The Impact of European Carbon Market on Firm Productivity: Evidence from Italian Manufacturing Firms.*

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April 27, 2018

PRELIMINARY DRAFT

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Abstract

In the Kyoto Protocol framework, the EU committed itself to reducing its greenhouse gas (GHG) emissions by 20 percent until 2020 compared with 1990 levels. One of the main policies adopted to fulfill this goal is the European Union Emission Trading System (EU ETS): a cap-and-trade scheme for GHG emission allowances. In this project, we exploit the introduction of the ETS and its institutional changes to provide evidence of the causal impact of this European policy on firms' outcomes, disentangling the effects on profitability and productivity. This study is based on an original and comprehensive database of Italian manufacturing plants gathering data on EU ETS obligations and exchanged allowances, revenues, labor, polluting emissions and financial data.

The empirical analysis combines robust and recent techniques for public policy evaluation with structural estimation of firms' production function. Preliminary results show a positive effect of the policy on productivity and heterogeneous effects among sectors.

Keywords: Emission trading; Productivity

*We thank for useful comments Jan De Loecker, Giovanni Marin, Celine Nauges, Fabiano Schivardi, Ulrick Wagner as well as participants in the reading group at the Toulouse School of Economics (2017), TSE Energy and Climate Center Workshop on Energy Economics (Toulouse) and TSE Environmental Winter Seminar (2018). All errors are ours.

The opinion expressed and arguments employed herein are those of the author and do not necessarily reflect the official views of the OECD or the governments of its members countries.

1 Introduction

Since the early nineties, the EU concern on climate change has continuously grown. In the framework of Kyoto Protocol, the EU committed itself to reducing its GHG emissions by 20 percent in 2020 compared with 1990 levels. Therefore, in 2003 the EU established an emission allowances trading scheme, the European Union Emission Trading System (EU ETS), today's largest cap-and-trade scheme in the world. Faced with a change in their cost structures, firms under the scheme have reorganized their productive process.

The objectives of this study are twofold. Our main objective is to identify the causal effect of EU ETS on industry production choices. In particular, we want to study the effect of ETS in firms' total factor productivity. With the term productivity we refer to Total Factor Productivity (henceforth, TFP), which reflects the overall efficiency with which inputs are combined in the production process. We focus on this distinction since the TFP growth is a main driver of the country divergence in growth as suggested by Klenow and Rodriguez-Clare (1997). Lastly, our approach will be useful to further research since our study could be replicated using data from other European countries that are also under the EU ETS regulation.

One of the main concerns related to environmental regulations is its effect on firms' performance. Economic theory does not provide clear predictions. On the one hand, the opportunity cost of polluting is sometimes assumed to distort firms' optimal choices of production (Gray (1987)). On the other hand, in the early nineties Porter shed a new light on the debate stating that a well-designed regulation could enhance competitiveness (Porter, 1991; Porter and Van der Linde, 1995). Porter's main idea was that firms do not optimally choose their inputs or technological level, therefore environmental policy provides incentives to firms to invest in technologies that not only reduce the environmental footprints but also reduce costs or increase productivity (see Ambec et al. (2013) for a review of the literature). Most of the empirical papers analyzing the effect of Porter's hypothesis study the effect of command and control (Greenstone et al. (2012)) and taxation (Labonne and Johnstone (2006)) policies or compare these effects (Lanoie et al. (2011)), while the Porter's argument refers to market based type of policies, such as the European cap-and-trade.

Recent studies have focused on EU ETS ex-post evaluation, however there is not any conclusive evidence on the impact of this policy on firm outcomes (Martin et al. (2015)).

Studies investigating the impact of EU ETS showed that it reduced the CO2 emissions and triggered the development of new low-carbon technologies throughout Europe (Wagner et al., 2014; Petrick and Wagner, 2014; Calel and Dechezlepretre, 2016). Although some of these studies investigated the effect of the scheme on firm outcomes, using firm or plant-level data, none of them identified the channels through which the firms modified their production technology. Lutz (2016) provides a first attempts to further investigate this question, although his analysis does not disentangle the different effects on performance, nor provides an explanation on the channels that have determined a technological change. This project aims at filling this gap, clearly distinguishing between the effects on productivity and profitability. In order to do so, we exploit a unique Italian database of firm-level balance-sheet data combined with other sources of information about emissions, technological changes and input and output markets.

Italy represents an interesting setting to study firm outcomes induced by environmental regulation. We have access to privately owned Italian balance-sheet data, that we complement with various databases. In the last decades, Italy's per capita GDP has decreased by around 1% every 10 years: a much steeper slow down than what was observed in other industrialized countries, including European countries. This deterioration in growth prospects mainly results from a substantial zeroing of productivity growth in all productive sectors. The component which has markedly differentiated Italy from other countries is the declining Total Factor Productivity (TFP) as documented in Calligaris (2015). Therefore, studying the role of this regulation on TFP is particularly relevant. Given the predominant role of the manufacturing industry in the Italian economy, the Italian government is quite concerned about the market distortions due to the system. For this reason, Italy voted against the "Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments" on the 28th February 2017. Despite evidence-based analysis are necessary to inform the political debate, there are no studies investigating the effect of EU ETS in Italy. Calel and Dechezlepretre (2016) use data from 18 European countries to study the effect of the policy on technological change, Italy is not included in the sample. Replicating the analysis on the effect of ETS on emission intensity is particularly challenging given the lack of available information on fuel consumption or emission at plant (or firms) level for firms not regulated by the EU ETS.

