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## Abstract

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JEL Classification: D44, H23, L32, Q40, Q52

Keywords: electricity, emission permits, Multiunit auctions, cap-and-trade regulation, government-controlled companies

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# Revisiting Cap-and-Trade in Presence of Publicly Owned Polluters: The Case of Italy 2006-2018 *

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March 17, 2021

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# 1 Introduction

Climate change mitigation is currently a top policy priority. Carbon pricing is considered by economists and experts as an alternative that is superior to command-and-control regulation (see, among others, Borenstein (2012), Institute for Policy Integrity (2015), Borenstein, Bushnell, Wolak and Zaragoza-Watkins (2019), Andersson (2019)). Carbon pricing, through carbon taxes or through cap-and-trade systems, is also gaining traction as a policy. In 2019, about 15% of global greenhouse gases emissions were priced (World Bank 2019).[1] About half of them were traded within one of the 20 cap-and-trade arrangements active around the world (Icap 2019). Overall, the yearly value of permits consumed in 2018 in the cap-and-trade systems around the world totalled €144 billion (Refinitiv 2019), with a 250% increase over 2018. At the same time, in 2018, governments raised more than $44 billions in carbon taxes. In 2021, the scheduled massive expansion of China's cap-and-trade system will give emissions trading systems an additional remarkable boost. As a result, 14% of global GHG emissions would then be covered by cap-and-trade (and a total 20% of emissions would then be priced).

The electricity sector is of paramount importance in the carbon markets. In 2019, it originated more than 40% of global CO2 emissions from fuel combustion (International Energy Agency 2019)[2], as well as more than 60% of verified emissions in the European Union emissions trading system (EU-ETS henceforth) (Naegele and Zaklan 2019).

We empirically document that carbon pricing schemes do not work efficiently when the major firms in the market are government-controlled. We use the Italian electricity spot market example to show that government-controlled companies' behavior departs from profit-maximization. They do not internalize emission prices implied by the EU-ETS in their bids, which reduces pass-through of emission costs and decreases productive efficiency in the short run (day-ahead and spot markets). They also exhibit a different pattern of investment in emissions abatement as a function of emission prices vis-à-vis their private counterparts, i.e., there is a long run effect as well. In an important paper, Fowlie (2010) has documented such differential long run effects for the case of $NO_x$ emissions.

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[1] This figure does not include implicit carbon taxes, such as fuel taxes. Overall, in 2019, 57 carbon pricing initiatives were in place around the world.

[2] The figure includes electricity generation, combined heat and power generation, as well as non residential heat generation.

She analyzes the $NO_x$ Budget Program, a large emissions trading program that covers 19 Eastern U.S. states. Exploiting the variation in ownership structure (public vs private) and in the regulatory regimes to which different coal-fired generators are subjected, she shows that government-owned and rate-based regulated firms are more likely to adopt capital intensive compliance options than deregulated, privately-owned plants, which are then more likely to use permits. This is consistent with a difference in the cost of capital across the types of firms. We complement and extend her results in this paper by showing that government control leads to a stark inefficiency both in the short-run and in the long-run, resulting from the failure to equalize the marginal abatement costs across firms. In particular, we show that, unlike its rivals, Enel, the government-controlled major Italian generating company,[3] is not fully internalizing the emission costs in its bids. This holds true in general, and even when we compare very similar generating units, with roughly identical cost functions, subject to the same residual demand, but with different ownership. We argue, as a result, that Enel's objective function is different than that of its rivals.

In the electricity sector government control is not an exception. In 2018, in 18 out of the 30 countries that are part of EU-ETS, the government owns a share of the largest electricity generator (which is typically even larger than Enel in terms of the share of installed generation capacity) equal to or above that held by the Italian government in Enel.[4] Around the world, the 7 largest electricity generating companies by installed capacity (and 13 out of the 14 largest) are more than 50% owned by the national governments (International Energy Agency 2018).[5]

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[3] Enel is partially government owned, with the government owning a controlling stake and de facto appointing the management. Government ownership is at 23.6%, with other investors being fragmented.

[4] In particular, in 2018, out of the 30 countries (in addition to Italy - the other 27 EU member States, plus Norway, Iceland and Lichtenstein), 17 of them have their largest generator characterized by both a share of installed capacity above 30% of the total installed capacity in that country, and with the government of that country involved in that company with a share equal to or above that of Enel: Austria (Verbund), Bulgaria (BEH), Croatia (HEP Group), Cyprus (Electricity Authority of Cyprus), Czech (CEZ), Denmark (Orsted), Estonia (Eesti Energia), Finland (Fortum), France (EDF), Greece (PPC), Hungary (MVM Group), Poland (in this case the four mayor generators - PGE, Energa, Tauron, Enea - all have the government as shareholder with shares above 30%, and together they have a 90% market share), Slovakia (SE), Slovenia (HSE), Sweden (Vattenfall), Norway (Statkraft, although in that case most of the generation is hydroelectric), Iceland (Landsvirkjun).

[5] The first 7 companies by generation capacity in 2018 were: China Energy Investment Group (230 GW, fully state-owned), China Huaneng Group (172 GW, fully state-owned), China Huadian Corp (146 GW, fully state-owned), China Datang Corp (138 GW, fully state owned), Electricité de France (129 GW, 83.7% state owned), State Power Investment Corp, (China fully state owned), Korea Electric Power Corp (90 GW, 51% state-owned, by the Korea Development Bank and the Government of South Korea). Enel, ranking 8th in the list, is the first in which the government, which still has a control stake of 23.6%, does not hold the absolute majority. The first fully private company is Duke Energy Corporation, which ranks 15th.

Government ownership of large electricity generators is thus the rule, with some prominent exceptions, including United States, Germany, Spain and Australia. The most important paper that estimates the internalization and the pass-through of allowance prices to final prices in the EU-ETS framework, Fabra and Reguant (2014), analyzes one of the exceptions, i.e., Spain.[6] It finds that emission prices are almost fully internalized and fully passed through during the initial stages of the EU-ETS. Using a much longer time series, with the EU-ETS in place for over a decade, We find a very similar result for non-government controlled companies in Italy. However, the behavior of government-controlled companies is markedly different.

The efficiency of carbon pricing rests on the presumption that regulated firms are profit-maximizers. This assumption is necessary for carbon pricing to deliver an efficient abatement pattern across firms in the industry. In the short run, profit-maximizing firms consider the tax or the permits (direct or opportunity) cost in their production and pricing decisions, and, on aggregate, marginal abatement costs are equalized across firms and across sectors.[7] Under plausible assumptions on the competitive environment, carbon price yields higher equilibrium prices and lower equilibrium quantities, which also contribute to an emission reduction through a decrease in electricity demanded. In the long run, expected returns to investments in emissions reduction, determined by expectations on the evolution of carbon prices, are equalized across sectors.

**Simple example:** When firms are instead not profit-maximizers, carbon pricing fails to provide the correct incentives, and its static and dynamic efficiency properties diminish or vanish altogether. To see the failure of static efficiency, consider a simple case of two firms producing output $q$ using a single input $x$ and emissions $e$, so that $q = f(x, e)$, with $\frac{\partial q}{\partial x} > 0$ and $\frac{\partial q}{\partial e} > 0$. They operate in a perfectly competitive environment, where they face a price $p$. Both companies also face a regulated price per unit of emissions $p_e$, which they take as given (the price could be set through a tax or through tradable permits). Assume firm $i$ is profit-maximizing, while firm $j$ is not. In particular, firm $j$ does not fully respond to the environmental policy, and internalizes only

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[6] Other related papers (Hintermann (2016) and Nazifi, Trück and Zhu (2021)) also refer to exceptions, i.e., Germany and Australia.

[7] The resulting increase in prices, in turn, induces consumers to reduce demand, perhaps by adopting energy saving measures.

a portion $\phi \in [0,1)$ of the price per emission $p_e$. The objective function for firm $i$ is then:

$$\max_{x_i,e_i} \pi_i = pf(x_i,e_i) - C\left(x_i\right) - p_e e_i$$

The objective function for firm $j$ is instead:

$$\max_{x_j,e_j} \pi_j = pf(x_j,e_j) - C\left(x_j\right) - \phi p_e e_j$$

The first order conditions for the optimal choice of $e$, for $i$ and $j$ respectively, require:

$$p\left(\frac{\partial f}{\partial e_i} + \frac{\partial f}{\partial x_i}\frac{\partial x_i}{\partial e_i}\right) - \frac{\partial C}{\partial x_i}\frac{\partial x_i}{\partial e_i} = p_e \tag{1}$$

$$p\left(\frac{\partial f}{\partial e_j} + \frac{\partial f}{\partial x_j}\frac{\partial x_j}{\partial e_j}\right) - \frac{\partial C}{\partial x_j}\frac{\partial x_j}{\partial e_j} = \phi p_e \tag{2}$$

It follows directly from (1) and (2) that the marginal abatement costs for firm $i$ and $j$, represented by the left hand sides of the above equations, are, at the optimum, equal to two different amounts ($p_e$ and $\phi p_e$). The larger the difference $p_e - \phi p_e$, i.e., the smaller $\phi$, the larger the difference between the marginal abatement costs of the two companies in equilibrium, and the larger the inefficiency.

In addition, since policy makers set carbon taxes under the implicit presumption that firms internalize them in their objective function, a carbon tax applied to firms that are not maximizing profits may fail to achieve the desired target of emission abatement altogether.

We identify government control of firms as a source of deviations from profit-maximizing behaviors. Hortaçsu, Luco, Puller and Zhu (2019) identified an alternative reason of departure from profit maximization in the fact that some generators lack strategic sophistication. They use the Texan electricity market, where firms are private, as their example. They find that strategic sophistication is positively related to firms' size and to managerial education.

Our paper provides a novel stark channel that makes carbon pricing poorly suited as an environmental policy. Fowlie, Reguant and Ryan (2016), emphasize market power as an alternative channel leading to inefficient outcomes under carbon pricing. A number of additional papers have emphasized challenges and inefficiencies stemming from the imperfect design of carbon pricing policies, due either to their political feasibility constraints, or to the inefficient combination of carbon pricing with other forms of regulation. Borenstein et al. (2019) argue that capping emissions in a cap-and-trade system may prove politically infeasible. The high volatility of emission prices, in turn determined by high uncertainty in the business-as-usual emissions, is likely to be politically unacceptable, thus triggering the introduction of price floors and price ceilings that end up being binding with high probability. Other papers have emphasized inefficiencies triggered by the overlap of different policies. Böhringer and Rosendahl (2010) look at the interaction between cap-and-trade and command-and-control policies to stimulate renewables, and find that it may promote the inefficient utilization of relatively polluting conventional fuels. Inefficiencies stemming from their interaction are further exacerbated when, within a multi-jurisdiction ETS system, different command-and-control policies are implemented in different jurisdictions (Perino, Ritz, and van Benthem 2019). Abito (2020) estimates substantial abatement inefficiencies related to the overlap of carbon pricing with suboptimal economic regulation, in the form of rate of return regulation. Finally, the poor design of carbon policy, in particular related to its limited geographic scope, triggers inefficiencies associated to carbon leakage (see, for instance Fowlie et al. (2016)).

