the EU ETS in phase 1. We report these categories in Table 1.

Table 1: Categories of activities covered by the EU ETS in phase 1 (2005-07)

Activities	Greenhouse gases
Energy activities	
Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations)	Carbon dioxide
Mineral oil refineries	Carbon dioxide
Coke ovens	Carbon dioxide
Production and processing of ferrous metals	
Metal ore (including sulphide ore) roasting or sintering installations	Carbon dioxide
Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2,5 tonnes per hour	Carbon dioxide
Mineral industry	
Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day	Carbon dioxide
Installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day	Carbon dioxide
Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day, and/or with a kiln capacity exceeding 4 m^3 and with a setting density per kiln exceeding 300 kg/m^3	Carbon dioxide
Other activities	
Industrial plants for the production of	Carbon dioxide
(a) pulp from timber or other fibrous materials	
(b) paper and board with a production capacity exceeding 20 tonnes per day	Carbon dioxide

Source: 2003/87/EC Directive.

2. Literature review

2.1 The Porter hypothesis

The impact of environmental regulation on macroeconomic variables such as GDP, productivity, innovation, employment, investment or trade, is far from clear. According to neoclassical economics, more stringent environmental policies inflate production costs. Such a negative link between environmental regulation and performance was first questioned by Porter (1991) and Porter and Van der Linde (1995). The *Porter hypothesis* (PH) states that well-designed environmental policies may encourage innovation and (thus) enhance productivity. In a dynamic perspective, the costs to comply with the regulation would incentivize firms to reorganize the process of production and thus to innovate. Such innovation efforts could lead to a reduction in pollution control costs, and to an increase in firms' productivity.

One problem with the PH is the implicit assumption that some systematic profit opportunities are ignored in the absence of regulation. Porter and Van der Linde (1995) explicitly assume that firms do not always make optimal choices. Hence, the PH can hardly be conceived without departing from the classic assumption of profit maximization. According to Palmer *et al.* (1995), this is one of the main weaknesses of the PH.

Initially, the PH was backed by anecdotal evidence, without a rigorous theoretical explanation of the underlying factors. Many of these were developed only subsequently. Palmer *et al.* (1995) make a distinction between (i) behavioral arguments, such as *strategic effects internal to the firm*, e.g. by assuming that managers are risk averse (Kennedy, 1994) or conservative (Aghion *et al.*, 1997); and (ii) *strategic effects of competition between firms*, e.g. spillover effects of R&D. Jacquemin and D'aspremont (1988) show that, in the presence of such spillover effects, firms will underinvest in R&D. Consequently, environmental regulation that encourages firms to invest more in R&D could improve the situation for all.

To better categorize empirical testing approaches, the PH has been differentiated into three versions (Jaffe and Palmer, 1997). The *weak PH* states that environmental regulation leads to an increase in "environmental innovation", i.e. more innovation directed at minimizing the costs of the environmental input/output subject to regulation. According to the *strong PH,* costs saved thanks to innovation and to improved production processes outweigh compliance costs, leading to increased productivity, profitability and competitiveness. Finally, the *narrow PH* claims that more flexible environmental policy instruments, such as an ETS, are more likely to increase innovation and to improve company performance than non-market instruments such as standards and bans. Market-based and flexible instruments, such as emission taxes or tradable allowances, are more favorable to innovation than standards since they leave more freedom to firms on the technological solution to minimize compliance costs.

2.2 Empirical results

Weak PH

As noted by Kozluck and Zipperer (2014), a major challenge for empirical tests of the PH is the measurement of the policy variable. Galeotti *et al.* (2015) proxy environmental policy stringency with pollution abatement and control expenditures. For manufacturing sectors of 17 European countries over 1997-2009, they find evidence of a positive impact of environmental regulation on the output of innovation activity, proxied by patents. Hence, they find evidence of the weak PH, although not of the strong one. Similarly, Van Leeuwen and Mohnen (2017) study green innovation in Netherlands following the methodology introduced by Crépon *et al.* (1998). They build an environmental regulation dummy thanks to the CIS survey for accounting the existence or anticipation of environmental regulation. They also find evidence of the weak PH. Furthermore, TFP can be increased when regulation boosts process-integrated eco-innovations, whereas pollution-reducing eco-innovations tend to reduce TFP.

Recently, more and more researchers have specifically focused on the impact of ETS on the performance of firms. The methodology is generally that of a propensity score matching to get close controls for the regulated firms and then a DID estimation. The effect of ETS on innovation is generally supported, confirming again the weak PH. Tang *et al.* (2020) study the impact of SO_2 ETS in China, and find a positive impact on innovation. Anderson *et al.* (2011) also find that manufacturing firms covered by the EU ETS have a greater probability of environmental innovation. Hence, in general the weak PH is supported by the data.

Strong PH

There is less empirical support for the strong PH. An interesting study focusing only on the effect of environmental regulation on TFP is the one of Albrizio *et al.* (2017). They use the environmental policy stringency (EPS) index for OECD countries at industry and firm level. They find that environmental policies lead to subsequent short-run increase in productivity growth for the most productive industries and firms; but conclude that the effect may come from process improvement as well as from offshoring. At the same time, less productive firms experience a fall in TFP.

The studies focusing on the impact of the EU ETS on several firm-level performance variables give multiple results. Regarding employment, the results of Dussaux (2020) for French manufacturing firms over 2001-16 shows that the energy cost increase by the EU ETS has no statistically significant effect on net employment on average: output and workers are reallocated from energy-intensive firms to energy-efficient firms. Dechezleprêtre *et al.* (2018) find that the EU ETS led to a statistically significant increase in revenue and in fixed assets of regulated firms from manufacturing and electricity sectors in France, Netherlands, Norway, and the UK over 2002-14. Di Maria and Jaraité (2011) conclude that the carbon price has no effect on the overall productivity of public power plants in 24 European countries over 1996-2007, but it affects technological change positively and efficiency negatively. They measure productivity with a data envelopment analysis, estimating a “best-practice” frontier given the available information, and placing each observation on or below the frontier. Finally, Colmer *et al.* (2020) conclude that the EU ETS had no negative effects on the scale of production for French manufacturing firms over 1996-2012. Instead, firms reduced the emissions intensity of value-added by making targeted investments. There is no evidence that firms outsourced production to unregulated firms or markets, which supports the argument that the EU ETS is not harming the economy.

Finally, some studies confirmed that the EU ETS has increased the productivity of regulated firms. For Germany, Löschel *et al.* (2019) find a positive impact on the productivity at the plant level, especially during phase 1 (2005-07). They measure productivity as the distance to the stochastic production frontier. Some studies also present more conclusive evidence of the EU ETS impact on productivity in phase 2 (2008-12): Klemesten *et al.* (2020) find positive effect on Norwegian firms' labor productivity in phase 2, so as Marin *et al.* (2018) who conclude that manufacturing firms in 19 European countries have reacted to the EU ETS by passing-through costs to their customers and improving labor productivity.

We contribute to the research by focusing on the heterogeneous effects of the EU ETS on TFP depending on firms’ characteristics, essentially size, distance to frontier, and financial constraints. Moreover, we show heterogeneous effects by sector and by country. Finally, we test whether companies may have anticipated the implementation of the EU ETS and subsequently been more successful in adapting to it.

3. Methodology and data

We study the impact of the introduction of the EU ETS, in 2005, on firm-level TFP through an event study approach. This choice is motivated by the fact that the introduction of the EU ETS may be considered a structural reform: even though the initial price was very low (see Figure 1), manufacturing firms are making decisions over a long horizon, so they had to incorporate the new scheme (and not just spot price) in their business plans and risk assessments. In a second step, we study the specific impact of the ETS price.

One major advantage of studying the introduction of the EU ETS is that it is an exogenous event, hence it allows to capture a causal relationship. However, the European Commission presented the first design of the EU ETS in 2000 and the Directive was adopted in 2003, so we cannot rule out an anticipation effect whereby firms would have already invested and reorganized their production in advance. Symmetrically, the impact of this reform may take time to materialize. If policies trigger higher R&D investment, it may take years to actually bring about measurable improvements in technology and processes. In the following, we will account for these anticipation as well as lagged effects.

The firm-level data used are extracted from the Amadeus-Orbis database (through Bureau van Dijk). The panel consists of manufacturing firms in France, Italy and Spain from 2000 to 2017. The selection of these countries is done with respect to their high rates of coverage when compared to European business registers (Kalemli-Özcan *et al.*, 2015).

3.1 Measurement of TFP

Firm-level TFP is recovered from an estimated firm-level production function, using the standard estimation of Levinshon and Petrin (2003), building on Olley and Pakes (1996). Because shocks on productivity and on firm-level choices about production factors are likely to be correlated, the OLS estimation of firm-level production function introduces a simultaneity or endogeneity bias. Hence, the methodology consists in using intermediate inputs[3] as a proxy for unobserved productivity shocks. Assuming a Cobb-Douglas production function, we run the following regression:

$$y_{it} = \beta_0 + \beta_k k_{it} + \beta_l l_{it} + s_t(k_{it}, m_{it}) + u_{it} \quad (1)$$

where y_{it} is firm *i*'s value added in period *t*, $k_{it}$is capital, $l_{it}$is labor, m_{it} represents intermediate inputs and $s_t(k_{it}, m_{it})$ proxies ω_{it}, the unobserved productivity shock. More specifically, $s_t(k_{it}, m_{it})$ represents $m_t^{-1}(k_{it}, \omega_{it})$, the inverted demand function for intermediate inputs with respect to the productivity shock ω_{it}. Labor is assumed to be freely and costlessly adjustable, whereas capital is assumed to be determined by past capital and the firm's decision to invest in period *t*-1. These variables are related to the information contained in Amadeus data, using the book value of total assets for k_{it}, the number of employees for l_{it} and materials for m_{it}. Value-added y_{it} is proxied by sales less the cost of materials.