In order to investigate firm performances, we build on the empirical literature on total factor productivity estimation (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Collard-Wexler and De Loecker, 2014; Ackerberg et al., 2015)) and the effects of trade on firm productivity (De Loecker, 2007; De Loecker and Warzynski, 2012; De Loecker, 2013; De Loecker and Goldberg, 2014).[1] In particular, we explicitly allow Emission Trading System to affect the evolution of productivity. Further, we model how firms under ETS react to the policy choosing whether to reduce emissions and sell allowances or buy them and how this choice affects the evolution of productivity. Lastly, in order to identify the causal effect of ETS, we exploit the fact that only a subset of the plants was selected for participation. Since relying on usual parallel trend assumption seems unreliable for firms inherently different for size or industry, we complement a usual Diff-in-diff approach with matching methods as suggested in Fowlie et al. (2012) and similarly to what is done in Wagner et al. (2014) Petrick and Wagner (2014) and Jaraitė and Di Maria (2012).

Preliminary results suggest a positive effect of the policy on total factor productivity in the years before the economic crises. However, results are more ambiguous when we take into account heterogeneity in sectors.

The reminder of the paper is structured as follows. In Section 2 we describe some institutional features of EU ETS, the Italian specificities and we present the dataset we constructed. In Section 3 we describe the empirical strategy. In Section 4 results are presented and in Section 5 we conclude.

2 Background and data

In this section we provide information on the Emission Trading System and highlight some of the institutional features which we exploit to identify the effect of this environmental policy on total factor productivity. We also introduce a novel dataset we compiled combining balance sheet of Italian manufacturing firms with emission trading registry.

[1] To estimate productivity we prefer a control function approach since it overcomes the issue of simultaneity, i.e., more efficient producers are, all else equal, likely to use more materials. In other words, using this approach we are taking into account the fact that input are endogenous functions of TFP. Greenstone et al. (2012) measure productivity using index number measures. Differently from this approach, control function one does not require to assume that firms faces no adjustment costs of input, which seems rather implausible especially when thinking to capital inputs. Finally, it does not require to assume constant return to scale: the input elasticities are determined endogenously and do not necessarily sum up to 1. Fortunately, empirical results in the literature using micro-level TFP data have been typically rather robust to different methods used to obtain the TFP measure (see, for example, Syverson (2011)).

2.1 Emission Trading System

The EU ETS is a classical cap-and-trade scheme for CO2 emissions: regulated plants receive EU Allowance Units (EUA), which are emission permits, that are tradable across plants in all countries participating to the scheme. During the first phase (2005-2007) EUAs were allocated based on historical emissions. The second phase (2008-2013) coincided with the beginning of the Kyoto commitment period and a goal was set to reduce GHG emissions by 8%. The current phase started in 2014 and will last until 2020 with a reduction target of 20%. In the last two phases, some changes in the allocation systems and the sectors covered were made.[2]

The Directive applies to combustion installation with a rated thermal input exceeding 20MW. Moreover, some "process regulated sectors" are covered: paper products, manufacture of coke and refined petroleum product, manufacture of glass ceramic and cement and manufacture of basic metals. In some sectors only plants above a certain output capacity are included. Aviation was included in 2013 and until 2016 the EU ETS applies only to flights between airports located in the European Economic Area (EEA).[3]

One of the main concerns about the efficacy of this policy is related to the EUA prices (see Figure 1), which is considered not high enough to induce technological changes. In particular, an important drop in prices took place in late April 2006: several member states reported their emissions and all were lower than expected. As these reports arrived within a one week period, the price for both Phase I and Phase II allowances fell significantly. Phase I price dropped by 50% and the Phase II one by about 30%. The Phase I price held at around 15€ during the summer of 2006, but as there was no banking between the two phases and as it became increasingly clear that Phase I emissions would be below the cap, in the fall the price fell to a few euro-cents. Meanwhile, the Phase II price recovered to over 20€ as Phase II began and reached almost 30€. The economic crisis of late 2008 reduced the EUA price again by about 50%. After some recovery in price in early 2009, the EUA price experienced a two-year period of remarkable stability with a price around 15€ until summer of 2011: price fell again by around 50% to a new level of 7-8€ for 2012 before falling to a level around 4€ with the start of Phase III.

However, even if prices have been volatile and low, the volume of EUAs traded has

[2] For a comprehensive review see Ellerman et al. (2016)

[3] For further details on sectors and thresholds see Appendix A.

Figure 1: Price trend EUA CER

Notes: Price trends for EU emission allowances (EUAs) and certified emission reductions (CERs), 2005–14. Source: EEX (EUA price), 2015; ICE ECX (CER price), 2015. Graph produced by European Environment Agency

progressively increased over time (Point Carbon). The volume traded exceeded 50 million tons per month in 2006, while in 2011 trading volumes reached over ten times that amount, suggesting that firms were considering the opportunity cost of polluting. We want to exploit the informations on allocated and verified emissions to understand better how firms react to this policy. Each long installation (allocation $\geq$ emissions) is a potential seller of EUA; and each short installation (allocation $\leq$ emissions) is a potential buyer.