Another stream of papers has, instead, emphasized the positive effects of carbon pricing. Calel and Dechezleprêtre (2016) and Calel (2020) show that the EU-ETS boosts patenting of low-carbon technologies, while not crowding out patenting for the others. Gerarden, Reeder and Stock (2020) find that the efficiency of carbon pricing is not undermined by its interaction with upstream policies, such as the royalty surcharge on US federal coal.

Political economy considerations may well rationalize our finding that the objective function of government-controlled firms differs from profit maximization, and that government-controlled enterprises may pursue political goals (Shleifer and Vishny 1994). A government-controlled company affects the government's benefit function not only through the stream of profits it can extract from it, but also through its effects on the government's perception in the eyes of the public opinion, which, in turn, may affect the probability of the government to remain in power.

The implications of our results are perhaps even starker in an environment with a carbon tax than in one with a cap-and-trade system. While, when firms are profit-maximizing, the two policies are equivalent, as long as they are both carefully designed and politically accepted (Stavins 2020), they produce different results when firms are not profit maximizers. In this case, cap-and-trade, by capping emissions, at least mitigates them by design (unless firms grossly violate the emission rules (Martin, Muuls and Wagner 2016)). To the contrary, under a carbon tax, failure to internalize the carbon price may make the policy not only inefficient, but also ineffective in mitigating emissions, both in the short and in the long run.

Finally, based on our findings, we can draw the clear implication that the upcoming expansion of cap-and-trade in China, where the seven major generators are fully government-owned, is likely to bring about inefficiencies. A more efficient mitigation policy, in China, should, perhaps ironically, involve a command-and-control approach.

## 2 Primer on the Italian Electricity Market

The Italian market is a fairly representative one in Europe, not only because of the ownership structure of its main players, but also because of its size, its fuel mix, its organization and the timing of its liberalization.

In 2017, with a net generation of 285.1 TWh and a consumption of 320.4 TWh, Italy was the fourth largest electricity market in Europe. The fuel mix of the Italian electricity generation in 2017 is dominated by natural gas (44.27%), followed by renewables (40.83%), coal (13.47%) and oil (1.44%). In the last 15 years, the share of renewables has markedly increased (from levels of 18.26% and of 31.48% in 2006 and in 2012, respectively), mostly at the expense of oil (whose share exceeded 10% in 2006), and partly at the expense of coal (whose share peaked at 16.4% in 2012, and then declined). Hydro power has traditionally been by far the largest renewable source. In 2017, it still was the largest, albeit by a smaller margin, covering slightly more than a third of all renewables. All fossil fuel generator types frequently serve as marginal generation sources, with coal approximately 15% of time and natural gas close to 40%.

The Italian electricity sector started its transition from a vertically integrated monopoly run by Enel to a liberalized market in 1999.[8] Entry of generators competing with the incumbent was gradual but steady. Enel's share of generating capacity declined, from 44.97% in 2006 to 34.74% in 2012 and 27.52% in 2018. Enel remains the largest generator in Italy by capacity and by production.[9] Even after liberalization and partial privatization, Enel's control remains with the Italian government. The government directly controls 23.6 %, while other investors are fragmented (at the beginning of 2019, they were 57.6% institutional investors, and 18.8% retail investors). The government has had a controlling share of Enel throughout the period covered by our analysis.[10] While Italy is the major market for Enel, where it collects approximately half of its revenue and half of its profit, Enel is a global company, with a prominent presence, in particular, in Spain (where it controls Endesa), and in South America (Enel 2018). Based on generation capacity, it ranks eight in the world (International Energy Agency 2018). The two primary sources in Enel's generation mix in 2018 are coal (for a bit less than 40%) and hydro (for about a third). Compared to the average Italian generation mix, Enel is more focused on coal (in 2018, 80% of the Italian coal-fueled generation comes from Enel), and less on natural gas.

Another prominent generating company, Eni, is partially government-controlled, with the government holding, in 2018, 30.10% of shares (25.76% through the government-owned investment bank Cassa Depositi e Prestiti). In 2018 Eni ranked fourth in terms of generation capacity, after Enel, Edison and A2A. Eni's generation mix is almost exclusively based on natural gas, with no coal and almost no renewables.

Along with generation, competition intensified in the retail sector as well. In 2004, as a fundamental step in the liberalization process, Italy started a designed power exchange market, where transactions occur under the coordination of a system operator.[11] Besides the organized spot market, electricity transactions in Italy can also occur via bilateral physical forward contracts. Many electricity markets around the world are now deregulated and transactions, similarly to Italy, occur

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[8] See 1999 Decreto Bersani, available at:
`https://it.wikipedia.org/wiki/Decreto_legislativo_16_marzo_1999,_n._79`.

[9] See ARERA (Various years).

[10] Enel was fully government-owned until 1999. Government share then declined to 68.3% after the first privatization round. It then declined further to 41.60% in 2004 (including 10.25% held by the government-controlled investment bank Cassa Depositi e Prestiti). It then gradually reduced to 31% in 2009, then to 25.5% in 2015, and to 23.6% in 2016.

[11] By 2007, all Italian consumers have been entitled to choose their suppliers. Previously, supply for residential consumers was operated by a monopolistic government-owned procurement company, called the Single Buyer.

both in a spot market, and through bilateral contracts.[12] About two thirds (ranging from 58% in 2011 to 72% in 2013, 2017 and 2018) of electricity is traded in the power exchange, about one third via bilateral forward contracts (Gestore Mercato Elettrico 2018).

The power exchange includes three major markets, the day-ahead, the intraday and the re-dispatch market. The day-ahead market plans for essentially all of the expected electricity. It is organized around multiunit uniform price auctions where generators submit their hourly bids via a supply schedule. Generators are paid the market-clearing prices specific to each hour and each zone,[13] while the demand side pays a quantity-weighted average of the different zonal prices for the hour. The intraday market allows for re-trading to update positions closer to the delivery time. In the re-dispatch market, the system operator requires power units to change their initial commitments (by increasing or decreasing them), so as to solve congestion issues that persist after the day-ahead and the intraday markets. The day-ahead market clears a lion's share in the power exchange. In 2018, about 213 TWh were traded in the day-ahead, a little more than a tenth of that (25 TWh) were traded in the intraday market, while around 33 TWh were traded in the re-dispatch market.

Prices on the Italian day-ahead market are high with respect to other major European markets, but there are indications of convergence. In 2008, the average Italian day-ahead price was 86.99 €/MWh (compared to 65.76 €/MWh in Germany, 69.15 €/MWh in France and 64.44 €/MWh in Spain), in 2013 it was 62.99 €/MWh in Italy (compared to 37.78 €/MWh in Germany, 43.24 €/MWh in France and 44.26 €/MWh in Spain), in 2018 it was 61.31 €/MWh in Italy (compared to 44.47 €/MWh in Germany, 50.20 €/MWh in France and 57.29 €/MWh in Spain). Figure 1 depicts average wholesale electricity prices in Italy.

As Figure 1 shows, prices in Italy are highly cyclical and volatile. This reflects on the one hand

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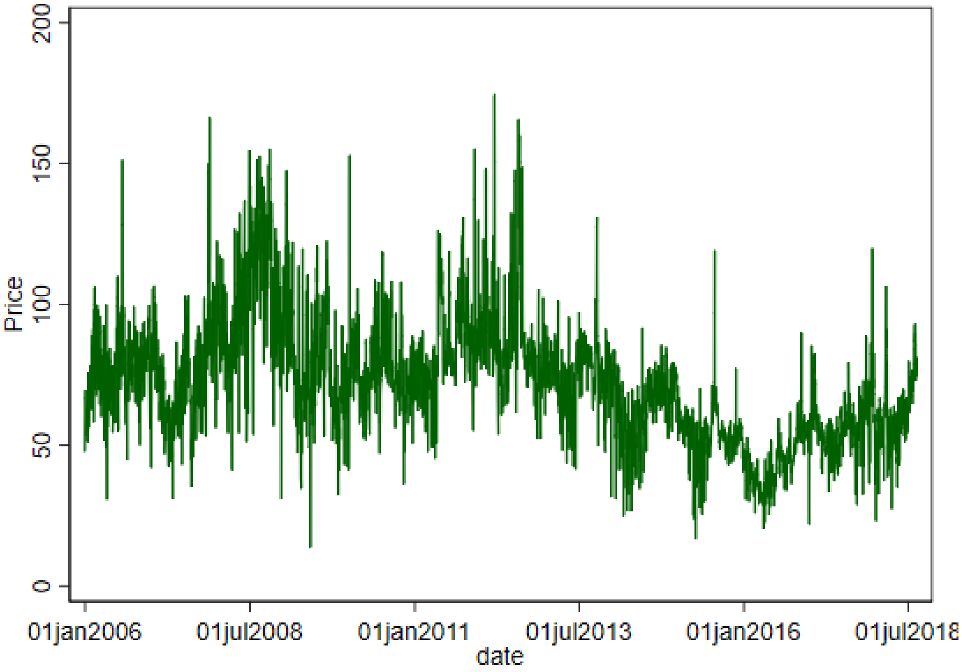
[12] Examples of countries whose electricity markets are organized similarly to the Italian one include all the major European countries (e.g., Germany, France, Great Britain, Italy, Spain, the Netherlands, Poland), several regions in the United States covering approximately 70% of the U.S. population (with the six exchanges ERCOT, PJM, CAISO, MISO, NYSO, ISO-NE, see `https://www.eia.gov/todayinenergy/detail.php?id=40913`), Australia, New Zealand, Japan. Other power exchanges, such as, for instance, the Colombian and the Brazilian one, have different rules (Cramton 2017).

[13] There are two major exceptions to this rule. First, renewable generation satisfying certain conditions is paid a fixed rate. Second, some units, designated by the System Operator (SO) as essential for a smooth network operation, must be ready to produce whenever asked to by the SO, and receive a fixed remuneration based on their average cost.

Figure 1: Electricity prices



Note: This figure depicts the average daily clearing price of the Italian day-ahead market. We use bidding data and for each day average over geographical zones and hours of day.

seasonal and daily cyclical variations, and on the other hand non cyclical changes, due, among other things, to weather conditions on both the demand and the supply side, and, on the supply side, to the availability of intermittent renewables. These are fairly established and common patterns in the electricity markets (see, e.g., Fabra and Reguant (2014)).

The overall market is divided into a number of zones. A zone is defined as a geographical unit within which the price on the day ahead market is the same at any given point in time. In any hour, day ahead prices may differ across zones. This happens when the transmission line linking them is congested. In 2018, the South had lower average day-ahead price than the North (59.37 to 60.71), the prices vary over time with a standard deviation of 22.

Besides the two government-controlled companies, Eni and Enel, the other generators are private (such as E.on or Sorgenia) or controlled by foreign government-owned companies, such as Edison (controlled by the French government-owned generator Electricité de France), which ranks third by installed capacity in 2018. Finally, some generators are controlled by local governments. These include A2A, where the municipalities of Brescia and Milan, in 2018, were holding 25% of the shares each. In 2018, A2A was the second market player by installed capacity.