Ideally, firm-level value-added should be deflated by firm-level production prices. Since firm-level prices are not available in the database, we follow the literature (Foster *et al.*, 2018) in controlling for sector-level prices through sector-time fixed effects. This amounts to incorporating firm-specific markups in the measure of TFP which must then be interpreted as revenue-based TFP, as discussed in Syverson (2011). If *treated* firms are able to pass their costs on to customers, this will show up in the fixed effect (if all firms of the sector are *treated*) or in firm-specific TFP (if only some firms are *treated* in a given sector).

Using the methodology of Kalemli-Özcan *et al.* (2015), all observations for a firm are dropped if total assets, sales, tangible fixed assets or employment are negative in any year. The same is done if employment exceeds 2,000,000 or if total assets, revenue or sales are missing. The most missing information is for employment. Employment data is imputed when there are less than four consecutive missing years, otherwise, observations are dropped (Altomonte *et al.*, 2018). Missing employment data is imputed from the predicted values of a regression of the number of employees at the firm level on labor cost, sales and year dummies - separate for each country and industry. Negative predictions or values above the 99.5th quantile of predicted values are excluded.

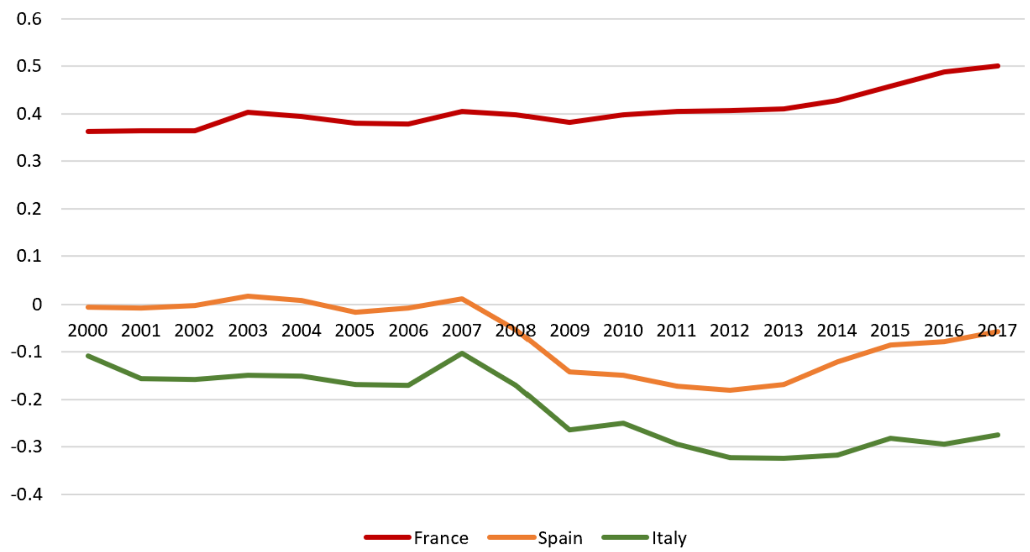
[3] Intermediate inputs are used, instead of investment, as originally proposed by Olley and Pakes (1996) because the former allows to include observations with zero investment but positive intermediate input use.

After the estimation of the production function, firm-level TFP $\widehat{\omega_{it}}$ is recovered as follows:

$$\widehat{\omega_{it}} = y_{it} - \widehat{\beta_l} l_{it} - \widehat{\beta_k} k_{it} \quad (2)$$

The final sample has on average around 90,000 firms per year in Italy, 70,000 in Spain, and 60,000 in France, over 2000-17. These number are not constant over time, due to new entries and exits from the Amadeus-Orbis database. Figure 2 shows the unweighted average of TFP for each country. We regress the log of firm-level TFP on sector fixed effects and on country-time fixed effects, and we plot the latter. On average, TFP is higher and increasing in France whereas it is rather flat in Spain and Italy, and even declining after the 2008 global financial crisis.

Figure 2: Evolution of TFP in each of the three countries



Source: Authors' calculation based on Amadeus-Orbis database.

Note: The graph shows α_{ct} estimated from the regression: $\text{TFP}_{isct} = \alpha_{ct} + \beta_s + u_{isct}$ where TFP_{isct} is the logarithm of TFP of firm i, in sector s, country c, and year t.

The analysis is run on existing firms, with a variable coverage across countries and years, characteristic of the Amadeus-Orbis database. Furthermore, Bajgar *et al.* (2020) show that firms in Orbis are disproportionately large, old, high-wage, and most importantly, they are disproportionately productive, even conditional on their size. Therefore, the results may incorporate composition effects that are impossible to identify. This feature means that the results should be interpreted qualitatively rather than quantitatively.

Regulated firms

In order to estimate the effects of the implementation of the EU ETS on productivity, we identify firms that are subject to this treatment, based on the Union Registry[4]. All EU ETS operations were centralized into this registry in 2012. This database has information on stationary installations (transferred from the national registries used before 2012) and for aircraft operators (included since January 2012).

[4] We use the "List of operators in the EU ETS", updated on 04/2022: Union Registry (europa.eu).

We are able to identify 508 manufacturing firms in our Amadeus-Orbis database that where regulated by the EU ETS in France, Italy and Spain at the time of its implementation in 2005. This represents 7,796 observations from 2000 to 2017. Matching the two databases by company name, we select first the matches with a correspondence greater than 70%. Then, we check line by line for any error. The Amadeus-Orbis database contains information on firms, but not individual installations. Thus, if the installation of a particular firm is affected, we study the impact of the EU ETS on the entire firm. In the heterogeneity analysis section, we separate firms by size in order to identify likely single-establishment firms.

Six manufacturing sectors account for 75% of regulated companies: 25% of the *treated* firms are from food industry, 17% from paper and cardboard, 13% from other non-metallic mineral product, 8% from chemicals, 7% from metallurgy and 5% from metal product. The high number of *treated* firms from food industry results from this sector being very well covered in the Amadeus-Orbis database (13% of the firms covered by Amadeus-Orbis). Firms in the food sector have energy intensive activities, i.e. combustion installations with a rated thermal input exceeding 20 MW, and combustion of fuels. This high proportion of *treated* firms from the food industry is confirmed in other studies, such as the one of Marin *et al.* (2018).

Surprisingly, the *treated* firms are mostly from France (56%) and Italy (40%). As shown in Table 2 from the OECD's STAN database, the share of the six *treated* sectors is similar in Spain as in the two other countries. In fact, although Spanish firms are only a minority in our database, their distribution across the six *treated* sectors is similar as for France and Italy. Line (i) shows the share of value added from OECD's STAN database, and line (ii) shows the percentage of presence of the sectors in the Amadeus-Orbis database for each country.

Table 2: Value added share in total economy, 2005, current prices and Amadeus-Orbis share, in %

Industries	France	Italy	Spain
Food			
(i) OECD VA share	2.1	1.5	1.8
(ii) Amadeus share	21.6	8.0	12.4
Paper and cardboard			
(i)	0.3	0.4	0.4
(ii)	1.5	1.8	1.6
Other non-metallic product			
(i)	0.5	1.1	1.2
(ii)	4.3	5.8	6.5
Chemicals			
(i)	0.9	0.7	0.9
(ii)	2.5	2.8	3.4
Metallurgy			
(i)	0.4	0.7	0.7
(ii)	1.0	1.7	2.0
Metal product			
(i)	1.2	2.0	1.6
(ii)	16.8	20.2	19.9

Source: OECD's STAN and Amadeus-Orbis databases.

We next analyze the inherent characteristics of *treated* firms. We observe systematic differences as they are larger with respect to all the firm-level variables that will be used in the analysis: the number of employees, the level of sales, of total assets, *etc*. An interesting point is also that *treated* firms are more indebted. We report the summary statistics in Table 3. Clearly, *treated* firms cannot directly be compared to non-treated ones. Hence we rely on a propensity score matching.

3.2 Matching

We want to compare firms that are similar prior to the EU ETS implementation to avoid selection bias. The propensity score matching (PSM) – difference in difference (DID) method allows to reduce systematic differences in enterprise TFP trends between *treated* and *control* firms, and to reduce the inherent bias of DID method estimation. The propensity score is the conditional probability of assignment to a particular treatment given observed covariates.

We estimate the propensity score using multiple matching variables: $Asset_{isct}$ is the log of total asset of firm *i* in sector *s*, country *c,* at time *t*; $mean_{2000-04}(TFP)_{isc}$ is the average of log-TFP for years 2000-04; and the 2-digit NACE sector of the firm. The pre-treatment TFP variable allows us to have a control group of firms with comparable level of TFP before treatment. Matching on sector implies that we control for sector specific shocks that may have occurred after the introduction of the EU ETS. This set of matching variables is chosen to produce a comparison firm that has similar characteristics to a treatment firm while maximizing the number of successful matches. The dependent variable is $id_{isc} = 1$ for *treated* firms.

We perform a Logit regression to estimate the propensity score. The choice of Logit instead of Probit is made because the literature is not clear as how to accommodate sample weights in the context of matching. The recommendation to date is to ignore sampling weights and to estimate the propensity score using a Logit model (Leuven and Sianesi, 2003). We match with replacement to allow for a larger sample size[5].

Table 3 reports the summary statistics for the regulated and unregulated firms, before and after the PSM. In Figure 3, we draw the density plots of basic variables between regulated and unregulated firms, before and after PSM. Finally, Figure 4 shows the trend of firm TFP for the three groups: the *treated*, *control* and *unmatched* firms.