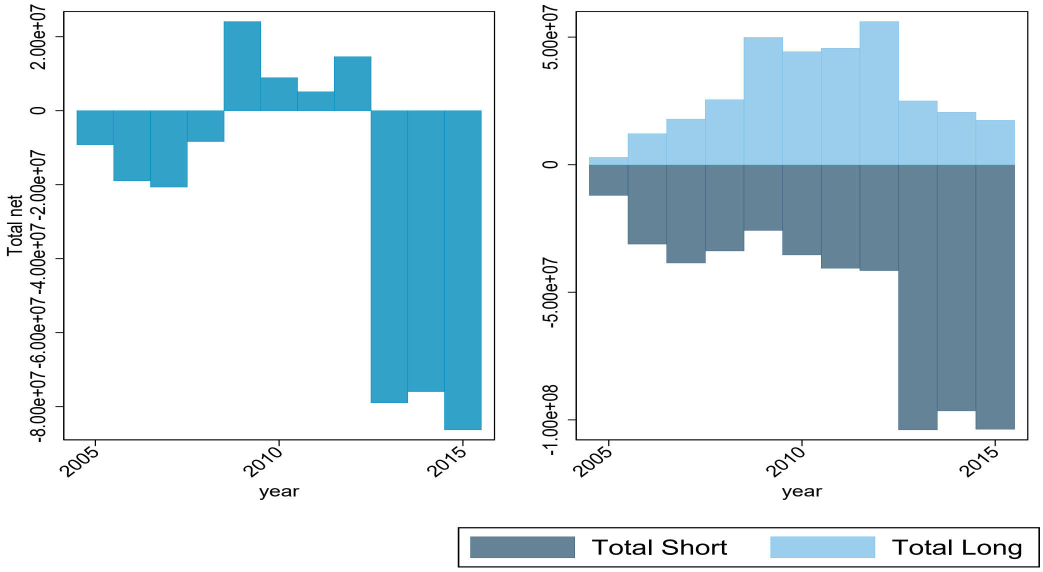
Looking at the Italian manufacturing sector, Figure 2 shows that, differently from other countries, during the first phase there wasn't an overallocation od permits for Italian manufacturing firms. In other words, firms were buying allowances. In the second phase it is overall positive, although the panel on the right shows that there are both firms selling and buying.

2.2 Data

We collected a unique and comprehensive database of Italian manufacturing plants. This database is built from several sources:

The Community Independent Transaction Log (CITL) database contains all plants under regulation in the first Phase while the European Union Transaction Log (EUTL) contains data on the subsequent phases. It is run by the European Commission and

Figure 2: Short and long positions by year



Notes: Left panel shows the total net position (number of allowances-number of verified emissions) of Italian manufacturing plants. Right panel shows the sum total long position (allocation $\geq$ emissions) and total short ones (allocation $\leq$ emissions)

publicly available on its website.

The CERVED database contains balance sheet information for Italian limited liability companies. The data are recorded by the Italian Registry of Companies and from financial statements filed at the Italian Chambers of Commerce. It provides information on more than 600,000 joint stock, public and private limited share companies and limited liability Italian companies (S.p.a. and S.r.l.). The information provided includes credit reports, company profiles and summary financial statements (balance sheet, profit and loss accounts and ratios). Data are available for each year between 1995 and 2015.

There are 893 account holders in the CITL registers, 875 of them are also recorded in the CERVED database. In particular, we will keep the 662 manufacturing firms which are recorded in CERVED. Thus, we have a matching rate of 99%. In order to do the matching we are aggregating plants data at firm level. We also combine these databases with information at plant level (ISTAT dataset Asia), in order to check how many plants of a firm are under regulation. Among the regulated firms, 44% of them are mono-plants and 25% have 2 plants. Therefore, many of them are not multi-plant firms, meaning that only few plants under ETS can reallocate their production among plants. As a matter of fact, 53% of the firms have all their plants regulated under ETS. Only 25% of the firms have less than half of their plants regulated under ETS.

Further, information related to technology adoption is contained in the Best Available Technique reference document carried out in the Framework of Article 13(1) of the Industrial Emissions Directive (IED, 2010/75/EU).

In Table 1 we report the main characteristics of plants in the CITL registry, by ETS Phases. We will focus on the 667 manufacturing firms under regulation in the different phases.

Table 1: CITL summary statistics

	Phase I	Phase II	Phase III	Total
Plants under regulation	1025	1165	1343	1634
Firms under regulation	556	657	790	843
- *Manufacturing*	405	460	561	664

Note: The table reports details on the number of Italian plants and firms under regulation as reported in the European Union Transaction Log (EUTL).

In Table 2 we report the main variables object of analysis, using observations from 2002 in order to compare average characteristics of manufacturing firms with the one covered by EU ETS. Panel A shows the characteristics of all limited liability manufacturing companies. Only the 0.5% of these are regulated under the EU-ETS. Firms under ETS, which summary statistics are reported in Panel B, are on average bigger than the others. If we concentrate on the process regulated sectors[4]

Although on average firms under policy are bigger than the others, looking at the distribution of covariates we can see that there are some overlapping between the two group of firms. This will be the starting point for the potential outcome identification strategy we will follow. In fact, given that factors that are related to firm-level productivity dynamics vary significantly across the treatment and comparison groups, an unconditional differences-in-differences will be biased. In order to reduce this bias, we employ strategies that condition on observable covariates.

3 Empirical strategy

In the empirical analysis we proceed in two steps: first of all, we estimate a production function that would take into account the change in productivity and input mix after the

[4]pulp and paper products, manufacture of coke and refined petroleum product, manufacture of glass ceramic and cement and manufacture of basic metals, then we have that 3% of firms are regulated (Panel D.) and, again, regulated firms are bigger than the average firms in these sectors (Panel C.).