The companies controlled by the Italian government might have an incentive to respond to political incentives in their pricing decisions, since the companies' performance affects the citizens' perceptions of the government itself and the government essentially controls all personnel decisions. Importantly, the dimension of performance that citizens deem important to assess the government's ability or benevolence may not necessarily coincide with profits, but might instead correspond to outcomes such as the electricity price level or its volatility. Companies controlled by foreign governments presumably do not face similar political incentives, as a foreign government is not affected by the perceptions of Italian residents. In the case of companies controlled by municipalities, given zonal pricing and a single national price for buyers, a disproportionate portion of the benefits of strategies that potentially deviate from profit-maximization would be enjoyed by voters in other municipalities, while the cost of such strategies would be incurred locally in the form of lower profit. As a result, political incentives seem very much diluted, with the likely result that these companies rationally attempt to maximize profits. Of the two companies controlled by the Italian government, Enel and Eni, our analysis focuses on Enel. This choice is motivated by the different generation mix of the two companies. Eni uses almost entirely natural gas, with an emission rate much lower than coal, which is the dominant fuel used by Enel. As a result, the inefficiencies that Eni could potentially trigger would be far less severe than those caused by Enel.

# 3 Data

## 3.1 Wholesale Auction Market

We use detailed data on the hourly bids submitted to the Italian day-ahead electricity market from January 2006 to August 2018 that are made publicly available through the Italian system operator with a slight time delay.

Generators, each day, submit up to 24 hourly supply functions, one per-hour,[14] while traders and

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[14] The maximum number of price quantity pair in a supply bid for a unit has varied over the years, from 4 to being uncapped.

large consumers submit up to 24 hourly demand functions. Bids are then ordered, and aggregate demand and supply functions are constructed. When inter-zonal transmission capacity is exceeded, the market is subdivided into several zonal markets, each of which is cleared by a different zonal price. We observe all the price-quantity pairs submitted by each firm for each of their production units for each of the 24 hours of the day for the 13 years in the sample, as well as all the price-quantity pairs submitted by the buyers. The data also include the amount of electricity sold via bilateral physical contracts, so we observe the entire hourly net production of each generating unit.

Table 1 summarizes the bidding and production data that we use in our analysis. As we will describe in more detail below, we focus on ex post marginal bids as in Fabra and Reguant (2014).[15] Panel A summarizes bids that are ex post marginal, and Panel B summarizes bids that are both ex post marginal and not submitted as a first step of the offer curve. Since observations summarized in Panel B will be used in our analysis that leverages the necessary condition for static profit maximization, the well-documented presence of ramp-up costs (Wolak 2001) and other dynamic constraints (Reguant 2014) might distort this condition, especially at the first step of the supply curve.

In addition to the data on electricity generation, we use publicly available geocoded weather data, on temperature, humidity and wind speed.[16]

### 3.2 Marginal costs

Our data allow us to measure the marginal costs incurred by thermal power plants. For each thermal unit, we have engineering estimates of the "heat rate", i.e., the rate at which, for each amount of instantaneous electricity supplied, the power plant converts the energy content of the fuel into electricity (provided by the Milan-based research consultancy company Ref-E). We also have engineering estimates of different fuels' heating value (Ref-E). We complement them with data on fuel costs. Fuel costs for natural gas units are the monthly natural gas spot prices in Italy plus a distribution charge, obtained from Ref-E. For coal units, we use the monthly average CIF (cost,

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[15] In principle, we could even enlarge the data set if we were to take a stand which bids have positive probability of being marginal, of which the ex post marginal ones are a strict subset by definition.

[16] We use data from `https://archivio-meteo.distile.it/` for 2006-2016, and from `https://www.meteo.it/` for 2017-2018. We use data of the provincial capital of the province where the power plant is located.

insurance and freights) for coal delivered to Italy (obtained from Platts) plus a distribution charge obtained from Ref-E.

### 3.3 Emission Permits

The EU-ETS is the largest multi-national emissions trading scheme in the world. It covers installations that are collectively responsible for almost 50% of the EU's emissions of $CO_2$, in the power generation sector, in aviation (as of 2010), and in other energy intensive industries (including iron and steel, pulp and paper, refineries, and cement).

Under the EU-ETS, each regulated installation must surrender every year an amount of allowances corresponding to its emissions. Allowances are initially allocated by member states to industrial operators through two different methods. In the first trading period (Phase 1), covering 2005–2007, as well as in the second period (Phase 2), covering 2008–2012, the overwhelming majority of allowances (above 90%) has been initially freely allocated to industrial operators based on recent emissions, under the so-called grandfathering (Chevallier 2012). In the third trading period (Phase 3), covering 2013-2020, allowances have been primarily allocated via an auction.[17] After the initial allocation, the operators within EU-ETS may re-assign or trade their allowances by several means: (i) privately, moving allowances between operators within a company and across national borders, (ii) over the counter, using a broker to privately match buyers and sellers, and (iii) trading on the spot market of one of Europe's climate exchanges. Allowances do not expire and can be transferred across time, the only relevant exception having been the impossibility to transfer allowances issued during Phase 1 to Phase 2. For our analysis we use the time series of EU-ETS futures prices obtained from Reuters. The prices of a tonne of $CO_2$ emission exhibits substantial variation. In Phase 1, they ranged from above €30 to almost 0, at the end of 2007, before the expiration of allowances issued until then. In Phase 2 and 3, they also ranged from above €30 in 2008 to around €3 in 2013. Expectations on the future stringency of the cap, along with demand considerations, shape the market price.

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[17] In particular, in the power generation sector all of the permits have been auctioned off in Phase 3 (with the only exception of new member states, that have received some permits for free). In the manufacturing sector, the share of auctioned permits has ranged from 20% (in 2013) to 70% (in 2020), while in the aviation industry most of the allocation (85%) has been free. Overall, these patterns have been consistent with the EU Directive 2018/410, which

Table 1: Summary statistics

| | mean | sd | p25 | p50 | p75 |
|---|---|---|---|---|---|
| **Panel A: marginal bids** | | | | | |
| ***All*** | | | | | |
| EUA price | 11.03 | 7.81 | 4.90 | 9.15 | 16.08 |
| Coal price | 12.51 | 2.95 | 10.07 | 11.68 | 14.75 |
| Gas price | 35.43 | 7.59 | 30.25 | 34.96 | 38.98 |
| Observations | 231,662 | | | | |
| ***Public*** | | | | | |
| Bid | 71.01 | 34.99 | 48.11 | 64.50 | 90.01 |
| Marginal cost of permits | 13.75 | 14.67 | 3.38 | 8.99 | 18.40 |
| Total quantity produced | 163.60 | 188.76 | 37.41 | 106.77 | 222.43 |
| Marginal bid quantity | 111.58 | 122.64 | 25.00 | 70.00 | 157.90 |
| Marginal fuel cost | 42.11 | 20.89 | 26.79 | 37.99 | 51.37 |
| Capacity of the generator | 976.52 | 593.99 | 510.00 | 935.95 | 1210.00 |
| Utilization | 0.18 | 0.17 | 0.06 | 0.14 | 0.25 |
| Observations | 138,030 | | | | |
| ***Private*** | | | | | |
| Bid | 78.77 | 42.70 | 51.35 | 65.71 | 90.00 |
| Marginal cost of permits | 11.46 | 11.95 | 3.26 | 7.46 | 14.56 |
| Total quantity produced | 74.12 | 77.27 | 19.91 | 50.52 | 104.68 |
| Marginal bid quantity | 61.10 | 59.93 | 16.89 | 43.10 | 87.44 |
| Marginal fuel cost | 46.40 | 21.43 | 33.01 | 40.37 | 53.35 |
| Capacity of the generator | 413.59 | 198.80 | 248.00 | 378.00 | 597.00 |
| Utilization | 0.19 | 0.18 | 0.06 | 0.14 | 0.29 |
| Observations | 93,632 | | | | |
| **Panel B: optimal bids** | | | | | |
| ***All*** | | | | | |
| EUA price | 11.36 | 8.33 | 4.77 | 10.25 | 16.35 |
| Coal price | 12.41 | 3.06 | 9.86 | 11.63 | 14.73 |
| Gas price | 35.44 | 7.53 | 30.77 | 34.94 | 38.78 |
| Observations | 138,515 | | | | |
| ***Public*** | | | | | |
| Bid | 70.33 | 34.57 | 48.00 | 64.50 | 89.01 |
| Marginal cost of permits | 7.16 | 7.17 | 1.41 | 4.95 | 11.52 |
| Total quantity produced | 490.17 | 455.68 | 167.59 | 340.00 | 632.23 |
| Marginal bid quantity | 113.73 | 129.17 | 23.69 | 65.56 | 160.00 |
| Marginal fuel cost | 51.58 | 27.47 | 30.24 | 46.27 | 64.82 |
| Capacity of the generator | 1347.19 | 650.23 | 1056.00 | 1151.00 | 1815.00 |
| Utilization | 0.37 | 0.27 | 0.18 | 0.28 | 0.55 |
| Observations | 81,905 | | | | |
| ***Private*** | | | | | |
| Bid | 67.15 | 29.35 | 49.72 | 62.54 | 77.75 |
| Marginal cost of permits | 4.57 | 3.96 | 1.94 | 3.57 | 5.54 |
| Total quantity produced | 474.76 | 406.58 | 220.93 | 342.46 | 645.00 |
| Marginal bid quantity | 67.94 | 64.86 | 19.57 | 48.20 | 100.00 |
| Marginal fuel cost | 50.38 | 16.90 | 38.99 | 47.21 | 59.42 |
| Capacity of the generator | 1403.09 | 694.99 | 959.11 | 1128.00 | 2218.50 |
| Utilization | 0.34 | 0.23 | 0.20 | 0.27 | 0.41 |
| Observations | 56,610 | | | | |

This table shows the summary statistics for the main variables. In panel A, we restrict the sample to all marginal bids as they set the electricity price, and we work with these for the bulk of this paper. The EUA price shows the price of the permit in EUR per tonne of CO2. Coal price and gas prices are in EUR per tonne. The marginal cost of permits shows the marginal cost of EUA for producing an additional MWh of electricity for the marginal generator, similarly for marginal fuel costs. Capacity is in MW. Utilization refers to quantity produced as a share of capacity. Panel B provides analogous summary statistics for the sample of all bids used for the structural analysis (bids for which the first order conditions likely hold, were the exact conditions are defined in Section 5.2).

Figure 2: Emission permit prices

NOTE: This figure shows the daily price of the EUA futures based on Reuters.

## 4 Case Study

We begin our empirical analysis with a simple case study of two coal fueled generators, Fusina and Monfalcone. These generators are geographically close (as of 2012 both part of the North zone[18]), they are very similar in size and have almost identical heat curves. Crucially, they differ in their ownership. Fusina is owned by the government-controlled generator Enel, while Monfalcone by the non-government controlled company A2A. As a result, it is reasonable to think that, if we detect any differences in their behavior, this could be attributed to their ownership structure.

We show that, in fact, they differ in how they respond to changes in emission allowances prices. To do so we project their bids on the price of the EUA permit. In Columns 1-2 of Table 2, we include no controls, in Columns 3-4 we condition on produced quantity. The quantity produced might alter the marginal costs and therefore affect the response to a cost shock. Finally in Columns 5-6 we

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set a target of 57% of the permits to be allocated through auctions in Phase 3.