[5] In contrast, when matching without replacement, a given control firm is used as a match in a given year for one particular *treated* firm, and cannot be used for any other observation. This may introduce a bias in the asymptotic distribution of the post-matching regression estimator. Moreover, in our analysis, it is essential to observe the evolution of economic performance of firms over time, justifying the match with replacement. Beyond a one-to-one matching, this allows us to keep a large number of control observations.

Table 3: Summary statistics for regulated and unregulated firms

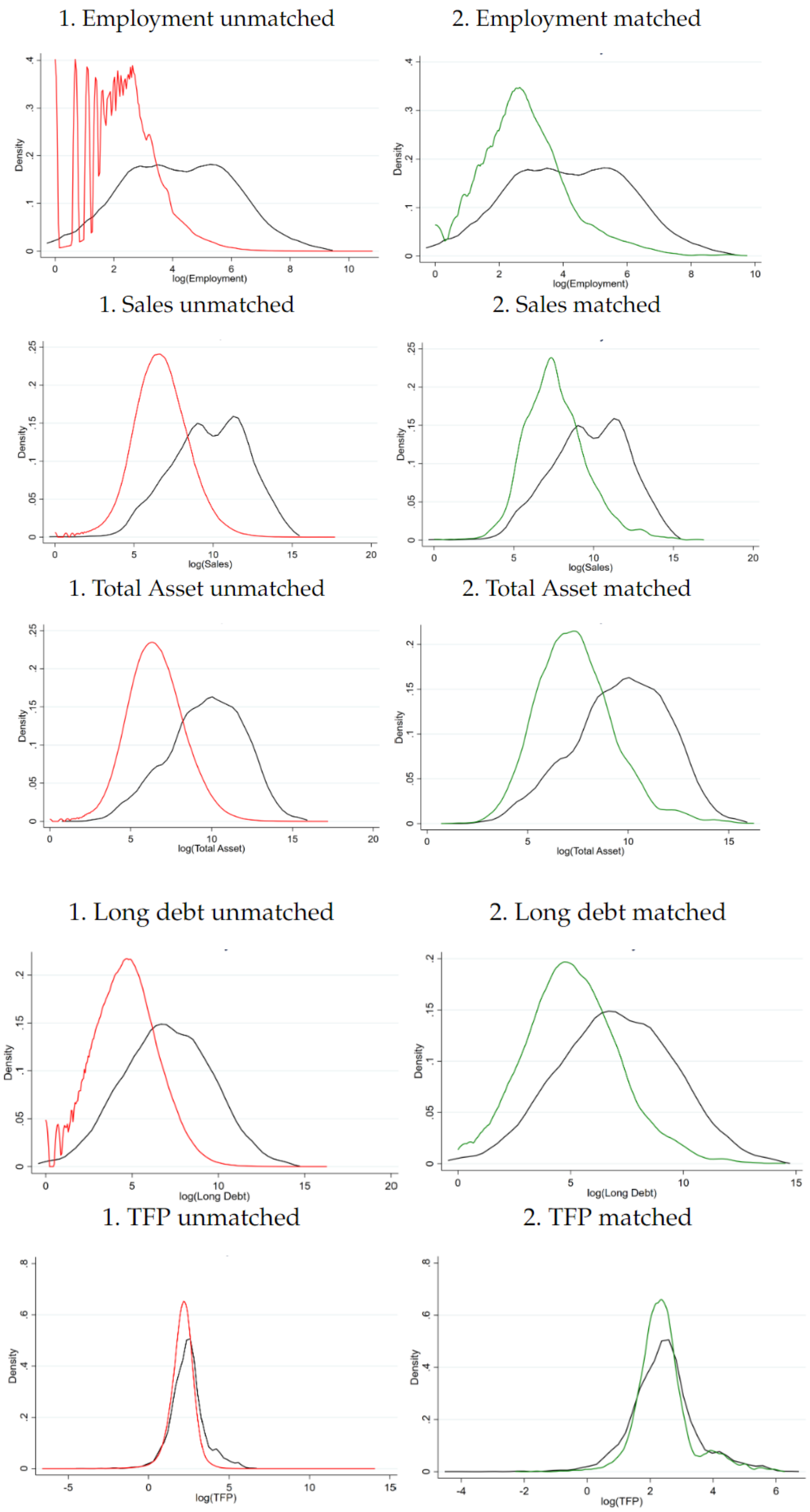
	(1) Pre-Match Unregulated	(2) Pre-Match Regulated	(3) Post-Match Unregulated	(4) Pre-Match Difference (Full Sample)	(5) Post-Match Difference (Matched Sample)
Log(Employment)	2.26	4.17	2.77	1.90***	1.40***
Std. dev.	(1.20)	(1.88)	(1.40)	(0.01)	(0.02)
Min	0	0	0		
Max	10.8	9.16	9.75		
Obs	3,758,887	7,518	12,759	3,766,405	20,277
Log(Sales)	6.69	9.77	7.63	3.07***	2.13***
Std. dev.	(1.76)	(2.38)	(1.97)	(0.02)	(0.03)
Min	0	0	0		
Max	17.71	15.11	16.92		
Obs	3,955,984	7,752	12,971	3,963,736	20,723
Log(Total Asset)	6.55	9.63	7.39	3.08***	2.24***
Std. dev.	(1.75)	(2.34)	(1.95)	(0.02)	(0.03)
Min	0	1.09	0.69		
Max	17.19	15.57	16.25		
Obs	4,026,335	7,796	13,012	4,034,131	20,808
Log(Long debt)	4.60	7.02	5.06	2.42***	1.96***
Std. dev.	(1.88)	(2.55)	(2.14)	(0.03)	(0.05)
Min	0	0	0		
Max	16.28	14.29	14.52		
Obs	1,853,566	3,918	6,220	1,857,484	10,138
Log(TFP)	2.09	2.43	2.41	0.34***	0.01
Std. dev.	(0.73)	(1.04)	(0.87)	(0.01)	(0.01)
Min	−6.61	−4.40	−2.28		
Max	14.08	6.59	6.28		
Obs	2,763,876	6,352	10,481	2,770,228	16,833
Sector				−2.93***	0.05
Std. dev.				(0.08)	(0.09)

Source: Amadeus-Orbis and Union Registry databases.

Note: Columns 1, 2 and 3 report the mean, standard deviation, minimum and maximum for each variable, with the number of available observations, respectively for pre-match unregulated firms, regulated firms, and post-match unregulated (*control*) firms over the years 2000-17. Reported coefficients in columns 4 and 5 measure the average difference in outcome variables between regulated and unregulated firms in the pre- and post-match samples. The baseline differences are much smaller after the PSM. Especially, there is no significant difference for the log-TFP variable, and the matching based on sector is well realized. ***p<0.01,**p<0.05,*p<0.1.

Some differences persist between the treated and control groups (e.g., the sales variable). However, since the matching is done within each sector (using the NACE-2-digit covariate) and since it takes into account the size of the firms (total assets variable), we are able to compare firms with the same characteristics. We present in Appendix A, Table A1, the number of observations of *treated* and *control* firms, by sector. This Table ensures that we have a sufficient number of control firms per sector.

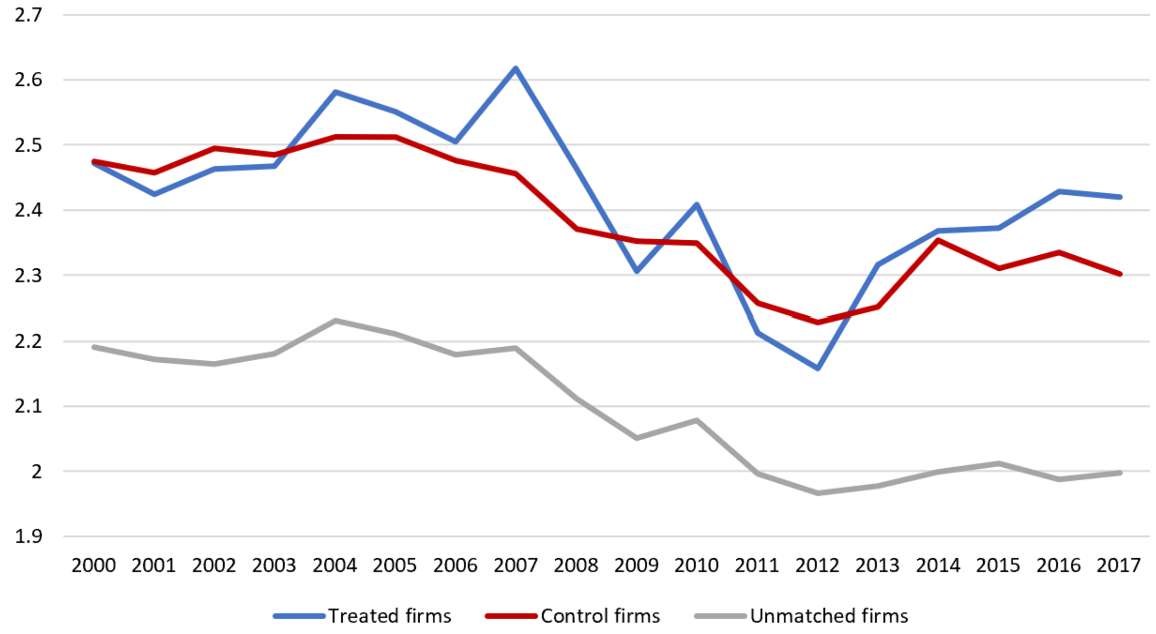
Figure 3: Density plots showing differences between regulated and unregulated firms in the pre- and post-match samples



Source: Amadeus-Orbis and Union Registry databases.