Table 2: Covariates in 2002

	Mean	**St. Dev.**	**5th pctile**	**25th pctile**	**50th pctile**	**75th pctile**	**95th pctile**
A. Manufacturing firms (N. obs: 91,187)							
Real value added	1,994	39,807	39	171	444	1,163	5,729
Real gross output	8,415	102,046	159	609	1,600	4,512	24,338
Real capital	1,670	15,143	8	53	209	857	5,324
Real cost of labour	1,162	6,855	22	114	299	758	3,617
Real intermediate	4,555	71,098	10	166	602	2,051	12,780
B. Manufacturing firms, under ETS (N. obs: 494)							
Real value added	62,498.5	523,101.8	919.0	3,568.5	12,079.2	35,299.8	180,663.3
Real gross output	22,0404.1	956,731.0	3,714.7	14,667.0	51,281.6	168,276.0	720,263.7
Real capital	56,515.1	162,701.8	1,210.4	5,313.5	17,242.0	46,232.5	203,011.7
Real cost of labour	23,509	54,165	523	1,905	6,535	20,113	110,941
Real intermediate	122,926	541,313	1,247	6,092	22,685	88,544	431562
C. Manufacturing firms - process regulated sectors (N. obs: 8,351)							
Real value added	4,291	127,152	43	204	549	1,535	8,621
Real gross output	20,146	302,822	196	878	2,422	6,994	41827
Real capital	3,934	30,055	14	127	525	1,744	11416
Real cost of labour	1,666	10,745	27	135	341	923	4,944
Real intermediate	12,982	217,345	41	343	1,151	3,625	23,178
D. Manufacturing firms, under ETS - process regulated sectors (N. obs: 266)							
Real value added	71,068	706,902	783	2,806	7,824	25,989	125,534
Real gross output	215,560	1,244,050	3,175	11,297	32,901	127,898	603,151
Real capital	51,606	146,917	928	4,740	11,561	39,776	218,533
Real cost of labour	17,536	49,640	464	1,234	3,589	14,561	58,488
Real intermediate	122,960	702,455	993	4,779	12,827	60,847	334,892

Notes: An observation is a firm. All the statistics refer to the year 2002. Base year 2010. "process regulated sectors": paper products, manufacture of coke and refined petroleum product, manufacture of glass ceramic and cement and manufacture of basic metals

introduction of ETS, then we identify the causal effect of ETS on firm-level productivity.

3.1 Production function estimation

We consider the following Cobb-Douglas production function for firm i at time t generating output (y_{it}, logarithm of gross output) from labor (l_{it}), capital (k_{it}) and materials(m_{it}):

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_{it} + \epsilon_{it} \tag{1}$$

where ω captures productivity and comprises the constant term, and ϵ is a standard i.i.d. error term capturing unanticipated shocks to production and measurement error.

We want to estimate a robust production function that takes into account the possible effect of the policy on the productivity process. To do that, we refer to the literature on estimating production function using proxy estimators, Olley and Pakes (1996) (OP), Levinsohn and Petrin (2003) (LP) and Ackerberg et al. (2015) (ACF).

In order to isolate ϵ, that is the part of the output determined by an unanticipated shock at time t, from the unobserved productivity ω_{it}, this method relies on optimal choice of investments (OP) or intermediate inputs (LP) to control for unobserved productivity shocks. The crucial assumption here is the strict monotonicity of investment (or intermediate inputs) demand function in ω_{it}. However, as pointed out by (De Loecker, 2013, 2007) monotonicity of investment in productivity could not hold when introducing new state variables, such as environmental regulation in this case: carbon trading can be modeled as an increase in cost of input for some firms. Therefore, the monotonicity assumption would not hold if we do not explicitly take into account the difference between ETS and non-ETS firms in the demand for input.

Another crucial assumption in these estimation procedures is a Markow process for productivity. Productivity at time $t+1$ consists of expected productivity given a firm's information set, and a productivity shock ξ_{it+1}: $\omega_{it+1} = g_1(\omega_{it})+\xi_{it+1}$. Following De Loecker (2013), we use an ACF estimation procedure, and we consider a productivity process where being under ETS is allowed to impact the future probability:

$$\omega_{it+1} = g(\omega_{it}, ETS_{it}) + \xi_{it+1} \tag{2}$$

where ETS_{it} is a vector that captures the "experience" of being regulated, and it can be extended to capture the number of certificates received.

Not including ETS in the productivity process, we would not be able to distinguish between cases in which the correlation between productivity and being under the policy is due to an underlying process whereby firms with exogenously high productivity incur the fixed cost of increasing their combustion/output capacity; or whether the correlation is a consequence of the increased cost of emitting, which induce firms to adopt technologies directly affecting productivity. These channels could both explain productivity variations, we will rely on matching on observables, as in De Loecker (2007), to control for a potential self-selection effect. At any rate, we need to allow for Emission Trading System to to take place or, more formally, include export information in the productivity process.

Estimation procedure

The first stage in ACF is given by rewriting (1) as $y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + \omega_{it} + f_t^{-1}(m_{it}, k_{it}, l_{it}) + \epsilon_{it}$, where f_t^{-1} is the investment proxy for productivity. In our case, in order to take into account the different optimal input choice that firms under ETS could make, we include the ETS status in the proxy for productivity, so that the monotonicity assumption would not be violated.