[18] Until 2011, Monfalcone was part of a different, very small, zone, designated as the Monfalcone zone.

Table 2: Case study: Comparing private and public generators in Fusina and Monfalcone

| | (1)<br>bid | (2)<br>bid | (3)<br>bid | (4)<br>bid | (5)<br>bid | (6)<br>bid |
|---|---|---|---|---|---|---|
| EUA price | 1.312$^{***}$ | 0.341$^{***}$ | 1.333$^{***}$ | 0.125$^{***}$ | 0.687$^{***}$ | 0.337$^{***}$ |
| | (0.0156) | (0.0112) | (0.0155) | (0.0094) | (0.0213) | (0.0132) |
| Controls | None | None | Quantity | Quantity | All | All |
| Ownership | Private | Public | Private | Public | Private | Public |
| N | 201,729 | 160,977 | 201,729 | 160,977 | 143,243 | 117,151 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

*Notes*: This table shows results of projecting all positive bids on price of EUA permits. Quantity controls refer to awarded quantity: proxied by a linear and quadratic term. All controls refer to coal prices, precipitation, humidity, wind speed, year trend, time of the day FE, month FE, day of week FE.

include a wide range of controls: coal prices, weather controls (wind speed, humidity, precipitation), time trends, month FE, time of day FE and day of week FE.

Our results suggest (across a wide array of specifications) that the prices of the CO2 permits affect the bidding behavior of the A2A generator (Monfalcone) more than the publicly owned generator in Fusina. The public generator hence responds less to a change in emission costs. In the next sections we show that this is a widespread phenomenon in the electricity market, a pattern that holds both in the short run (in the day-ahead and spot markets) and in the long run (at the investment frequency level).

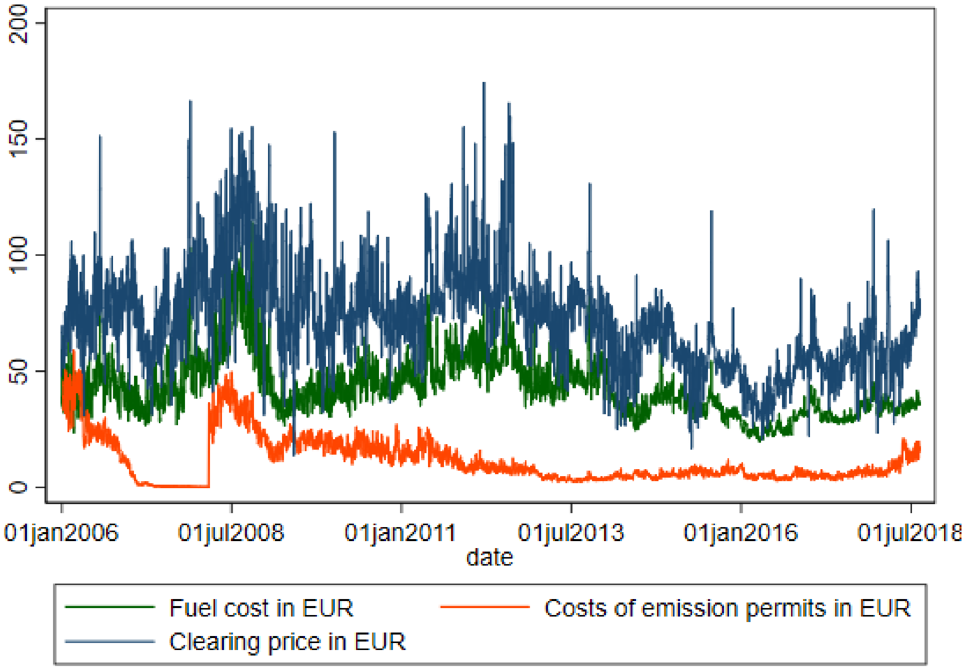
# 5 Empirical Results

## 5.1 Pass-through of Emission Costs

In the initial step of our analysis we study pass-through of emission prices and its dependence on the ownership structure of the price setting company. Since heterogeneity in pass-through of marginal costs might be caused by differences in market power, in the next section we introduce a bidding model to address this issue explicitly.

To study the average pass-through in our sample, we begin by estimating the following regres-

Figure 3: Electricity prices and costs



Note: This figure compares average daily clearing price of the Italian day-ahead market with marginal costs of the corresponding marginal generator. Marginal costs are calculated using heat curve data, EUA prices and monthly coal and gas prices.

sion:

$$p_{tzh} = \rho\tau_t e_{tzh} + \beta_0 \mathbf{X}_{tzh} + \beta_1 \mathbf{I}_{tzh} + \epsilon_{tzh} \tag{3}$$

where $p_{tzh}$ is the hourly zonal electricity price, $\tau_t e_{th}$ is the marginal emission cost for the price-setting generator in hour $h$ and zone $z$, composed of the price of emission allowances $\tau_t$ and the emission rate of the marginal (price-setting) generator $e_{tzh}$, and the corresponding coefficient $\rho$ is the equilibrium pass-through.

As in Fabra and Reguant (2014), we use an instrumental variable approach to identify the pass-through $\rho$ on the marginal emission cost $\tau_t e_{tzh}$ on the marginal hourly zonal bid, which sets the hourly zonal price. In particular, we instrument the marginal costs with the emission permit costs.[19]

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[19] The marginal emission cost is potentially endogenous, as the marginal emission rate, depending on the identity of the marginal generator, is affected by unobserved demand or supply shocks. This is particularly problematic, since different technologies exhibit both starkly different emission rates, and starkly different fuel costs. For example, natural gas is more expensive than coal, so it is more likely to be the price-setting technology when prices are high,

We include year, month of sample, day of the week, and hour fixed effects. In some specifications, we additionally include month*hour fixed effects, to account for changes in sunlight across months potentially affecting demand as well as photovoltatic supply, as well as demand shifters (temperature), and supply shifters (wind speed, given the importance of wind generation, and humidity, correlated to photovoltaic generation). We will study pass-through of both emission permit costs and fuel costs. We additionally control for emission prices when studying pass-through of fuel costs, and for fuel prices when studying pass-through of emission costs.

Results presented in Column 1 of Table 3 show that roughly one half of the allowance price is passed through to final consumers. This pass-through rate is at odds with results in Fabra and Reguant (2014), who obtain an almost complete pass-through of about 85%. This difference could be explained in different ways. First, Fabra and Reguant (2014) cover an initial, experimental, stage of the EU-ETS, with fairly tiny price variation, and it is not clear what expectations about future emission prices market participants might have had. Second, the Spanish market might actually not be a representative market for ETS. We focus on one particularly stark dimension of difference, that is, government ownership. At the time of Fabra and Reguant (2014)'s analysis, the Spanish government had no controlling stake in the two main electricity generating companies, Endesa and Iberdrola.[20]

We thus look at the extent to which the different ownership structure can account for the differential pass-through. We split the sample based on ownership structure. We run a first regression in which we study the cost pass-through for the government-controlled company, Enel, and a second one in which we study the pass-through for the rest of the companies. For expositional simplicity, in the rest of the paper we will refer to all the other companies as "private," or "non-government controlled," since in the vast majority of them (with the above discussed exception of Eni), the central government has no controlling stake. Columns 2 and 3 of Table 3 present the results

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and coal is more likely to set prices when they are low. Given coal's higher emission rate than natural gas, this may bias downward our results. We thus instrument the marginal emissions costs, $\tau_t e_{th}$ with the allowances prices $\tau_t$. This provides us with a consistent estimate of $\rho$, as long as individual companies are unable to affect the allowance prices. There is some evidence that large electricity generators may have exerted market power in the allowances market at least in Phase 1 (Hintermann 2017). However, the inclusion of controls and fixed effects should mitigate at least some of these endogeneity concerns.

[20] At the beginning of 2004, the two main generators in Spain (Endesa and Iberdrola) had a combined market share above 60% (Crampes and Fabra 2005).

of this analysis and we find a formidable difference in the estimates. The government-controlled company passes through less than 30% (20 to 28% depending on the exact specification) of the emission cost, while non-government controlled companies exhibit an almost complete pass through (ranging from 72 in the most parsimonious specification to 93% in our preferred specification). Our estimates for pass-through of private companies are remarkably close to Fabra and Reguant's (2014), especially considering we use over a decade worth of data spanning substantial variation in the emission permit prices.

A standard robustness test in this literature considers pass-through differences between peak and off-peak hours. Generators may face significant costs, among other things, when switching on and off a unit, or when ramping it up. These opportunity costs, faced primarily off-peak, are factored in by profit-maximizing generators, which may, as a result, submit bids that may differ from statically optimal ones, with an effect on pass-through across peak and off-peak. Tables 4 and 5 show a modest difference between peak and off-peak pass-through, ranging from 15% in the most parsimonious to 5% in our preferred specification. This is a much smaller difference than the 40-60% difference between peak and off-peak in FR.

We then move to estimating the pass-through of fuel costs. The estimation of the pass-through on fuel prices suffers from an endogeneity issue similar to that faced when estimating the pass-through from emission costs. To tackle this, we instrument the fuel costs with fuel prices.

Tables 6 and 7 show that the pattern of pass-through on fuel cost is broadly consistent with that of pass-through on emission costs, albeit slightly lower. Government-controlled companies pass through less than 40% of the cost, while the other companies pass through about 80% of the cost. Measures of fuel costs are more noisy than allowance prices, since we do not observe the individual contracts that firms sign with their suppliers.

The emission and the fuel cost pass-through could differ across the two types of companies because of at least two reasons. First, differences in the cost functions (and, in particular, differences in emission rates, types of fuel, and thermal efficiency), which can give rise to different competitive conditions. Second, differences in the cost internalization, which in turn could result, as we will discuss later, from political incentives being at play in the government-controlled firm. In the next

Table 3: Pass-through Results

| | (1)<br>bid | (2)<br>bid | (3)<br>bid |
|---|---|---|---|
| marg. em. cost | 0.515$^{***}$ | 0.286$^{***}$ | 0.933$^{***}$ |
| | (0.0288) | (0.0279) | (0.0917) |
| temperature avg | 2.667$^{***}$ | 1.302$^{***}$ | 3.886$^{***}$ |
| | (0.1218) | (0.1684) | (0.1968) |
| temperature max | -0.896$^{***}$ | -0.356$^{**}$ | -1.525$^{***}$ |
| | (0.1113) | (0.1471) | (0.1864) |
| wind avg | 0.773$^{***}$ | -0.411$^{***}$ | 2.121$^{***}$ |
| | (0.0399) | (0.0435) | (0.0793) |
| wind squared | -0.0223$^{***}$ | 0.00655$^{***}$ | -0.0534$^{***}$ |
| | (0.0012) | (0.0012) | (0.0027) |
| wind max squared | 0.000323 | 0.00169$^{***}$ | -0.00187$^{***}$ |
| | (0.0002) | (0.0002) | (0.0004) |
| humidity | -0.0781$^{***}$ | -0.0983$^{***}$ | -0.0767$^{***}$ |
| | (0.0060) | (0.0065) | (0.0107) |
| year FE | Yes | Yes | Yes |
| month FE | Yes | Yes | Yes |
| hour FE | Yes | Yes | Yes |
| day FE | Yes | Yes | Yes |
| month/temperature | Yes | Yes | Yes |
| month/hour FE | Yes | Yes | Yes |
| input price/hour | Yes | Yes | Yes |
| N | 169,259 | 100,633 | 68,626 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

*Notes*: This Table shows results of estimating Equation 3 with the full set of control variables. Column 1 includes all observations. Column 2 estimates the model on the subset of data when the government-controlled company Enel is the marginal generator. Column 3 uses only the other generators.