Note: The figures report the density plots of log-employment, log-sales, log-total asset, log-long debt and log-TFP over the year 2000-17. In all figures the black lines represent regulated firms. In the unmatched sample the distribution of each variable for unregulated firms is represented in red, while it is marked in green for the matched sample.

Figure 4: Evolution of TFP for regulated, control and unmatched firms



Source: Amadeus-Orbis and Union Registry databases.

Note: The figure reports the mean of log-TFP for *treated, control* and *unmatched* firms over the year 2000-17. The y-axis indicates the log of TFP. For example, in 2007, regulated firms have, on average, an estimated log of TFP of 2.62.

In Figure 4, we observe that, on average, TFP is higher in treatment and control groups than for unmatched firms. This is a mechanical consequence of the matching. All groups experienced a strong decrease of TFP after the 2008 global financial crisis. The decline continues until 2012, the end of the European sovereign debt crisis, before gradually recovering. Interestingly, regulated firms seem to have suffered more from the 2008 crisis than their matched controls.

3.3 Control variables and preliminary estimation

Firm-level controls are taken from the Amadeus-Orbis database. We follow Kalemli-Özcan *et al.* (2015) in controlling for sales. Contemporaneous sales are introduced in logs to filter log-TFP for the firm-specific pro-cyclicality of TFP, since capital and labor cannot be perfectly adjusted in the short run. We control for the contemporaneous number of employees in log, and the long-term debt of the firms in log. Finally, we add the log of tangible fixed asset, as a measure of firm collateral. As seen in Section 3.1, the Porter outcome seems to only occur when the externality associated with pollution is combined with another distortion, such as market imperfection: asymmetric information, market power, technological spillovers, *etc* (Ambec and Barla, 2006). Thus, we will examine whether the impact of the EU ETS is differentiated according to a measure of market imperfection.

Before studying the impact of the EU ETS on productivity, we run the following, preliminary estimation:

$$TFP_{isct} = \beta_0 + \beta_1 Sales_{isct} + \beta_2 Debt_{isct} + \beta_3 TFASS_{isct} + \beta_4 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (3)$$

where TFP_{isct} is the log-TFP, $Sales_{isct}$ is the logarithm of the sales, $Debt_{isct}$ is the logarithm of the long-term debt, $TFASS_{isct}$ is the logarithm of the tangible fixed asset, and Emp_{isct} is the logarithm of the number of employees. FE_i and FE_{st} are firm and sector-time fixed effects,[6] and the error terms are clustered at the sector level.[7] There is no country fixed effect, since these are included in the firm fixed effects. Tests were conducted to confirm the robustness of our choice of fixed effects. The results are reported in Table 4. In

[6] We use the same set of fixed effects as in Kalemli-Özcan *et al.* (2018).
[7] We cluster at sector level because the treatment is unlikely to be randomly assigned across sectors.

specification (1) we have all the described firm-level control variables. In (2) we drop $Debt_{isct}$ which allows us to retain more observations since data on the debt is often missing. In (3) we drop $TFASS_{isct}$ to test for the possible collinearity between long-term debt and tangible fixed assets. In (4), we drop $Debt_{isct}$ but we regress on the sample of (1), in order to check that there is no sample bias when $Debt_{isct}$ is present.

Table 4: Preliminary estimation. The impact of firm-level variables on TFP

	(1)	(2)	(3)	(4)
Sales	0.74*** (0.01)	0.72*** (0.01)	0.72*** (0.01)	0.74*** (0.01)
Long Debt	−0.03*** (0.00)		−0.04*** (0.00)	
Tangible-F-Asset	−0.06*** (0.00)	−0.07*** (0.00)		−0.07*** (0.00)
Employees	−0.48*** (0.01)	−0.47*** (0.01)	−0.49*** (0.01)	−0.48*** (0.01)
Constant	−1.63*** (0.07)	−1.61*** (0.06)	−1.68** (0.07)	−1.68*** (0.07)
Sector-Year FE	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes
R2	0.91	0.89	0.90	0.91
N	1102308	2228300	1305838	1102308
No. of clusters	24.00	24.00	24.00	24.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

As expected, TFP is pro-cyclical: when firm-level sales increase relative to the sector-time corresponding grouping, TFP increases due to economies of scale, higher capacity utilization or a higher markup. The elasticity of TFP with respect to sales is estimated here to be 0.74 in Column (1) for example. More long-term debt seems to have a significant negative impact on TFP. As highlighted by Kalemli-Özcan *et al.* (2018), highly indebted firms tend to prioritize servicing their debt rather than investing in capacity and productivity. Similarly, more collateral, proxied by tangible fixed asset, seems to have a negative impact on TFP, in line with the literature on capital misallocation (see, e.g. Reis (2013) and Kalemli-Özcan *et al.* (2017)): new funding flows to firms with higher net worth or higher collateral, which are not necessarily more productive. Finally, in the short run, while holding capital fixed, an increase in the number of employees reduces TFP, as expected.

The impact of all variables appears very stable across the different specifications. In the following, we use specifications (1) and (2). Specification (1) is the most complete in terms of variables as it includes long-term debt. Specification (2) has fewer variables but more observations. We drop (3) as it was only used to check for a possible collinearity between debt and tangible assets. We also drop (4) as it was used to check that we have no sampling issue.

4. The permanent impact of the EU ETS on TFP

4.1 Main estimations

The impact of the EU ETS on firms' TFP is analyzed using a DID model between *treated* and *control* firms, before and after 2005:

$$TFP_{isct} = \beta_0 + \beta_1\, Post_t * id_{isc} + \beta_2 Sales_{isct} + \beta_3 Debt_{isct} + \beta_4 TFASS_{isct} + \beta_5 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (4)$$

where $id_{isc} = 1$ for the *treated* firms and $Post_t = 1$ for years 2005 and after. The coefficient estimate $\widehat{\beta_1}$ represents the permanent impact of the EU ETS on *treated* firms' TFP. The results are reported in Table 5. The number of observations is much reduced compared to the preliminary estimation because we are now working on the matched sample of firms. All control variables have the same sign and significance levels as in the preliminary estimation. The first line of the table reports the non-significant effect of the EU ETS on *treated* firms' TFP: the introduction of the EU ETS in 2005 is neither a drag nor a boost (PH) on TFP.

Table 5: Baseline. The permanent impact of the EU ETS on TFP

	(1)	(2)
ETS permanent effect	0.07 (0.06)	0.04 (0.02)
Sales	0.69*** (0.03)	0.68*** (0.02)
Long Debt	−0.02*** (0.00)	
Tangible-F-Asset	−0.06*** (0.01)	−0.07*** (0.01)
Employees	−0.50*** (0.02)	−0.45*** (0.02)
Constant	−1.33*** (0.16)	−1.45*** (0.15)
Sector-Year FE	yes	yes
Firm FE	yes	yes
R2	0.95	0.94
N	6172	12716
No. of clusters	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Carbon price

We now modulate the stringency of the EU ETS by accounting for the ETS price, as some studies find a different impact of the EU ETS conditional on the carbon price:

$$TFP_{isct} = \beta_0 + \beta_1\, Post_t * id_{isc} + \beta_2\, Price_t * \ id_{isc} + \beta_3 Sales_{isct} + \beta_4 Debt_{isct} + \beta_5 TFASS_{isct} + \beta_6 Emp_{isct}$$

$$+FE_i + FE_{st} + u_{isct} \qquad (5)$$

where $Price_t$ is the log of carbon price established on the EU ETS market since 2005, hence $Price_t = 0$ for $t \in \{2000; 2004\}$. Table 6 reports the results.

Table 6: Baseline. The permanent impact of the EU ETS on TFP, controlling for carbon price

	(1)	(2)
ETS permanent effect	0.10* (0.05)	0.05** (0.02)
ETS * Carbon price	−0.01 (0.01)	−0.01 (0.01)
Sales	0.69*** (0.03)	0.68*** (0.02)
Long Debt	−0.02*** (0.00)	
Tangible-F-Asset	−0.07*** (0.01)	−0.07*** (0.01)
Employees	−0.50*** (0.02)	−0.45*** (0.02)
Constant	−1.33*** (0.16)	−1.45*** (0.15)
Sector-Year FE	yes	yes
Firm FE	yes	yes
R2	0.95	0.94
N	6172	12716
No. of clusters	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

The interaction of the EU ETS treatment dummy with the carbon price is negative but not significant. However, the impact of the EU ETS treatment dummy itself becomes positive and significant, which tends to validate the strong PH, although with limited significance. The estimated coefficient in Column (2) for the EU ETS effect on productivity is 0.05 at a 5% significance level, meaning that regulated firms had an increase of 5% of TFP with the introduction of the regulation.

Heterogeneity with firms' distance to the technology frontier and size

Albrizio *et al.* (2017) find a positive impact of the stringency of environmental regulation for firms that are close to the technology frontier, but negative for those that are further away. We replicate their results, using the EU ETS implementation dummy variable, through generalized method of moments (GMM) that controls for the Nickell (1981) bias in an auto-regressive panel specification.

Here we interact the ETS regulation with each firm's distance to the technology frontier:

$$TFP_{isct} = \beta_0 + \beta_1 Post_t * id_{isc} + \beta_2 Post_t * id_{isc} * gap_{isc,t-1} + \beta_3 gap_{isc,t-1} + \beta_4 Sales_{isct} + \beta_5 TFASS_{isct} + \beta_6 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (6)$$

where $gap_{isc,t-1} = \ln(\frac{\overline{TFP}_{s,t-1}}{TFP_{isc,t-1}})$ is the distance of firm *i* to the industry-frontier *s*, in year *t*-1.