The first stage is written as:

$$y_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m m_{it} + f_t^{-1}(m_{it}, k_{it}, l_{it}, ETS_{it}) + \epsilon_{it} \tag{3}$$

Following Ackerberg et al. (2015) k_{it} is chosen at $t-1$ while l_{it} is chosen at time $t-b$ where $(0 < b < 1)$. Therefore, in the first stage we do not identify labor or capital elasticities, we only obtain the expected output.

In the second stage we identify β_l and β_k using two independent moment conditions of the productivity shock ξ_{it+1}. These are obtained by the other crucial assumption illustrated above: the productivity follow a first-order Markov process. That is, xi is mean independent of all information known at time t. Given the endogenous productivity process (2), we rely on the following moment conditions:

$$E\left\{\xi_{it}(\beta_m\beta_l\beta_k)\begin{pmatrix} m_{it-1} \\ l_{it-1} \\ k_{it} \end{pmatrix}\right\} = 0 \tag{4}$$

where ξ_{it} is obtained exploiting the Markov chain assumption: $\omega_{it} = E(\omega_{it}|\omega_{it-1}) + \xi_{it} = g(\omega_{it-1}, ETS_{it-1}) + \xi_{it}$. We employ generalized method of moments to estimate labor and capital elasticities. Then, we use these estimates to recover the implied productivity.

3.2 EU ETS effect estimation

In order to identify the causal effect of the introduction of the Emission Trading System, we use the potential outcome framework. We estimate average effects of the treatment on the treated. We define $ETS_i = 1$ if firm i has all its plants under ETS regulation throughout all its phases, $ETS_i = 0$ if none of its plants is under ETS. Our objective is to produce an estimate of the ETS' treatment effect on the treated for some variables of interest, such as firms' productivity.

Our identification strategy is based on a difference-in-differences matching approach. Given the ETS assignment into treatment is not random, as described in Section2.1, firms in the treatment group tend to be bigger than firms in the control group (See Table2 for details). Since firm size is probably correlated to firm productivity growth, unconditional diff-in-diff would be biased. To construct a meaningful control group for the ETS firms, we implement strategies that condition on observable covariates. Comparing firms that are similar in size and other observable characteristics helps in satisfying the parallel trend assumption required by the diff-in-diff, in the spirit of Heckman et al. (1997). The assumption is violated if the underlining determinants of productivity, such as the investments in technology, change differently in treated and matched firms for reasons other than the ETS.

In creating our control group, we refer to the literature that follow the seminal work of Rosenbaum and Rubin (1983), using the propensity score (i.e., the conditional probability of treatment) as a synthetic measure to control for several covariates. An alternative to the matching strategy would have been to leverage the discontinuity in treatment assignment and compare firms at the cutoff. In fact, albeit they vary by industry, the rules for inclusion into ETS are sharp and known. Unfortunately, data on individual installations' thermal input and (especially) output capacity are private information and we cannot observe it.

Given these premises, the set of firms' characteristics chosen to specify the propensity score is crucial. We want to provide narrow matching criteria, to be sure that the matched firms are in fact similar to the treated ones. In these regards, we adopt the approach of Calel and Dechezlepretre (2016) and we impose exact matching within strata defined by the intersection of industry and geographical region. Exact industry matching, performed at the 2-digit NACE level, controls for industry-wide exogenous changes in market conditions and accounts for industry-specific innovations in production. Exact geographical matching, performed on five Italian macro-areas[5], helps to control for local market conditions and changes in local institutions.

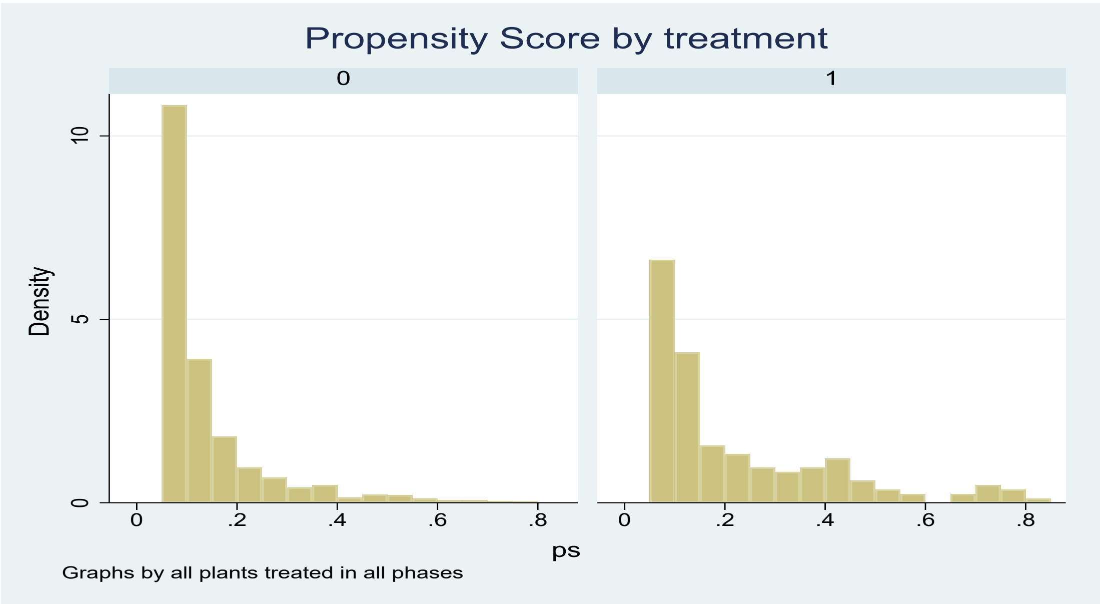
To provide a comparison measure for firms within the same stratum, we parametrically specify the propensity score as a function of pre-treatment age, gross output, capital, (log)

[5]The five macro-regions, corresponding to the first level of the Italian "Nomenclature of Territorial Units for Statistics" (NUTS-1), are: Nortwest, Northeast, Center, South, Islands.

number of workers and number of plants. We use 2002 data to avoid the risk of firms' strategic sorting outside of treatment:[6] the ETS had just been announced and the selection rules were not well defined yet, therefore it is impossible that firms have influenced the treatment assignment.