Table 4: Pass-through Results: Peak hours

| | (1)<br>bid | (2)<br>bid | (3)<br>bid | (4)<br>bid | (5)<br>bid |
|---|---|---|---|---|---|
| marg. em. cost | 0.602$^{***}$ | 0.570$^{***}$ | 0.632$^{***}$ | 0.599$^{***}$ | 0.547$^{***}$ |
| | (0.0486) | (0.0483) | (0.0458) | (0.0455) | (0.0460) |
| temperature avg | 3.311$^{***}$ | 3.710$^{***}$ | 3.248$^{***}$ | 3.640$^{***}$ | 3.728$^{***}$ |
| | (0.0767) | (0.1846) | (0.0739) | (0.1769) | (0.1760) |
| temperature max | -1.572$^{***}$ | -1.108$^{***}$ | -1.573$^{***}$ | -1.205$^{***}$ | -1.284$^{***}$ |
| | (0.0721) | (0.1779) | (0.0696) | (0.1685) | (0.1669) |
| wind avg | 0.295$^{***}$ | 0.195$^{**}$ | 0.322$^{***}$ | 0.227$^{**}$ | 0.265$^{***}$ |
| | (0.0994) | (0.0987) | (0.0962) | (0.0955) | (0.0938) |
| wind squared | -0.0135$^{***}$ | -0.0121$^{***}$ | -0.0147$^{***}$ | -0.0134$^{***}$ | -0.0145$^{***}$ |
| | (0.0025) | (0.0024) | (0.0024) | (0.0024) | (0.0023) |
| wind max | 0.366$^{***}$ | 0.428$^{***}$ | 0.392$^{***}$ | 0.457$^{***}$ | 0.467$^{***}$ |
| | (0.0534) | (0.0531) | (0.0521) | (0.0518) | (0.0510) |
| wind max squared | -0.00423$^{***}$ | -0.00474$^{***}$ | -0.00462$^{***}$ | -0.00518$^{***}$ | -0.00536$^{***}$ |
| | (0.0008) | (0.0007) | (0.0007) | (0.0007) | (0.0007) |
| humidity | -0.164$^{***}$ | -0.146$^{***}$ | -0.157$^{***}$ | -0.137$^{***}$ | -0.130$^{***}$ |
| | (0.0097) | (0.0097) | (0.0094) | (0.0094) | (0.0092) |
| year FE | Yes | Yes | Yes | Yes | Yes |
| month FE | Yes | Yes | Yes | Yes | Yes |
| hour FE | Yes | Yes | Yes | Yes | Yes |
| day FE | Yes | Yes | Yes | Yes | Yes |
| month/temperature | No | Yes | No | Yes | Yes |
| month/hour FE | No | No | Yes | Yes | Yes |
| input price/hour | No | No | No | No | Yes |
| N | 91,385 | 91,385 | 91,385 | 91,385 | 91,385 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

NOTE: This table shows results of estimating Equation 3 only during peak hour. Peak hours are defined between 8am and 8pm. Columns 1-5 vary the set of controls.

Table 5: Pass-through Results: Off-peak hours

| | (1)<br>bid | (2)<br>bid | (3)<br>bid | (4)<br>bid | (5)<br>bid |
|---|---|---|---|---|---|
| marg. em. cost | 0.455$^{***}$ | 0.440$^{***}$ | 0.458$^{***}$ | 0.444$^{***}$ | 0.493$^{***}$ |
| | (0.0334) | (0.0332) | (0.0329) | (0.0329) | (0.0318) |
| temperature avg | 0.827$^{***}$ | 1.532$^{***}$ | 0.832$^{***}$ | 1.564$^{***}$ | 1.421$^{***}$ |
| | (0.0615) | (0.1509) | (0.0612) | (0.1520) | (0.1485) |
| temperature max | -0.0866 | -0.615$^{***}$ | -0.0894 | -0.667$^{***}$ | -0.477$^{***}$ |
| | (0.0588) | (0.1263) | (0.0586) | (0.1296) | (0.1272) |
| wind avg | 0.467$^{***}$ | 0.490$^{***}$ | 0.465$^{***}$ | 0.487$^{***}$ | 0.523$^{***}$ |
| | (0.0816) | (0.0814) | (0.0810) | (0.0809) | (0.0771) |
| wind squared | -0.0114$^{***}$ | -0.0123$^{***}$ | -0.0115$^{***}$ | -0.0124$^{***}$ | -0.0131$^{***}$ |
| | (0.0021) | (0.0021) | (0.0021) | (0.0020) | (0.0019) |
| wind max | 0.0289 | 0.0560 | 0.0335 | 0.0596 | 0.117$^{**}$ |
| | (0.0511) | (0.0508) | (0.0511) | (0.0509) | (0.0486) |
| wind max squared | -0.00130 | -0.00153$^{*}$ | -0.00136 | -0.00158$^{*}$ | -0.00230$^{***}$ |
| | (0.0008) | (0.0008) | (0.0009) | (0.0008) | (0.0008) |
| humidity | -0.0507$^{***}$ | -0.0356$^{***}$ | -0.0518$^{***}$ | -0.0371$^{***}$ | -0.0271$^{***}$ |
| | (0.0073) | (0.0073) | (0.0072) | (0.0073) | (0.0071) |
| year FE | Yes | Yes | Yes | Yes | Yes |
| month FE | Yes | Yes | Yes | Yes | Yes |
| hour FE | Yes | Yes | Yes | Yes | Yes |
| day FE | Yes | Yes | Yes | Yes | Yes |
| month/temperature | No | Yes | No | Yes | Yes |
| month/hour FE | No | No | Yes | Yes | Yes |
| input price/hour | No | No | No | No | Yes |
| N | 77,874 | 77,874 | 77,874 | 77,874 | 77,874 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

NOTE: This table shows results of estimating Equation 3 only during off-peak hour. Peak hours are defined between 8am and 8pm. Columns 1-5 vary the set of controls.

Table 6: Pass-through of fuel: private

| | (1)<br>bid | (2)<br>bid | (3)<br>bid | (4)<br>bid | (5)<br>bid |
|---|---|---|---|---|---|
| fuel_cost | 0.816*** | 0.798*** | 0.804*** | 0.784*** | 0.791*** |
| | (0.0111) | (0.0115) | (0.0110) | (0.0114) | (0.0112) |
| EUA price | 0.381*** | 0.367*** | 0.404*** | 0.393*** | -0.759*** |
| | (0.0415) | (0.0416) | (0.0402) | (0.0403) | (0.0842) |
| temperature avg | 2.297*** | 3.369*** | 2.219*** | 3.249*** | 2.992*** |
| | (0.0723) | (0.1731) | (0.0709) | (0.1684) | (0.1631) |
| temperature max | -0.918*** | -1.416*** | -0.891*** | -1.397*** | -1.136*** |
| | (0.0667) | (0.1669) | (0.0656) | (0.1590) | (0.1545) |
| wind avg | 1.055*** | 0.994*** | 1.076*** | 1.017*** | 0.879*** |
| | (0.0989) | (0.1002) | (0.0975) | (0.0989) | (0.0968) |
| wind squared | -0.0319*** | -0.0317*** | -0.0323*** | -0.0323*** | -0.0283*** |
| | (0.0027) | (0.0028) | (0.0027) | (0.0027) | (0.0027) |
| wind max | 0.187*** | 0.257*** | 0.164*** | 0.241*** | 0.310*** |
| | (0.0478) | (0.0490) | (0.0473) | (0.0486) | (0.0485) |
| wind max squared | -0.00247*** | -0.00326*** | -0.00219*** | -0.00310*** | -0.00442*** |
| | (0.0007) | (0.0007) | (0.0007) | (0.0007) | (0.0007) |
| humidity | -0.0799*** | -0.0704*** | -0.0793*** | -0.0690*** | -0.0582*** |
| | (0.0091) | (0.0091) | (0.0090) | (0.0090) | (0.0088) |
| year FE | Yes | Yes | Yes | Yes | Yes |
| month FE | Yes | Yes | Yes | Yes | Yes |
| hour FE | Yes | Yes | Yes | Yes | Yes |
| day FE | Yes | Yes | Yes | Yes | Yes |
| month/temperature | No | Yes | No | Yes | Yes |
| month/hour FE | No | No | Yes | Yes | Yes |
| input price/hour | No | No | No | No | Yes |
| N | 68,631 | 68,631 | 68,631 | 68,631 | 68,631 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Note: This table shows results of estimating Equation 3. Columns 1-5 vary the set of controls. The equation is estimated on the subset of data where private companies are marginal bidders.

Table 7: Pass-through of fuel: public

| | (1)<br>bid | (2)<br>bid | (3)<br>bid | (4)<br>bid | (5)<br>bid |
|---|---|---|---|---|---|
| fuel_cost | 0.390*** | 0.392*** | 0.382*** | 0.384*** | 0.380*** |
| | (0.0066) | (0.0066) | (0.0064) | (0.0064) | (0.0064) |
| EUA price | 0.159*** | 0.152*** | 0.183*** | 0.174*** | 0.0425 |
| | (0.0154) | (0.0154) | (0.0142) | (0.0143) | (0.0272) |
| temperature avg | -0.0108 | 1.044*** | 0.0518 | 1.115*** | 1.091*** |
| | (0.0591) | (0.1817) | (0.0569) | (0.1743) | (0.1742) |
| temperature max | 0.114** | -0.138 | 0.0422 | -0.309** | -0.313** |
| | (0.0537) | (0.1604) | (0.0518) | (0.1530) | (0.1530) |
| wind avg | -0.775*** | -0.722*** | -0.711*** | -0.658*** | -0.629*** |
| | (0.0745) | (0.0740) | (0.0728) | (0.0722) | (0.0719) |
| wind squared | 0.0127*** | 0.0113*** | 0.0108*** | 0.00941*** | 0.00882*** |
| | (0.0018) | (0.0018) | (0.0018) | (0.0018) | (0.0018) |
| wind max | 0.419*** | 0.410*** | 0.435*** | 0.427*** | 0.414*** |
| | (0.0463) | (0.0458) | (0.0465) | (0.0461) | (0.0459) |
| wind max squared | -0.00303*** | -0.00298*** | -0.00346*** | -0.00344*** | -0.00331*** |
| | (0.0007) | (0.0007) | (0.0007) | (0.0007) | (0.0007) |
| humidity | -0.0205*** | -0.0109 | -0.0245*** | -0.0142** | -0.0128* |
| | (0.0071) | (0.0072) | (0.0068) | (0.0068) | (0.0068) |
| year FE | Yes | Yes | Yes | Yes | Yes |
| month FE | Yes | Yes | Yes | Yes | Yes |
| hour FE | Yes | Yes | Yes | Yes | Yes |
| day FE | Yes | Yes | Yes | Yes | Yes |
| month/temperature | No | Yes | No | Yes | Yes |
| month/hour FE | No | No | Yes | Yes | Yes |
| input price/hour | No | No | No | No | Yes |
| N | 100,875 | 100,875 | 100,875 | 100,875 | 100,875 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Note: This table shows results of estimating Equation 3. Columns 1-5 vary the set of controls. The equation is estimated on the subset of data where public companies are marginal bidders.

section we introduce a formal bidding model that allows us to estimate optimal markups (given the perceived uncertainty about market clearing prices). We show that the pass-through heterogeneity is likely caused by heterogeneity in cost internalization.