The frontier $\overline{TFP}_{s,t-1}$ is defined as the average TFP of the top 5% firms for each industry, by year. For this calculation, we use all observations available, including the *unmatched* firms, but the estimation is run only on treatment and control groups. To circumvent the Nickell bias (Nickell, 1981), we use a system GMM. We choose a system GMM instead of a difference GMM as we have large panel units (firms) and our time span is moderately small. In order to maximize the sample size in panels with gap, we use orthogonal deviations transformations, as suggested by Roodman (2009). We carry out a one-step GMM estimation to alleviate concerns about finite sample problems associated with two-step GMM estimation (Doran and Schmidt, 2006). Finally, we collapse the instrument matrix. As each instrument generates one column for each time period and lag available for that time period, the size of the matrix can become quickly huge, which can be an issue. Table 7 reports the results.

Table 7: The permanent impact of the EU ETS on TFP, depending on distance to the technology frontier

	(1)	(2)
ETS permanent effect	0.90*** (0.23)	0.35* (0.21)
ETS * Frontier Gap	−1.07*** (0.22)	−0.56*** (0.20)
Frontier Gap	0.17 (0.19)	0.12 (0.15)
Sales	0.44*** (0.03)	0.43*** (0.03)
Tangible-F-Asset	−0.11*** (0.02)	−0.09*** (0.02)
Employees	−0.27*** (0.03)	−0.27*** (0.03)
Constant	0.17 (0.33)	0.47* (0.26)
IV	Gap(t-1)	Gap(t-2)
Firm FE	yes	yes
Year FE	yes	yes
Underlying Obs	8802	7520
Nb of instruments	32.00	31.00
AR tes t-2	0.12	0.18
Hansen p-value	0.05	0.86

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Our preferred specification is Column (2) that uses $gap_{isc,t-2}$ and its lags as instruments. Lagging the technology gap by 2 years is more robust to biases. Moreover, this specification is more robust with a p-value of the AR(2) test at 0.18 and a p-value for the Hansen test at 0.86. Our result is similar to the one of Albrizio *et al.* (2017). Adding a frontier gap enables to get significant positive estimate for $\widehat{\beta_1}$. The interaction between the EU ETS effect and the frontier gap is always significant and negative, reflecting that the most efficient firms benefit from the policy, while the least efficient ones suffer from the regulation. This is interesting since *treated* firms are often part of the "leader group". On the year 2005, we count 98 *treated* firms in the leader TFP group across industries. Knowing that we have identified 412 *treated* firms in 2005, the ratio of leaders among treatment group is 24%. We can conclude that the EU ETS is beneficial to efficient firms, and that regulated firms are often the most efficient.

As GMM estimations are sometimes unstable depending on the instrumentation, we alternatively carry out regressions separately for the different quintiles of firm size, knowing that size is correlated with productivity. In each sector, a firm is assigned a quintile (1 to 5) based on its size proxied by the mean number of employees over all years (to avoid changes in quintile from one year to the next, and not to disturb the interpretation of the estimates in the within dimension). The quintiles boundaries are defined based on treated and control firms only, which are larger than unmatched firms. The results are reported in Table 8.

Table 8: The permanent impact of the EU ETS on TFP by firm size

	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)
ETS permanent effect	−0.26** (0.10)	−0.11 (0.15)	0.22** (0.10)	0.21* (0.12)	0.20** (0.08)
Sales	0.70*** (0.06)	0.78*** (0.05)	0.68*** (0.08)	0.76*** (0.03)	0.62*** (0.04)
Long Debt	−0.05*** (0.02)	−0.02* (0.01)	−0.03*** (0.01)	−0.02 (0.01)	−0.02** (0.01)
Tangible-F-Asset	−0.03 (0.02)	−0.10*** (0.03)	−0.08*** (0.02)	−0.07 (0.05)	−0.07* (0.04)
Employees	−0.53*** (0.05)	−0.55*** (0.07)	−0.52*** (0.06)	−0.50*** (0.04)	−0.51*** (0.02)
Constant	−1.07*** (0.32)	−1.71*** (0.41)	−1.24** (0.52)	−2.06*** (0.33)	−0.52 (0.44)
Sector-Year FE	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes
R2	0.89	0.94	0.91	0.95	0.98
N	961	1089	1139	1317	1241
No. of clusters	16.00	17.00	17.00	17.00	17.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

The EU ETS has a strong negative impact on TFP of smaller *treated* firms, which are more likely to be single-establishment firms, whereas the impact is positive for Q3 to Q5. Other things being equal, the treatment reduces TFP by 26% for the first quintile of *treated* firms relative to the first quintile of *control* firms, whereas it increases TFP by 20% for the last quintile of treated firms. We cannot exclude a selection effect, with only large, productive firms being able to overcome the fixed costs related to the introduction of the EU ETS. Unfortunately, our data do not allow us to test this hypothesis. Absent a careful analysis of composition effects, these results should be interpreted qualitatively only. Furthermore, we have no information on the intensity of carbon emissions. It is possible that those treated firms that are in the first quintile are more intensive polluters (otherwise they would not be treated).

Financial frictions

The PH involves systematic profit opportunities being ignored in the absence of regulation. In short, there must be a market imperfection, which is fixed by the regulation. To test for such market imperfection, we can interact the EU ETS dummy with interest payments made by the firm: if there are financial constraints, then a non-treated firm with high interest payments will not be able to set its investment at optimal level, whereas a *treated* one will reorganize its production and enjoy higher TFP. We thus run the following regression:

$$TFP_{isct} = \beta_0 + \beta_1\, Post_t * id_{isc} + \beta_2\, Post_t *\, id_{isc} * IPAID_{isct} + \beta_3 IPAID_{isct} + \beta_4 Sales_{isct} + \beta_5 Debt_{isct} + \beta_6 TFASS_{isct} + \beta_7 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (7)$$

where $IPAID_{isct}$ is the log of interest payments. The results are reported in Table 9. Given the collinearity between long-term debt and interest payments, we concentrate on Column (2) where long-term debt is dropped. The impact of the EU ETS on the TFP of treated firms is found positive and significant, whereas the interaction with interest payments is negative and significant. This suggests that firms with high interest payments are less capable to adapt to the EU ETS regulation, consistent with the market friction hypothesis. For treated firms in the first quartile of interest payments, the net impact of the EU ETS is positive at 0.0596.

For firms at the median of interest payments, the impact is reduced but still positive at 0.0298. The impact of the EU ETS turns negative in the third quartile, at -0.0048[8]. Hence, the PH tends to be validated for unconstrained firms whereas the EU ETS weighs on the TFP of constrained firms. This results goes against the interpretation of the PH in terms of financial market failure.

Table 9: The permanent impact of the EU ETS on TFP depending on interest payments

	(1)	(2)
ETS permanent effect	0.15 (0.10)	0.13** (0.05)
ETS * IPAID	−0.01 (0.01)	−0.02*** (0.01)
IPAID	0.00 (0.00)	0.00 (0.00)
Sales	0.69*** (0.02)	0.69*** (0.02)
Long Debt	−0.02*** (0.00)	
Tangible-F-Asset	−0.07*** (0.01)	−0.07*** (0.01)
Employees	−0.50*** (0.02)	−0.46*** (0.02)
Constant	−1.38*** (0.17)	−1.60*** (0.15)
Sector-Year FE	yes	yes
Firm FE	yes	yes
R2	0.95	0.94
N	5707	11185
No. of clusters	22.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Alternatively, we can interact the EU ETS effect with the amount of short-term debt, which involves a rollover requirement. Short-term debt is unfortunately not widely available, which reduces the sample size. The results are reported in Appendix B, Table B1, with similar conclusions.

4.2 Other performance variables

We have found a positive impact of the EU ETS for larger firms, and a negative impact for smaller ones. In order to investigate the underlying mechanisms, we now estimate the impact of the EU ETS on various measures of firm size: log-fixed asset (FASS), log-total asset (TASS), log-turnover (REV), log-value added (VA) and log-employment (EMP). We lag all control variables and report the results in Table 10.

[8] The log of interest payments is 3.52, 5.01 and 6.74, respectively, for Q1, the median, and Q3.

Table 10: The permanent impact of the EU ETS on firm size

	(FASS)	(TASS)	(REV)	(VA)	(EMP)
ETS permanent effect	−0.06 (0.06)	−0.06* (0.03)	0.14*** (0.04)	0.10** (0.04)	−0.01 (0.04)
Sales (t-1)	0.31*** (0.03)	0.33*** (0.03)			0.35*** (0.03)
Tangible-F-Asset (t-1)			0.14*** (0.01)	0.15*** (0.02)	0.06*** (0.01)
Employees (t-1)	0.10*** (0.02)	0.07*** (0.01)	0.29*** (0.03)	0.30*** (0.02)	
Constant	3.93*** (0.24)	5.29*** (0.19)	6.57*** (0.11)	5.85*** (0.09)	−0.10 (0.25)
Sector-Year FE	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes
R2	0.96	0.98	0.97	0.97	0.96
N	17956	18101	13804	13637	13761
No. of clusters	23.00	23.00	23.00	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Interestingly, the effect of the EU ETS on total asset is negative and significant at 10%, meaning that regulated firms have lost 6% of total asset compared to their control firms after the introduction of the EU ETS. Regulated firms could have divested their least efficient and most polluting facilities. However, turnover and value added of regulated companies are both positively impacted by the EU ETS, of the order of +14% and +10% respectively. This may suggest surviving firms benefiting from a shift in demand if some smaller firms are forced to exit the market. Alternatively, regulated firms may be able to pass their higher marginal costs to their customers, inflating their revenues. This latter interpretation is supported by the European Commission (2015).