We have at least one firm on 65 strata, i.e. distinct combination of industry and geographical area, but we are able to estimate nontrivial propensity scores only for 25 of these.[7] Furthermore, we are forced to restrict ourselves to only those firms for which we have data for each variables included in the specification of the propensity score (79,430 firms). As a result, we initially restrict our scope from 91,128 firms to 41,206 (out of which 255 are treated according to our definition).

Figure 3: Propensity Score by treatment.



Notes: We plot the propensity score for treated firms (firms that are under ETS in the three phases) and untreated ones (firms that have never been under ETS). We restrict the sample away from 0 and 1 to graphically show the overlapping region. The matching procedure is furthermore refined by imposing within stratum matching.

Visual exploration of Figure 3, suggest that not every treated firm has a sufficiently similar one to compare to: a majority of firms in our dataset is in fact sensibly smaller than those under ETS. Notwithstanding, a common support can be established for most

[6]For the number of plants we use the closest year available to us, which is the 2004

[7]This means that those strata that are particularly sparse, because they contain no or very few firm in treatment or in control, are dropped. The excluded strata tend to be, but are not limited to, those of Center Italian firms in the manufacture of leather clothes and products, wood products, electrical and optical equipment, and transport equipment.

of the strata and a significant overlap is found for the majority of the firms, as shown in Appendix B, so that they could be matched to at least one in the control.

In order to perform the matching, we opt for a nearest neighbors selection with replacement and caliper. Our preferred estimates are based on the comparison with up to five nearest neighbors. We explore as well with one and twenty nearest neighbors, although the results do not change much because of the limited number of matched firms.

4 Results

Table 3 reports the estimated treatment effect based on the difference-in-difference matching estimator described in Section 3.2.

In all the specifications, we impose a caliper, i.e. a threshold in the maximum score distance, equal to 0.1. That is roughly equal to two standard deviations of the propensity score. We consider this a conservative choice that helps addressing the exceptional size of some treated firms: the number of matched treated firms drops to 228 (27 are dropped). We explore different calipers, generally with consistent results. Yet, we find the choice of the caliper to be very important in this context: while a too small caliper restricts the number of matches, leaving too few observations for reliable inference, a caliper that is too big results in loose matches.

Our estimates are based on one-to-five nearest neighbor matching. Each firm is matched on average with 4.7 firms. The counterfactual for each firm regulated by the policy is constructed starting from the 835 unique firms matched, as the mean outcome calculated among the five untreated firms with the most similar propensity score.

In column 1 we report the nearest neighbor matching with caliper, without adding any other covariate. In column 2 we report the result adding the industry fixed effect. In column 3 we add as covariates "netbuyer", a dummy variable equal to one if the firm emitted more than the initial allocated permits. The results shown in column 4 add firm fixed effects.

The results show a significant positive effect of the EU ETS on firm-level productivity ranging between 9.7 and 13.7 percent under all specifications.

In addition to the average treatment effect for the entire compliance period, we also estimate the annual effects of the EU ETS in order to investigate variations in the impact

Table 3: Matching Diff-in-Diff

VARIABLES	(1)	(2)†	(3)	(4)
policy	0.137***	0.132***	0.0969***	0.0972***
	(0.0326)	(0.0318)	(0.0503)	(0.0278)
netbuyer			0.111	
			(0.0738)	
policy * netbuyer			0.0558	
			(0.0661)	
Constant	0.236***	0.151	0.178***	0.255***
	(0.0372)	(0.105)	(0.0544)	(0.0375)
Industry fixed effects	no	yes	no	no
Firm fixed effects	no	no	no	yes
Observations	4,527	4,527	4,511	4,527
Number of id				228

Bootstrapped (1000 reps) standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

† The Bootstrap procedure produces several errors since some industries are not enough populated and some replications cannot produce standard errors in that case. Therefore we report here clustered standard errors instead.

over time and test the parallel trend assumption for the years before the treatment.

In Table 4 we report the results of the same specifications presented in Table 3, column1 and 4. In both specifications, we find a strong positive and significant effect of the policy in 2007. It is not surprising to see that the effect of the policy is delayed by two years since April 2006 was the real beginning of ETS in Italy.

The two specifications show a significant positive effect during the second and third compliance period. The positive effect of the policy in the third phase is an interesting result: this is the first paper that shows results for this phase in which the level of stringency of the cap was higher and increasing every year. Moreover, not only CO_2 is regulated but also other pollutants emissions and the allowances are allocated mainly through auctions. However, the higher stringency of the policy seems not to affect negatively firms' productivity.

In order to examine the parallel trend assumption, we report the coefficients of the annual treatment effect for the period before the policy. The annual treatment effect is generally not significant in the pre-treatment period.