### 5.2 Decomposing Market Power

We decompose bids into the cost and the mark-up components. We observe cost due to detailed engineering data about heat rates that are available at the level of individual generators. Following an approach frequently adopted in the previous literature (Wolak (2001), Wolak (2007), Reguant (2014)), we retrieve optimal markup from first order conditions for optimal bidding.

#### Model of Bidding

We model the day-ahead market as a uniform price auction, in which bidders (i.e., generators) have private information that impacts their bidding incentives. Generator $i$ is endowed with private information, $s_i$, representing its contract positions, urgency of maintenance etc. The total demand, $D$, is a random variable with a commonly known distribution $F(D)$.

The auction rules map the submitted offers into the market clearing price and firms' market clearing quantities. Both of them are random variables, since both are functions of the other firms' signals and equilibrium strategies as well as of the demand realization. We denote them by functions $P^c(S, D)$, $Q_i^c(S, D)$, respectively, and sometimes, to economize on space, we will omit their arguments.

Firm $i$'s expected profits, given it has forward contracts for quantity $Q_i^F$ at price $P_i^F$, can be written as:

$$E_{s_{-i},D}\left[Q_i^c(S,D) * P^c(S,D) - C_i\left(Q_i^c(S,D)\right)\right] + Q_i^F * \left(P_i^F - E_{s_{-i},D}P^c(S,D)\right) \tag{4}$$

where $C_i(q)$ is the total cost of producing $q$ MWh of electricity. Note that equation (4) implies that the price, at which the forward contract is signed, is irrelevant for the bidding behavior (as Wolak (2007) points out) - only the quantity in the forward contract matters, and only for those generators that can impact the market clearing price with positive probability.

Firms submit step functions as their offer curves, $\{b_k, q_k\}_{k=1}^{K}$ for each of their $J$ generators. For the sake of simplicity, we assume that bidding decisions are made at the generator level - and hence a bid for generator $j$ depends on its particular private signal, rather than on signals by other generators sharing the same owner. This implies that we can write firm $i$'s expected revenue from the auction as

$$
\begin{aligned}
&\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right)Q_{i}^{c}\left(S,D\right)\right] = \\
&= \quad \Pr\left(b_{k-1} < P^{c} < b_{k}\right) q_{k-1}\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right)|b_{k-1} < P^{c} < b_{k}\right] \\
&\qquad + \Pr\left(P^{c} = b_{k}\right) b_{k}\mathbb{E}_{S_{-i},D}\left[Q_{i}^{c}\left(S,D\right)|P^{c} = b_{k}\right] \\
&\qquad + \Pr\left(b_{k} < P^{c} < b_{k+1}\right) q_{k}\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right)|b_{k} < P^{c} < b_{k+1}\right] \\
&\qquad + \Pr\left(P^{c} \leq b_{k-1} \cup P^{c} \geq b_{k+1}\right)\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right)Q_{i}^{c}\left(S,D\right)|P^{c} \leq b_{k-1} \cup P^{c} \geq b_{k+1}\right] \\
&= \quad q_{k-1}\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right);b_{k-1} < P^{c} < b_{k}\right] + q_{k}\mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right);b_{k} < P^{c} < b_{k+1}\right] \\
&\qquad + b_{k}\mathbb{E}_{S_{-i},D}\left[Q^{c}\left(S,D\right);P^{c} = b_{k}\right] + \mathbb{E}_{S_{-i},D}\left[P^{c}\left(S,D\right)Q_{i}^{c}\left(S,D\right);P^{c} \leq b_{k-1} \cup P^{c} \geq b_{k+1}\right]
\end{aligned}
$$

where the last term does not depend on the particular step $k$, characterized by $b_k$ and $q_k$. The only states in which changing $b_k$ is relevant are those where the market clearing price lies in the interval $(b_{k-1}, b_{k+1})$.

To simplify the problem we assume that firms choose a continuous monotone increasing offer schedule $q_i\left(p\right)$. In this case (as $q_{k+1} \to q_k$ and $b_{k+1} \to b_k$), the first order conditions reduce to:

$$
\begin{aligned}
&\frac{\partial\mathbb{E}_{S_{-i},D|s_i}\left[C\left(Q_{i}^{c}\left(S,D\right)\right)|P^{c} = b_{k}\right]}{\partial b_{k}} = \\
&= \quad \mathbb{E}_{S_{-i},D|s_i}\left[Q_{i}^{c}\left(S,D\right)|P^{c} = b_{k}\right] + b_{k}\frac{\partial\mathbb{E}_{S_{-i},D|s_i}\left[Q_{i}^{c}\left(S,D\right)|P^{c} = b_{k}\right]}{\partial b_{k}} - Q_{i}^{F} * \frac{\partial E_{s_{-i},D}\left[P^{c}\left(S,D\right)|P^{c} = b_{k}\right]}{\partial b_{k}}
\end{aligned}
\tag{5}
$$

which is basically the condition used in Wolak (2007), Bushnell, Mansur and Saravia (2008) or Fabra and Reguant (2014). Equation (5) can be also written (abusing notation a bit) as $b = MC + \frac{\mathbb{E}Q^{N}(b)}{\mathbb{E}Q'(b)}$, where $Q^{N}(b)$ is the net supply of this generator at $b$ (i.e., market clearing demand, $Q_i^c$, minus the quantity contracted forward) and $Q(b)$ is the residual demand at price $b$. This is essentially a first order condition for optimality of a supply curve of an oligopolist that faces uncertain demand, which dictates that the bid should be equal to marginal cost plus a markup term.

### 5.3 Decomposition Results

We now take Equation (5) to the data by estimating the following equation:

$$bid_{i,g,m} = \gamma MC_{emission,i,g,m}(q) + \beta MC_{fuel,i,g,m}(q) + \theta \widehat{M}_{i,g,m} + \epsilon_{i,g,m} \tag{6}$$

where $bid_{i,g,m}$ is the bid $i$ of generator $g$ in market $m$. $\widehat{M}_{i,g,m}$ is the equilibrium mark-up over marginal cost, which depends on the elasticity of residual demand, hence on market power. Marginal costs are composed of marginal fuel cost and marginal emission costs. The error term captures potential errors in measurement of marginal costs, or other idiosyncratic shocks.

To estimate the optimal markup we use the resampling method based on Kastl (2011), where we draw from the empirical distribution of bids to simulate different realizations of the residual demand function. We provide details of the estimation in the Appendix.

The goal of our analysis is estimating $\gamma$, $\beta$, and $\theta$ for government-controlled and non-government controlled companies. $\gamma$ and $\beta$ measure the extent to which firms incorporate shocks to the emission cost and to the fuel cost respectively in their behavior, while $\theta$ measures the extent to which firms capture the mark-up opportunities. Notice that allowances cost is represented by their current spot market price, which does not depend on the price at which allowances were acquired (which could also be zero under the grandfathering regime). Hence, it is an opportunity cost. We restrict the sample of bids for the analysis by removing the first and the last step of the bid function. By excluding the first step, we mitigate concerns with startup costs and by excluding the last step, we mitigate concerns with capacity constraints. As before we restrict the analysis to bids that are ex post marginal.

Focusing on bids that turn out to be marginal ex post raises endogeneity concerns similar to those faced in our pass-through analysis in Section 5.1. The identity of the marginal technology depends on unobserved demand or supply shocks. For example, under a negative unobserved demand shock, it is more likely that the marginal technology is coal, characterized by a higher emission intensity. This would bias our markup estimate downward. We, therefore, instrument emission costs with permit prices, fuel costs with input prices (of coal, gas and oil), and markup with shifters of residual demand (temperature and wind).

Table 8: Bid decomposition: private firms

|  | (1)<br>OLS | (2)<br>OLS | (3)<br>3SLS | (4)<br>3SLS+controls |
|---|---|---|---|---|
| marg. em. cost | $0.764^{***}$ | $1.656^{***}$ | $1.084^{***}$ | $0.766^{***}$ |
|  | (0.0730) | (0.0535) | (0.0512) | (0.0437) |
| marg. fuel cost | $0.278^{***}$ | $0.587^{***}$ | $0.800^{***}$ | $0.745^{***}$ |
|  | (0.0170) | (0.0121) | (0.0144) | (0.0122) |
| optimal markup | 1 | $0.173^{***}$ | $0.541^{***}$ | $0.704^{***}$ |
|  |  | (0.0055) | (0.0249) | (0.0194) |
| N | 32,233 | 32,233 | 26,017 | 26,017 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

NOTE: This table shows results of estimating Equation 6 on the set of private generators. The first column fixes the coefficient on markup to 1 and estimates the coefficients on marginal costs via OLS. Column 2 does an analogous analysis but estimates the coefficient on the markup term. Column 3 projects bids on marginal costs and markups via 3SLS. Marginal emission costs are instrumented with emission allowances costs, marginal fuel costs are instrumented with fuel costs and markups are instruments with shifters of residual demand (wind speed and temperature). Column 4 uses the same specification but also includes month fixed effects to control for seasonal effects.

Similarly to Fabra and Reguant (2014) we first regress bids on marginal costs (while fixing $\gamma = 1$), and then we instrument the optimal markup with shifters of residual demand (wind speed and temperature). Tables 8 and 9 show once again a striking difference in behavior between government-controlled and non-government controlled generators. The government-controlled generator internalizes only about 15% of marginal emissions costs, and about 25% of marginal fuel costs. Non government-controlled generators internalize about 75% of both marginal costs. Also, while markup for non government-controlled generators is broadly in line with profit maximization (with approximately 70% of the profit-maximizing increase in bids realized), the government controlled company does not seem to bid strategically. Taken together, our results imply that the government-controlled generator is not maximizing profit, and is not internalizing marginal emission costs. The fact that the government-controlled companies does not maximize profits implies that marginal abatement costs are not equalized across companies (and across sectors), which clearly undermines the effectiveness of the regulation, at least in the short run.