Hence, although the EU ETS does not seem to have had any significant effect on regulated companies' TFP as a whole, we do find a positive (resp. negative) effect for large (resp. small) firms, possibly due to pass-through or extensive margin effects. We also find a positive (resp. negative) effect for unconstrained (resp. constrained) firms.

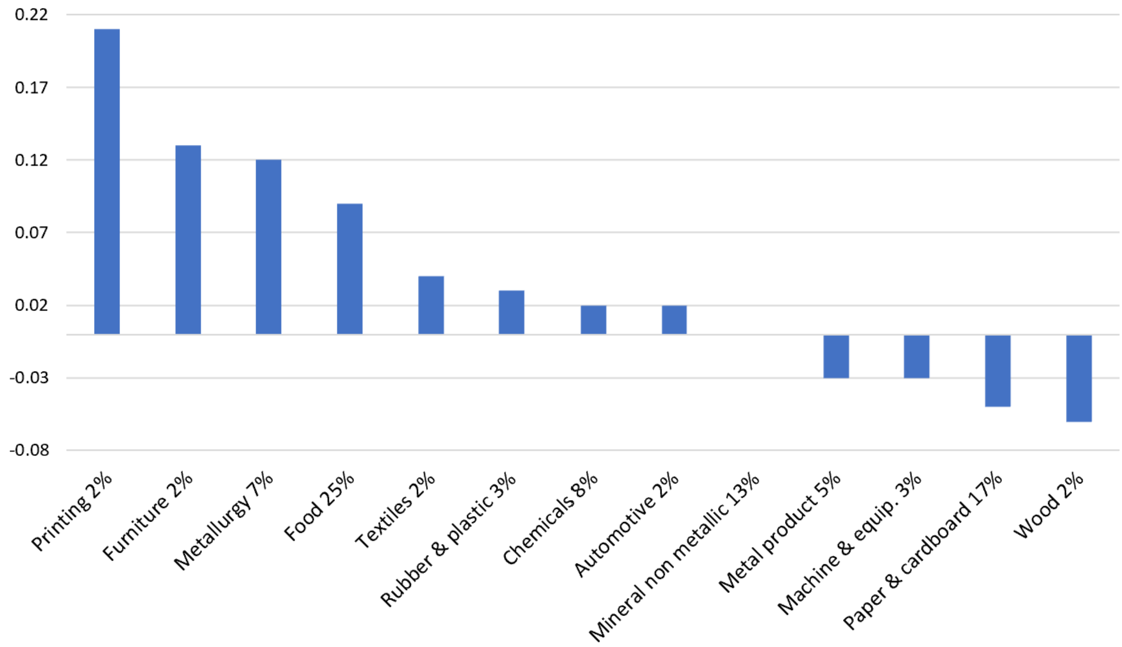
4.3 Heterogeneity across sectors

Regulated firms are present in all manufacturing sectors except in the Tobacco industry in our sample. 75% of regulated firms are from only six sectors, as presented in the Section 4.2. We investigate whether the EU ETS has a different impact on firms, according to their sector. To ensure robust results, we look for differential effects only if the sector includes at least 2% of regulated firms. This leads us to estimate the impact of the EU ETS on firms of 13 sectors, representing 91% of the regulated firms. We estimate:

$$TFP_{isct} = \alpha_0 + \beta_s \sum_{s=10}^{33} Post_t * id_{ic} * d_s + \alpha_1 Sales_{isct} + \alpha_2 TFASS_{isct} + \alpha_3 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (8)$$

where d_s is a dummy equals to one for each sector. The regression by sector implies a low number of observations in each sector. To ensure the validity of our results, we rely on specifications with the highest number of observations, i.e. excluding long-term debt. The results are reported in Appendix B, Table B2. Strikingly, the coefficients on EU ETS are all significant, but of different signs and magnitudes. Figure 5 shows these coefficients in declining order. The introduction of the EU ETS has a positive impact on TFP in printing, furniture, metallurgy and food, but a negative one in the paper and wood industries. The great heterogeneity of the coefficients can easily explain why the EU ETS shows non-significant when all sectors are pooled.

Figure 5: The permanent impact of the EU ETS on TFP, by sector



Note: The figure reports the $\hat{\beta}_s$ estimates from Equation (8). The y-axis indicates the log of TFP. For example, regulated firms from the food industry had an increase of productivity of 9% due to the EU ETS. The figure shows first the sectors with the highest positive impact from the EU ETS on TFP. The x-axis shows the percentage of regulated firms in each sector.

4.4 Heterogeneity across countries

Similarly, we can investigate possible heterogeneities across countries by interacting the treatment (EU ETS regulation) with a country dummy:

$$TFP_{isct} = \alpha_0 + \beta_c \sum_{s=1}^{3} Post_t * id_{is} * c_c + \alpha_1 Sales_{isct} + \alpha_2 TFASS_{isct} + \alpha_3 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (9)$$

where c_c is a dummy equals to one for country c.

The results are reported in Table 11. Strikingly, the ETS regulation has a positive and significant impact on TFP for French firms, but the impact is insignificant in Italy and Spain. However, firms are larger on average in France than in the other two countries: the median number of employees of regulated firms in France is 167, compared to 42 in Spain and 24 in Italy. We thus replicate the analysis separately by quintile of size. Unfortunately, there are not enough observations for Spanish regulated firms to make this size differentiation, so we run the regressions only for Italy and France. The results (Table 11) show that the EU ETS regulation has a positive impact on TFP for French firms in Q3, while the coefficient is never significant in Italy. To investigate further the effect on each country separately, we subsequently re-estimate the same equation but only for the French sample, then the Italian one. The results for French regulated firms are displayed in Table 12. The impact of the EU ETS remains significant and positive, and greater for larger firms in France (although not for the last quintile of firms). The results for the Italian sample are reported in Appendix B, Table B3. It confirms that the EU ETS has no significant effect for regulated firms in Italy, although it is difficult to say whether the result trully reflects an Italian pattern or rather a different coverage of Italian firms in Orbis.

Table 11: The permanent impact of the EU ETS on firm-level TFP, by country

	(All)	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)
ETS * France	0.05** (0.02)	0.05 (0.06)	0.09 (0.06)	0.18*** (0.06)	0.09 (0.07)	0.02 (0.03)
ETS * Italy	0.03 (0.03)	−0.18 (0.13)	0.10 (0.11)	0.10 (0.09)	0.08 (0.05)	−0.02 (0.06)
ETS * Spain	−0.05 (0.11)					
Firm control variables	yes	yes	yes	yes	yes	yes
Sector-Year FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.94	0.88	0.89	0.91	0.96	0.98
N	12716	2363	2404	2477	2639	2456
No. of clusters	23.00	21.00	22.00	21.00	21.00	21.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Table 12: The permanent impact of the EU ETS on firm-level TFP in France, by size

	(All)	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)
ETS effect in France	0.05** (0.02)	0.04 (0.06)	0.06 (0.06)	0.16** (0.06)	0.13** (0.06)	0.03 (0.02)
Firm control variables	yes	yes	yes	yes	yes	yes
Sector-Year FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.95	0.92	0.92	0.94	0.96	0.98
N	10325	2036	1784	1853	2170	2110
No. of clusters	23.00	21.00	21.00	20.00	21.00	21.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

On the whole, it seems that large firms tend to benefit from the EU ETS regulation, although this result may be specific to France. In France, we finally estimate the impact of the EU ETS as a 5% increase of TFP for regulated firms.

5. Time–varying effects of the EU ETS

So far, we have measured a uniform impact of the EU ETS from 2005 onward. In Table 6, we have seen that the ETS price does not modulate the impact of the treatment over time. However, the EU ETS has evolved over time not just in terms of carbon price. Additionally, its introduction in 2005 may have been anticipated by future regulated firms. In this section we investigate the time-varying effects of the EU ETS on firm-level TFP.

5.1 Year-specific effects

We start by interacting the ETS treatment with a year dummy, in order to measure how the EU ETS may have affected TFP differently over time:

$$TFP_{isct} = \alpha_0 + \beta_t \sum_{t=2000}^{2017} id_{isc} * year_t + \alpha_1 Sales_{isct} + \alpha_2 Debt_{isct} + \alpha_3 TFASS_{isct} + \alpha_4 Emp_{isct}$$

$$+FE_i + FE_{st} + u_{isct} \qquad (10)$$

where $year_t = 1$ for the year $t \in \{2000; 2017\}$. We report the results in Table 13, where the two columns differ in the number of observations due to the inclusion or not of the control for long-term debt.