A more intuitive way to show the same results is with the aid of a simple graph plotting the difference in the logarithm of total factor productivity of matched EU ETS and non-EU ETS firms, both before and after the EU ETS came into effect (see Figure 4). There are several noteworthy features of this graph. Firstly, matching appears to have produced a set of EU ETS and non-EU ETS firms roughly comparable prior to 2005. Secondly, the difference in productivity begin to diverge from zero after 2005, coinciding with the introduction of the new policy.[8] During the Second Phase the effect of the policy is still positive, even if the price of EUA felt. The first years of the Third Phase show again a positive effect of the policy, suggesting that the higher stringency level of the policy is not affecting negatively firm outcome.

Possible channels

Once we observe a positive effect of the policy or, at least, non negative, we want to identify the channels through which the policy enhance the total factor productivity. The first candidate to explain the different variation in TFP between regulated and unregulated firms is a variation in real capital and/or labor expenditures.

The second candidate is the different evolution of input elasticities. In order to further

[8] Although the official starting of the policy is 2005, the real beginning of the policy is April 2006.

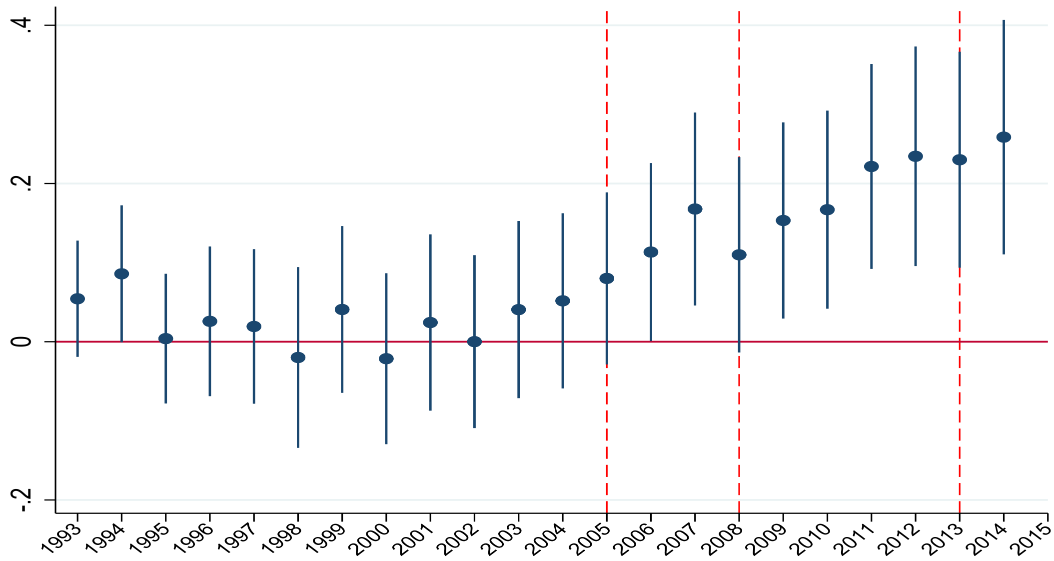
Table 4: Event Study

		(1)	(2)	(3)	(4)
			s.e.		s.e.
Pre-treatment	y1994	0.0543	(0.0360)	0.0538*	(0.0320)
	y1995	0.0859**	(0.0425)	0.0690*	(0.0390)
	y1996	0.00393	(0.0406)	-0.0130	(0.0376)
	y1997	0.0258	(0.0460)	-0.00361	(0.0454)
	y1998	0.0193	(0.0476)	-0.00380	(0.0449)
	y1999	-0.0199	(0.0544)	-0.0537	(0.0534)
	y2000	0.0408	(0.0522)	0.0219	(0.0479)
	y2001	-0.0214	(0.0536)	-0.0283	(0.0477)
	y2002	0.0243	(0.0565)	-0.0118	(0.0517)
	y2003	0.000137	(0.0560)	-0.0255	(0.0505)
	y2004	0.0406	(0.0576)	0.00548	(0.0527)
Phase I	y2005	0.0517	(0.0557)	0.0183	(0.0490)
	y2006	0.0801	(0.0537)	0.0419	(0.0496)
	y2007	0.113**	(0.0552)	0.0719	(0.0516)
Phase II	y2008	0.168***	(0.0599)	0.115**	(0.0537)
	y2009	0.110*	(0.0603)	0.0558	(0.0547)
	y2010	0.153**	(0.0616)	0.111**	(0.0545)
	y2011	0.167***	(0.0645)	0.120**	(0.0543)
	y2012	0.222***	(0.0642)	0.148***	(0.0547)
Phase III	y2013	0.234***	(0.0693)	0.165***	(0.0600)
	y2014	0.230***	(0.0718)	0.132**	(0.0599)
	y2015	0.259***	(0.0755)	0.133**	(0.0619)
	Constant	0.215***	(0.0557)	0.251***	(0.0556)
	Firm FE			yes	
	Obs.	4,527		4,527	
	# id			228	

Bootstrapped (1000 reps) standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 4: Difference in log(TFP) between treatment and comparison firms over time.



Notes: We plot the difference in logarithm of the total factor productivity computed with ACF procedure of matched EU ETS and non-EU ETS firms, both before and after the EU ETS came into effect.

investigate production function specifications, we estimate the elasticities of capital and labor for the firms not subject to ETS before the introduction of ETS, the extra effect due to being a firm that will be regulated by ETS, the extra effect of firms not under ETS after the introduction of ETS and being under ETS after the introduction of ETS. Preliminary results show different results in different sectors.