Table 9: Bid decomposition: public firms

|  | (1)<br>OLS | (2)<br>OLS | (3)<br>3SLS | (4)<br>3SLS+controls |
|---|---|---|---|---|
| marg. em. cost | $0.207^{***}$ | 0.0315 | -0.0109 | $0.151^{***}$ |
|  | (0.0221) | (0.0195) | (0.0224) | (0.0167) |
| marg. fuel cost | $0.140^{***}$ | $0.177^{***}$ | $0.241^{***}$ | $0.243^{***}$ |
|  | (0.0061) | (0.0054) | (0.0076) | (0.0055) |
| optimal markup | 1 | $0.172^{***}$ | -0.00793 | 0.0126 |
|  |  | (0.0053) | (0.0369) | (0.0257) |
| N | 36,128 | 36,128 | 33,679 | 33,679 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

NOTE: This table shows results of estimating Equation 6 on the public generator. The first column fixes the coefficient on markup to 1 and estimates the coefficients on marginal costs via OLS. In Column we also estimate the coefficient on the markup term. Column 3 projects bids on marginal costs and markups via 3SLS. Marginal emission costs are instrumented with emission allowances costs, marginal fuel costs are instrumented with fuel costs and markups are instruments with shifters of residual demand (wind speed and temperature). Column 4 uses the same specification but also includes month fixed effects to control for seasonal effects.

## 5.4 Discussion of heterogeneous behavior

Our findings imply that government-owned companies, unlike their private counterparts, fail to internalize costs in their bids, and do not optimally respond to their rivals' bids. We advance several possible motivations behind this heterogeneous behavior.

First, public companies may also attach some weight to consumer surplus. In such a scenario the levels of bids might indeed differ for public generators, nevertheless they should still supply energy at the minimum costs, which requires internalization of all input costs. Such explanation could not rationalize differences in pass-through.

A second potential motivation might lie in Enel's antitrust concerns. Throughout the period in our sample, Enel has been the largest generator, albeit by an increasingly smaller margin over time. A model of antitrust concerns would generate similar predictions to a model of attachment of a positive weight to consumer surplus. As a result, similarly to above, this model would be consistent with a difference in levels of bids, but not with a difference in pass-through.

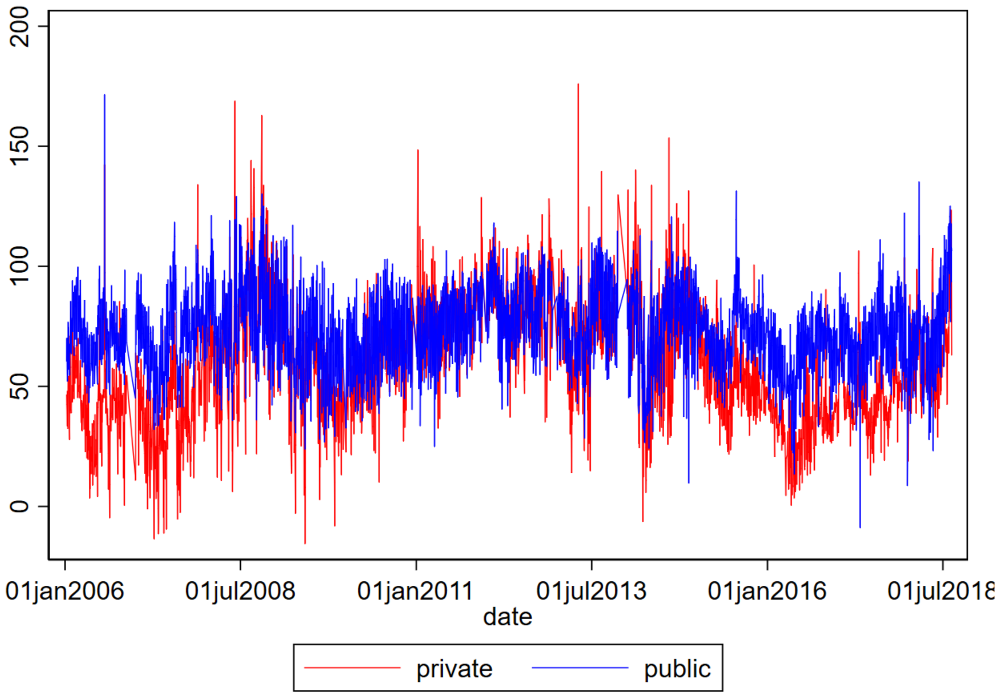
An alternative explanation might consist of differential strategic sophistication. Different firms could have a different ability at predicting their residual demand and at placing optimal bids. Hortaçsu et al. (2019) show that strategic sophistication is positively correlated with firm's size. As the non-internalizing firm is the largest in the Italian electricity market, differential strategic sophistication does not rationalize our findings. In addition, there is not a clear and direct link between strategic sophistication and cost internalization. A similar explanation, but potentially explaining the lack of cost internalization as well, has to do with the adjustment costs. Companies do not adjust their bids in response to the opportunity cost of allowances or of the actual input costs as frequently as predicted by the model (or their actual costs for fuel costs) because bid adjustments are costly (in terms of people and software to be employed for the activity). Adjustment costs, however, are likely subject to economies of scale, given the fixed cost involved in setting up a pricing unit. Hence, a model of adjustment costs would predict that, if anybody, the smallest firms would be more inclined to give up the higher markup to avoid the adjustment costs. Our results are again inconsistent with this explanation.

Additional potential rationalizations for the failure to internalize emission prices have been put forward. One of them (Goeree, Holt, Palmer, Shobe and Burtraw 2010) involves the lack of understanding that permits have an opportunity cost. Another one involves transaction costs in the emissions market (Stavins 1995). Again, it seems unlikely that the largest, and longest-living, company suffers from such lack of understanding, or that it faces higher transaction costs vis-à-vis comparable smaller firms, as the internalization patterns in our data suggests. If anything, it should be smaller and less established company that have a smaller understanding of the market, and face higher transaction costs.

Another possible motivation is that government-owned companies try to decrease the volatility of market prices for political reasons. A government-controlled company, especially if its strategies are visible and important for its citizens, affects the probability of the government to remain in power, as it potentially affects citizens' perception of government ability and accountability. These political incentives might lead government-controlled companies to target a reduction in price volatility, possibly because poorly informed consumers, who have a preference for lower costs, might perceive small price volatility as an indicator of a more cost-reflective price. This is consistent with previous evidence in 2004, right at the beginning of the liberalization process, that Enel was smoothing out prices across different geographical areas with respect to the profit-maximizing outcome (Boffa, Pingali and Vannoni 2010).

To test this motivation, we perform an analysis based on our decomposition results, in which we compare a situation in which we treat all the bids as if they were coming from non-government controlled companies, to one in which we treat all the bids as if they were coming from the government-controlled company. Our results show that the standard deviation of market clearing prices is considerably lower, by about 22% (from 46 to 36 Euros), when we treat all the bids as if they were coming from the government-controlled company.

Figure 4: Variability of electricity prices



NOTE: This figure predicts electricity prices under a counterfactual ownership structure. The blue line shows predicted electricity prices under the assumption that all marginal generators bid according to the bidding equation of the public generator. Analogously, the red led predicts prices for private generators. For simplicity we hold the set of marginal generators fixed.

## 5.5 Anecdotal evidence on political incentives for government-controlled firms

Our preferred political rationalization of the different behavior between public and private firms requires that top level managers get rewarded by the government for responding to political incentives. This argument is consistent with the existence of two separate labor markets for managers, one for ”public” managers and one for private managers. A casual look into the history of government-controlled companies in Italy, and in particular into the history of the two government-owned generators Enel and Eni [21]/provides strong anecdotal support for this theory. Public managers in the energy sector very rarely move to private energy companies, while mostly moving to other government-controlled companies operating in different sectors, or remaining with the same employer for very long spells.

We first look at Enel. Paolo Scaroni, Enel's CEO between 2002 and 2004, was then appointed ENI's CEO (for the spell 2005-2014), moving between the two most prominent Italian government-owned companies.[22] His successor, Fulvio Conti (who was Enel's CEO in 2004-2014), before joining Enel, was chief financial officer at the fully government owned Italian railway monopoly (owner of the infrastructure and, back then, monopolistic provider of the railways services) Ferrovie dello Stato, and, immediately after, was CFO at Telecom, which had just been privatized, and whose CEO was Franco Bernabè, previously Eni's CEO (1992-1999). After this tenure at Enel, Conti again held other top managerial positions at Telecom.[23] Conti's successor, Francesco Starace, whose tenure started in 2014, had a long experience in Enel, which he joined in 2000. He had previously worked for Alstom, a French multinational operating primarily in the rail transport and in the power markets, controlled by the French government.[24]

Between Scaroni and Bernabé, Vittorio Mincato was Eni's CEO. He kept his post between 1999 and 2005. Afterwards, he became Chairman of the Board of Poste Italiane, the Italian fully government-owned postal services company.[25] Finally, the current Eni's CEO, Claudio Descalzi,

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[21] As a reminder, in the empirical analysis we consider Enel only among government-controlled generators, given the different generation mix of the two companies, and the resulting lower potential inefficiencies that Eni could trigger

[22] `https://www.acmilaninfo.com/who-is-paolo-scaroni-the-new-president-of-ac-milan/`

[23] `https://www.telecomitalia.com/content/dam/telecomitalia/organigramma/curriculum/it/ContiFulvio.pdf` .

[24] `https://www.enel.com/investors/governance/board-of-directors/francesco-starace-chief-executive-officer-general-`

[25] `https://www.referenceforbusiness.com/biography/M-R/Mincato-Vittorio-1936.html`

has been with Eni since 1981, right after his degree.[26]

Even Enel's Chairmen of the Board are deeply entrenched with the public management system. Chicco Testa (who served in the 1996-2002 spell) was previously chairman of the multiutility company, controlled by the Rome municipality, ACEA, while being a member of the Italian House of Representative elected with the Comunist (and then Social-Democratic) party. His successor was Piero Gnudi, who served between 2002 and 2011, and was previously chairman of IRI, the Italian fully government-owned holding company in charge of the portfolio of the government-owned Italian manufacturing and service companies, until its dissolution in 2002. After his tenure at Enel, he went on to become the Minister for Tourism, and Sport in the Monti government.

Paolo Andrea Colombo served between 2011 and 2014, and then went on to become chairman of Saipem (starting in 2015), a company involved in infrastructures and services for the oil and gas sector, controlled by Eni and by the fully government-owned investment bank Cassa Depositi e Prestiti.

To summarize, it is very common for "public" managers to move between publicly owned firms. It thus seems very likely that managers within this market follow different goals than those of their non-government counterpart, as their incentives might be more aligned with politicians' objectives.

## 6 Long Term versus Short Term Effects

Failure to maximize profits results in the short term in different power plants being used than optimal. This implies that equality of marginal abatement costs - one of the major arguments in favor of carbon pricing - does not hold. We now turn to the long-run differential investment incentives between government-controlled companies and their counterpart. There is evidence of a differential response to ETS between government-owned and private companies (Clò, Ferraris and Florio 2017) in Europe, in terms of greenhouse-gas emissions and carbon intensity. Fowlie (2010) documented a positive effect of public ownership on the probability of adopting more capital intensive environmental compliance options in the United States' $NO_x$ market. We document here similar differences in Italy's carbon market.

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[26] `https://www.eni.com/en-IT/about-us/our-management/biographies.html/claudio-descalzi`

### 6.1 Differential response of emission intensity

We study the differential medium and long-run response, between public and private generators footnoteIn this Section, given that Eni does not have coal-fuelled generation facilities, and it has a negligible share of renewables, it does not matter whether we include Eni among the public or the private generators does not affect our results., to variation in ETS prices in terms of changes in the emission intensity of their generation facilities. We first consider coal-fired power plants, and look at how they differentially adjust, based on ownership, their input choices as ETS prices vary. Different types of coal differ in their burning efficiency, which affects the power plant's emission intensity.