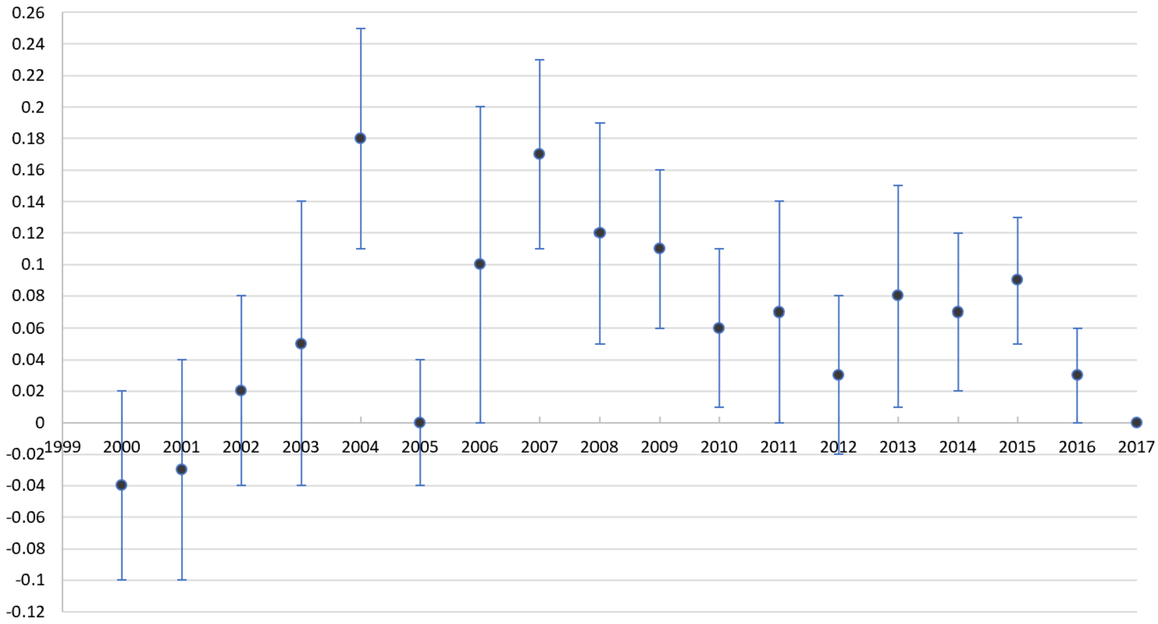
Table 13: The effect of the EU ETS on TFP, year by year, 2000-2017

	(1)	(2)
2000 ETS effect	−0.04 (0.06)	−0.05* (0.03)
2001 ETS effect	−0.03 (0.07)	−0.02 (0.04)
2002 ETS effect	0.02 (0.06)	0.00 (0.04)
2003 ETS effect	0.05 (0.09)	−0.03 (0.04)
2004 ETS effect	0.18** (0.07)	0.04 (0.08)
2005 ETS effect	0.00 (0.04)	−0.08** (0.03)
2006 ETS effect	0.10 (0.10)	0.03 (0.10)
2007 ETS effect	0.17*** (0.06)	0.07 (0.05)
2008 ETS effect	0.12 (0.07)	0.07 (0.06)
2009 ETS effect	0.11** (0.05)	0.03 (0.03)
2010 ETS effect	0.06 (0.05)	-0.00 (0.04)
2011 ETS effect	0.07 (0.07)	0.02 (0.05)
2012 ETS effect	0.03 (0.05)	0.02 (0.04)
2013 ETS effect	0.08 (0.07)	0.00 (0.06)
2014 ETS effect	0.07 (0.05)	0.03 (0.05)
2015 ETS effect	0.09** (0.04)	0.02 (0.04)
2016 ETS effect	0.03 (0.03)	0.01 (0.03)
2017 ETS effect	0.00 (0.00)	0.00 (0.00)
Firm control variables	yes	yes
Long debt control	yes	no
Sector-Year FE	yes	yes
Firm FE	yes	yes
R2	0.95	0.94
N	6172	12716
No. of clusters	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

We observe that a part of regulated firms (specification (1) where the long-term debt is inserted) have particular strong boosts of TFP in year 2004, 2007, 2009 and 2015. In particular, the significance in year 2004 can be interpreted as an anticipation effect of firms. In Figure 6, we report the $\widehat{\beta_t}$ estimates of Equation (10), specification (1).

Figure 6: The effect of the EU ETS on TFP of regulated firms, year by year (Table 13, Column (1))



Source: Amadeus-Orbis and Union Registry databases.

Note: The figure reports the $\widehat{\beta_t}$ estimates of equation (10), specification (1), and their 95% confidence intervals. For example, in 2004, regulated firms had an increase of TFP of 18%, probably due to the anticipation of the implementation of the regulation, which brought them to produce at maximum capacity. This time trend test analyses the impact of each year on the TFP of treated firms as compared to control ones.

The evolution of TFP for *treated* firms *before* the EU ETS implementation is particularly interesting. A possible interpretation could be that, knowing that a new regulation will be constraining in 2005, *treated* firms produced at maximum capacity until the deadline, with economies of scale that would temporarily increase TFP that particular year. Then, the drop observed in 2005 should perhaps not be over-interpreted, as it would follow a peak in 2004. Another way to investigate the possibility of an anticipation effect is to build a model of anticipation (see Appendix C).

5.2 EU ETS phases

Some authors have looked for differentiated effects of the EU ETS depending on the stringency of its different implementation phases (Klemesten et al., 2020). As the different phases of the EU ETS differ not only through prices (very low prices in phase 1; higher in phase 3) but also in allowances (allocated for free in phase 1; allocated with a reduced cap of 6.5% and only 90% of free allowances in phase 2; allocated by auction in phase 3), it is interesting to look for different impacts by phase.

We estimate the following equation:

$$TFP_{isct} = \alpha_0 + \beta_t \sum_{t=1}^{3} id_{isc} * phase_{pt} + \alpha_1 Sales_{isct} + \alpha_2 TFASS_{isct} + \alpha_3 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (11)$$

where $phase_{pt}$ is equal to one for phase *p*, i.e. phase 1 (2005-07), phase 2 (2008-12) and phase 3 (2013-20). Since our data spans up to 2017, we can only partially examine the effect of the EU ETS in phase 3. We study the impact of the EU ETS not only on TFP, but also on other performance variables (see Section 5.2). For the latter, the control variables are lagged. The results are reported in Table 14 for the regressions with sector-year fixed effects, and in Table 15 for those where sector-year fixed effects are replaced with sector fixed effects and phases dummy.

Table 14: The impact of the EU ETS, by phase (with sector-year fixed effects)

	(TFP)	(FASS)	(TASS)	(REV)	(VA)	(EMP)
ETS * phase 1	0.05** (0.02)	−0.06 (0.05)	−0.05 (0.03)	0.05 (0.04)	−0.00 (0.04)	−0.10*** (0.03)
ETS * phase 2	0.04 (0.02)	−0.07 (0.07)	−0.07** (0.03)	0.15*** (0.04)	0.11** (0.05)	0.00 (0.05)
ETS * phase 3	0.02 (0.03)	−0.05 (0.09)	−0.07* (0.04)	0.16*** (0.05)	0.11* (0.06)	0.02 (0.06)
Constant	−1.45*** (0.15)	3.93*** (0.24)	5.29*** (0.19)	6.57*** (0.11)	5.85*** (0.09)	−0.10 (0.25)
Firm control variables	yes	yes	yes	yes	yes	yes
Sector-Year FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.94	0.96	0.98	0.97	0.97	0.96
N	12716	17956	18101	13804	13637	13761
No. of clusters	23.00	23.00	23.00	23.00	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Table 15: Robustness check. The impact of the EU ETS, by phase (with phases dummy)

	(TFP)	(FASS)	(TASS)	(REV)	(VA)	(EMP)
ETS * phase 1	0.04 (0.03)	−0.02 (0.05)	−0.03 (0.02)	0.09* (0.05)	0.00 (0.03)	−0.09*** (0.03)
ETS * phase 2	0.01 (0.03)	−0.01 (0.06)	−0.04 (0.03)	0.18*** (0.03)	0.11** (0.05)	−0.02 (0.04)
ETS * phase 3	0.01 (0.03)	−0.01 (0.08)	−0.04 (0.04)	0.19*** (0.05)	0.11* (0.06)	−0.01 (0.04)
Constant	−1.30*** (0.15)	3.75*** (0.26)	5.13*** (0.20)	6.57*** (0.10)	5.95*** (0.10)	0.08 (0.24)
Firm control variables	yes	yes	yes	yes	yes	yes
Phases dummy	yes	yes	yes	yes	yes	yes
Sector-Year FE	no	no	no	no	no	no
Sector FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.93	0.96	0.98	0.97	0.97	0.96
N	12739	17971	18116	13820	13653	13777
No. of clusters	24.00	24.00	24.00	24.00	24.00	24.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Consistent with our previous results, firm-level TFP does not react differently on average to the EU ETS in the different implementation phases (the positive coefficient found in Table 14 for phase 1 is no longer significant in Table 15). As seen previously, such non-significance probably hides heterogeneous effects depending on size, sector and country. The effects of the ETS regulation on the other performance variables are confirmed.

Conclusion

This study provides new econometric evidence on the causal impact of the EU ETS on firm-level performance in the French, Italian and Spanish manufacturing sectors, with a matched difference-in-difference study design, based on Orbis data from 2000 to 2017.

As a general rule, the EU ETS is not found to have any significant impact on the TFP of "treated" firms, be it positive or negative. However, we do find a significant impact depending on firm characteristics. Specifically, larger firms or firms closer to the technology frontier tend to benefit from the EU ETS, whereas smaller firms and firms that are financially constrained (as measured by their interest payments) tend to see their TFP decline when covered by the scheme. The impact of the EU ETS also differs across sectors, the major beneficiaries being food, chemicals and metallurgy industries. At the country level, the effects are largely driven by French firms, regardless of their size.

The positive impact of the EU ETS on larger, more productive, less financially constrained firms may partially result from a cleansing effect, which our database does not allow to identify. However, the scheme had a positive impact on the turnover and added value of (remaining) treated firms only in phases 2 and 3 (not in phase 1), suggesting that there is more a cleansing effect. Another interpretation could be that larger, more productive firms were able to pass their increased marginal costs on to their customers, which ends up in higher measured TFP (European Commission, 2015).