The remaining candidates are technological improvements or managerial changes.

We are still investigating these possible channels.

5 Conclusion

One of the main concern related to introducing carbon prices is related to the potential negative effect on economic performances. Debates on this topic have animated political discussion when new-phases proposal were drafted. European states are currently designing the Post-2020 EU ETS compliance Phase and Italian government has shown major concern on the economic effect of a more stringent regulation.

This paper contributes to this debate investigating the causal effect of the first two phases of EU ETS on total factor productivity of Italian manufacturing firms regulated by this directive.

The industry production function is structurally estimated, taking into account estimation biased due to the endogeneity and incorporating the possibility that the policy could affect both the input choices and the productivity process.

In order to estimate the effect of ETS on firm level TFP, we implement a matching diff-in-diff strategy in order to overcome the issues related to EU ETS design: only larger and more polluting firms are regulated by ETS. That is, we match regulated firms with similar unregulated ones.

We find that EU ETS has a positive effect on TFP (albeit in the last years not statistically significant). This contrasts with the government idea that ETS would have had a negative effect on regulated manufacturing firms. We also check whether the positive effect is due to a variation in capital or labor expenditures, and both of them seem not to be affected by the policy.

There are some caveats in the results when commenting the data and that will be the object of our further analysis. First, we estimate revenue based production function. Although we perform our analysis at two-digit level and we deflate prices, we are not able to disentangle possible pass-through effects from TFP dynamics.

Second, in the current analysis we do not allow the policy to change the production function but only to affect the total factor productivity. Further analysis will be preformed in this direction.

Lastly, we cannot estimate the effect of the ETS on emission intensity (the main objective of the policy) given the lack of available data. We are exploring different channels to obtain further data. These information would be crucial also to investigate the mechanism through which the policy affect the variation in total factor productivity.

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Appendix - Not for publication

A ETS regulated sectors and thresholds

The sectors and the threshold are specified in the Annex I of the Directive 2003/87/EC integrated by the Directive 2009/29/EC. "The thresholds values given below generally refer to production capacities or outputs. Where several activities falling under the same category are carried out in the same installation, the capacities of such activities are added together."

Activities: Power stations and other combustion plants $\geq$20MW

Oil refineries

Coke ovens

Production and processing of ferrous metals: metal ore (including sulphide ore) roasting or sintering installations; 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.

Cement clinker: installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tons per day or lime in rotary kilns with a production capacity exceeding 50 tons per day or in other furnaces with a production capacity exceeding 50 tons per day.

Glass: Installations for the manufacture of glass including glass fiber with a melting capacity exceeding 20 tons per day.

Lime, bricks, ceramics: 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 tons per day, and/or with a kiln capacity exceeding 4 m3 and with a setting density per kiln exceeding 300 kg/m3

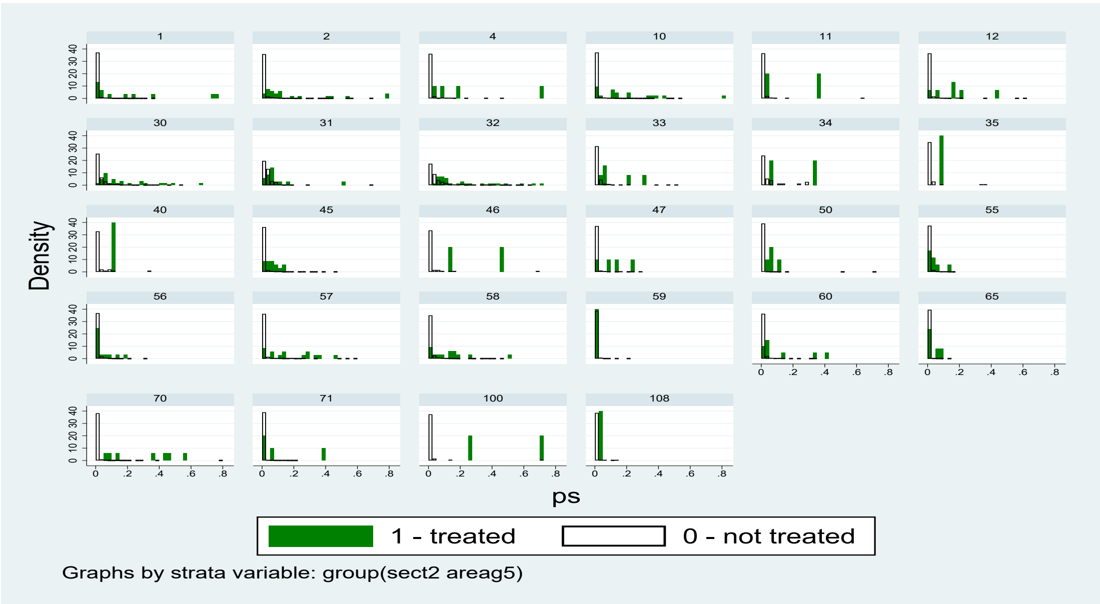
Pulp: from timber or other fibrous materials

Paper and board: with a production capacity exceeding 20 tons per day.

Aluminium (from phase 3) Petrochemicals (from phase 3) Aviation (from 1.1.2014)

B Matching procedure

Figure B.1: Propensity Score by stratum.



Notes: We plot the propensity score for each stratum with enough common support. We restrict the sample away from 0 and 1 to graphically show the overlapping region.