We also find some evidence of an anticipation effect: in 2004, those firms that will be covered by the EU ETS already know it, and their TFP peaks. The overall assessment of the impact of the scheme needs to take this anticipation effect into account.

On the whole, we find no evidence that the European carbon market is detrimental to firm-level TFP, for our sample. Further research will be needed to understand how this benign effect on TFP squares with increasing evidence on carbon leaks (see, e.g. Misch and Wingender (2021)): if the regulation is benign, why should companies outsource their carbon-intensive production? To answer this question, it would be necessary to study not just the intensive margin but also the extensive one, which is only possible with country-specific datasets.

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Appendix

Appendix A. Matching

Table A1: Number of observations of *treated* and *control* firms, by NACE-2-digit sector

NACE-2-digit	Treated firms	Control firms
10 - Food industry	1,964	2,294
11 - Beverage production	80	532
13 - Textile manufacturing	185	1,004
14 - Clothing industry	74	733
15 - Leather and footwear industry	94	599
16 - Woodworking	150	745
17 - Paper and carboard industry	1,348	447
18 - Printing and reproduction of records	169	1,107
19 - Coking and refining	85	8
20 - Chemicals industry	641	365
21 - Pharmaceuticals industry	54	102
22 - Manufacture of rubber and plastic products	214	860
23 - Manufacture of other non-metallic mineral products	977	545
24 - Metallurgy	515	277
25 - Manufacture of metal products	404	1,743
26 - Manufacture of computer, electronic and optical products	47	140
27 - Manufacture of electrical equipment	47	221
28 - Manufacture of machinery and equipment	240	590
29 - Automotive industry	149	169
30 - Manufacture of other transport equipment	81	74
31 - Furniture manufacturing	170	293
32 - Other manufacturing industries	87	105
33 - Repair and installation of machines and equipment	21	45
Total	7,796	12,998

Appendix B: Additional results

Table B1: The permanent impact of the EU ETS on TFP, controlling for the firms' level of loans

	(1)	(2)
ETS permanent effect	0.07 (0.07)	0.08* (0.05)
ETS * LOANS	0.01 (0.01)	−0.01** (0.00)
LOANS	−0.03** (0.01)	−0.01*** (0.00)
Sales	0.72*** (0.02)	0.72*** (0.02)
Long Debt	−0.02*** (0.00)	
Tangible-F-Asset	−0.05** (0.02)	−0.06*** (0.01)
Employees	−0.49*** (0.03)	−0.46*** (0.02)
Constant	−1.82*** (0.24)	−1.95*** (0.18)
Sector-Year FE	yes	yes
Firm FE	yes	yes
R2	0.95	0.95
N	3993	7490
No. of clusters	21.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Table B2: The permanent impact of the EU ETS on firm-level TFP, by sector

	(1)
Food	0.09*** (0.00)
Paper and cardboard	−0.05*** (0.00)
Mineral non metallic	0.00 (0.00)
Chemicals	0.02** (0.01)
Metallurgy	0.12*** (0.00)
Metal product	−0.03* (0.01)
Machine and equipment	−0.03*** (0.00)
Rubber and plastic	0.03*** (0.00)
Textiles	0.04*** (0.01)
Furniture	0.13*** (0.01)
Printing	0.21*** (0.01)
Wood	−0.06*** (0.01)
Automotive	0.02** (0.01)
Constant	−1.46*** (0.15)
Firm control variables	yes
Sector-Year FE	yes
Firm FE	yes
R2	0.94
N	12716
No. of clusters	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

The $\widehat{\beta_s}$ sectoral coefficients are ranked in order of representativeness of the regulated firms: Food industry (25% of the regulated firms), Paper and cardboard (17%), Mineral non-metallic (13%), Chemicals (8%), Metallurgy (7%), Metal product (5%), Machine and equipment (3%), Rubber and Plastic (3%), Textiles (2%), Furniture (2%), Printing (2%), Wood (2%) and Automotive (2%).

Table B3: The permanent impact of the EU ETS on firm-level TFP in Italy, by size

	(All)	(Q1)	(Q2)	(Q3)	(Q4)	(Q5)
ETS effect in Italy	0.02 (0.03)	−0.19 (0.13)	0.10 (0.11)	0.09 (0.10)	0.04 (0.07)	−0.01 (0.08)
Firm control variables	yes	yes	yes	yes	yes	yes
Sector-Year FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.92	0.88	0.88	0.90	0.96	0.98
N	10071	2166	2181	2042	1949	1402
No. of clusters	23.00	21.00	21.00	21.00	18.00	15.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

Appendix C. Anticipation effects

As seen in Section 6.1, it seems that some firms have anticipated the EU ETS implementation. We develop here an anticipation model.

As the first design of the EU ETS was first presented in 2000, and that the Directive was adopted in 2003, it cannot be ruled out that regulated companies took action in anticipation of its introduction in 2005. As underlined by Kozluck and Zipperer (2014), the impact of a policy change may predate its introduction if the change is credible and announced well in advance. In our case, firms may have invested to reduce their emissions, or, on the contrary, they may have decided to produce and pollute as much as possible before the regulation is implemented.

In order to model the anticipation effect of the EU ETS on firms' TFP, we follow the methodology of Malani and Reif (2015). The framework begins with a forward-looking regression:

$$y_t = \beta_0 d_t + \sum_{j=1}^{\infty} \beta_j E_t[d_{t+j}] + u_t \quad (12)$$

where y_t is the outcome, d_{t+j} a sequence of treatments, $E_t$indicates the expectation taken with respect to an agent's information set at time *t*, and u_t is an idiosyncratic error term uncorrelated with the regressors.

This framework is challenging as there is potentially an infinite number of expectation terms -*dimensionality problem*- and no data on expectations -*unobservable expectations*. To tackle these issues, we estimate a *quasi-myopic model* that includes a finite number *S* of anticipation terms while assuming perfect foresight:

$$y_t = \beta_0 d_t + \sum_{j=1}^{S} \beta_j E_t[d_{t+j}] + u_t \quad (13)$$

Consistent with perfect foresight, we substitute realizations d_{t+j} for expectations $E_t[d_{t+j}]$. This assumption is very strong and if not correct, results may be biased. In practice, we run the following regression:

$$TFP_{isct} = \beta_0 + \beta_1 d2005_t * id_{isc} + \sum_{j=1}^{S} \alpha_j * d2005_{t+j} * id_{isc} + \beta_2 Sales_{isct} + \beta_3 Debt_{isct} + \beta_4 TFASS_{isct}$$

$$+\beta_5 Emp_{isct} + FE_i + FE_{st} + u_{isct} \quad (14)$$

where $d2005_t = 1$ in 2005. $d2005_{t+j}$ is a dummy variable equal to 1 if a reform is adopted in period *t+j*. For example, the EU ETS is adopted in 2005, then $d2005_{t+1} = 1$ in 2004. When looking for anticipation effect, we restrict the treatment to only the year of its implementation (2005). The coefficient $\widehat{\beta_1}$ identifies the short-term effect of the EU ETS implementation. The ex-ante effect in period *t-j* is estimated by $\widehat{\alpha_j}$. We report the results in Table A2. We first regress without any anticipation effect, then we add the ex-ante effect in *t*-1, *t*-2, *etc*.

Table C1: Anticipation framework. The quasi-myopic model results

	(A)	(B)	(C)	(D)	(E)	(F)
2005 ETS effect	−0.09** (0.04)	−0.06 (0.04)	−0.06* (0.03)	−0.07* (0.03)	−0.07** (0.03)	−0.09** (0.04)
2004 ETS effect		0.12*** (0.04)	0.11*** (0.03)	0.11*** (0.03)	0.10*** (0.03)	0.08*** (0.03)
2003 ETS effect			−0.02 (0.04)	−0.02 (0.04)	−0.03 (0.05)	−0.05 (0.04)
2002 ETS effect				−0.02 (0.04)	−0.04 (0.05)	−0.06 (0.06)
2001 ETS effect					−0.09 (0.06)	−0.11 (0.07)
2000 ETS effect						−0.12 (0.08)
Sales	0.69*** (0.03)	0.69*** (0.03)	0.69*** (0.03)	0.69*** (0.03)	0.69*** (0.03)	0.69*** (0.03)
Long Debt	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)	−0.02*** (0.00)
Tangible-F-Asset	−0.07*** (0.01)	−0.07*** (0.01)	−0.07*** (0.01)	−0.07*** (0.01)	−0.07*** (0.01)	−0.06*** (0.01)
Employees	−0.50*** (0.02)	−0.50*** (0.02)	−0.50*** (0.02)	−0.50*** (0.02)	−0.50*** (0.02)	−0.50*** (0.02)
Constant	−1.30*** (0.15)	−1.30*** (0.15)	−1.30*** (0.15)	−1.30*** (0.15)	−1.30*** (0.15)	−1.30*** (0.15)
Sector-Year FE	yes	yes	yes	yes	yes	yes
Firm FE	yes	yes	yes	yes	yes	yes
R2	0.95	0.95	0.95	0.95	0.95	0.95
N	6172	6172	6172	6172	6172	6172
No. of clusters	23.00	23.00	23.00	23.00	23.00	23.00

Note: Standard errors clustered at the sector level. ***p<0.01,**p<0.05,*p<0.1.

The anticipation effect of the EU ETS implementation on firms' TFP is positive and significant in 2004. This result has to be taken with cautious. As described previously, we observe anticipation effect only for a part of regulated firms. There is no significant anticipation effect further 2004. The 2005 ETS effect reflects a sudden drop, that may be due to the EU ETS but it can also be due to a backlash from producing at full capacity until 31/12/2004.