We collect data on average yearly CO2 emission intensity (emission per MWh) for coal-fired power plants in Italy. We use a fixed effect model and a first differences model to argue that there is, even at this low frequency, a differential response to these incentives between the public and private generators. We estimate the following two models:

$$intensity_{i,t} = \beta \cdot eua\ price_t + \delta_i + time\ trend_t + \epsilon_{i,t} \tag{7}$$

$$intensity_{i,t} - intensity_{i,t-1} = \beta \cdot (eua\ price_t - eua\ price_{t-1}) + \epsilon_{i,t} \tag{8}$$

where $i$ denotes a generator and $t$ a year. *time trend* controls for a possible linear trend, while we cannot allow for a more flexible approach due to the frequency of observations. Both emission intensity and allowances price are calculated as yearly averages. Despite the low frequency of observations, Table 10 clearly shows that both models show the same relationship. The public generators does not respond to incentives, whereas private generators adjust their intensity based on the EUA prices.

As mentioned above, the differential response between the government-controlled and non government-controlled generators could be motivated by the differential incentives to respond to political pressure. De Marco and Macchiavelli (2016) and Ongena, Popov and Horen (2019) show that government ownership affects European banks behavior, in terms of the amount of sovereign bond holdings during sovereign crises. Similar forms of government "moral suasion" on government-

Table 10: Emission intensity responses

| | (1)<br>intensity | (2)<br>intensity | (3)<br>$\Delta$ intensity | (4)<br>$\Delta$ intensity |
|---|---|---|---|---|
| Average EUA price | 0.654 | -1.858$^{**}$ | | |
| | (0.8146) | (0.8598) | | |
| $\Delta$ EUA price | | | 0.763 | -1.663$^{***}$ |
| | | | (0.5072) | (0.4505) |
| Model | FE | FE | FD | FD |
| Ownership | Public | Private | Public | Private |
| Controls | Linear time trend | Linear time trend | Linear time trend | Linear time trend |
| N | 68 | 46 | 60 | 42 |

Standard errors in parentheses

$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Note: This table shows results of estimating the Equation 7 and 8. We split the sample between the public and private companies. The number of observations differs in FE and FD models because we do not have a balanced panel and cannot use some observations for estimation of the FD model.

owned companies are likely to have occurred in the Italian electricity sector, and to have affected the timing and the extent of Enel's investments. For example, when Francesco Starace was appointed as CEO in 2014, the then Italian Prime Minister Matteo Renzi emphasized his mandate to increase investments, and to decarbonize production.[27] The government has also strongly supported, and advertized to voters, the most prominent environmental investments undertaken by Enel. Two prominent examples are a 120 million Euros two-domed coal storage facility started in 2012 in its Brindisi plant, as well as the still ongoing project of a carbon capture and storage facility, again in Brindisi.[28] Evidence of the involvement of the Italian government in Enel's strategy is also provided by the current debate on the opportunity to directly involve Enel in the highly funded investment plan that will invest the financial resources allocated to the Italian government, partly in the form of subsidies, partly in the form of loans, through the European Recovery Fund.[29]

## 6.2 Investment into renewables

In Subsection 6.1 we looked at how firms respond to ETS prices by modifying emission intensity in existing coal-fired power plants through a different input choice. An alternative way to reduce the

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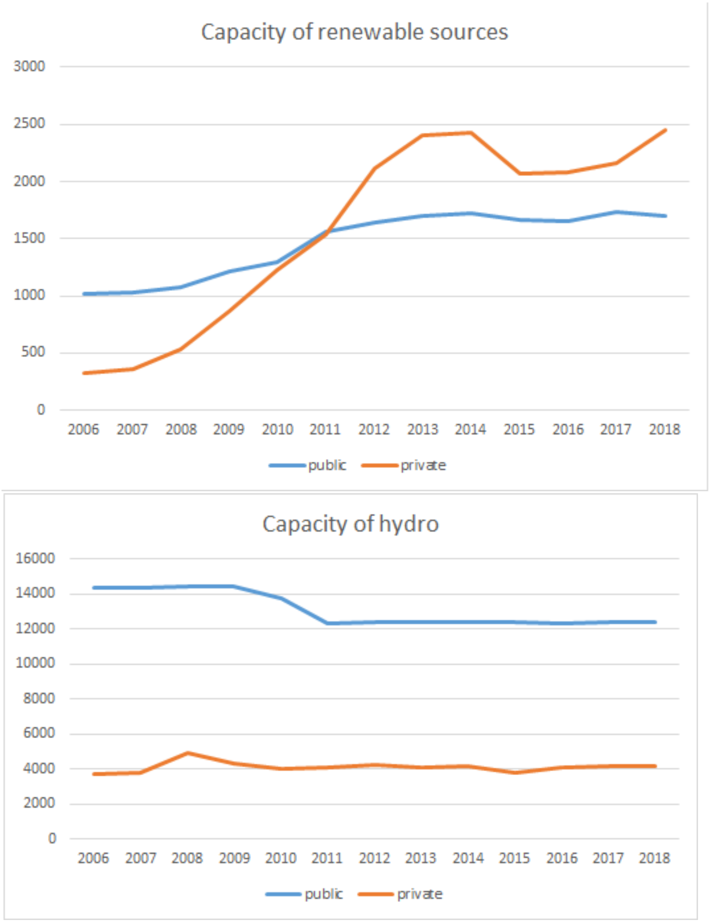
[27] See, for instance, `https://www.publicpolicy.it/lo-spillo-29-39636.html`.

[28] See, for instance, `https://www.minambiente.it/comunicati/il-ministro-prestigiacomo-brindisi-linaugurazione-dellimpi`

[29] See, for instance, `https://www.repubblica.it/economia/2020/07/01/news/un_comitato_di_esperti_e_missioni_strategiche_quinquennali_per_le_grandi_imprese_di_stato_-260677886/`.

Figure 5: Investment into capacity



Note: This figure shows the evolution over the years of the stock of renewable and hydro capacity by generator ownership (government controlled versus non-government controlled), using data from (ARERA Various years).

emission intensity of generation facilities lies, in the long-run, in building less polluting power plants. In this section we focus on the long-term trend of investment into renewables. Figure 5 shows the evolution of the stock of renewable generation, separately considering the hydro power plants, which on average have a significantly longer history, and all the other sources, primarily photovoltaic and wind. While it is hard to causally link such investment to the existence and intensity of the European Trading Scheme, the investment patterns for the government-controlled and the non government-controlled generators appear remarkably different, in particular for renewable sources different than hydro, which have been most dynamic in recent years.

# 7 Discussion: the ETS in China

Our findings question the ability of market-based environmental policies to achieve an efficient outcome, when firms are not profit-maximizing. This has stark implications on the inefficiencies that will be triggered by the market-based emissions trading system that is due to start by 2021 in China. Historically, China's electricity sector was operated by a single state-owned vertically integrated company. The 2002 reform has unbundled generation, transmission and distribution. In addition, it has organized generation around five major state-owned regional generators (Xu and Chen 2020), four of which, as of 2018, ranked in the first four places by installed generation capacity world-wide (International Energy Agency 2018).

Before the 2015 reform, wholesale price in electricity was administratively set by the central government, through benchmark tariffs. Generators belonging to the same technology class, where a technology class includes generators sharing similar average costs, share the same tariff (Kahrl, Williams, Jianhua and Junfeng 2011). The tariff was meant to be adjusted to reflect changes in input prices, while incentivizing improvements in efficiency. Political considerations reduced the frequency of adjustment of the benchmark tariff, thereby distorting the price signal (Lin, Kahrl, Yuan, Liu and Zhang 2019). Dispatch is managed by (government-owned) locally monopolistic grid companies acting as single buyers. It has followed the general principle of maintaining equal shares among generators and ensuring revenue sufficiency (Davidson and Perez-Arriaga 2020). Measures aimed at increasing the efficiency of the dispatch in economic terms (by making it more cost-reflective) or in environmental terms (by prioritizing renewable or less polluting sources), have been experimentally deployed, as pilots, in local markets starting in 2007.[30] The 2015 reform has laid out general principles and guidelines to expand the role for the market in the Chinese electricity sector. While its implementation has been, up to now, only partial, it is expected that the reform will ultimately expand the role for the market in electricity, in particular by favoring the transition to a dispatch based on economic principles, through the expansion of trading opportunities between generators and final customers, intermediated by power exchanges or by

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[30] For example, the government experimented, in five provinces (Jiangsu, Henan, Sichuan, Guangdong and Guizhou), the introduction of the fuel efficiency criterion in the alghoritm governing dispatch (Zhong, Xia, Chen and Kang 2015). The province of Guangdong has also introduced competitive retailing (Davidson and Perez-Arriaga 2020).

competitive retailers (Davidson and Perez-Arriaga 2020).

The market will play a larger role in environmental policy as well. Announced on December 19th, 2017, emissions trading is poised to become the world's largest cap and trade program (Zeng, Weishaar and Vedder 2018) following some experimentation on a regional scale. China is currently by far the world's biggest greenhouse gas emitter. With approximately 10.1 Gt of carbon dioxide[31] in 2018, it is well ahead of the second emitter, the United States (at 5.42 Gt). China has the largest electricity system in the world, with an installed capacity of roughly 1800GW at the end of 2018 (China Electricity Council 2019). The fuel mix is still dominated by coal, which accounts for more than 60% - although with a declining trend - of total generation. The electricity sector contributes substantially, for about a third, to China's carbon dioxide emissions (Goulder and Morgenstern 2018). The system is expected to cover companies emitting more than 26 Gt of carbon dioxide in eight sectors, including electricity.[32] Approximately half of China's total carbon dioxide emission (and about 40% of total GHG emissions) from around 6500 enterprises will be covered.

Crucially, the program will not place an aggregate cap invariant to output, but will set an emission standard, that is a standard emissions rate per unit of output (Pizer and Zhang 2018). A company is allocated allowances based on the emission standards and on the units of output. The program differs markedly from mass-based systems, such as EU ETS, which put a limit on total emissions, and takes instead the form of a tradable performance standard (TPS). The main economic difference between mass-based systems and TPS is that, while mass-based policies raise unit costs by abatement costs plus the carbon price applied to all emissions, a TPS provides a rebate on those costs equal to the carbon price applied to the established performance standards. Hence, a TPS tends to have smaller effects on product prices (Boom and Dijkstra 2009). Finally, a TPS, even when companies are profit-maximizing and operate in a market-based environment, does not achieve efficiency, because it does not equate the marginal abatement costs across firms. Consider the following example representing a situation of perfect competition, in which firms maximize profit in a market-based environment, based on Goulder and Morgenstern (2018). A firm produces

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[31] See: `http://www.globalcarbonatlas.org/en/content/welcome-carbon-atlas)`.

[32] The others being building materials, iron and steel, non-ferrous metal processing, petroleum refining, chemicals, pulp and paper, and aviation (Pizer and Zhang 2018).

output $q$ as a function of a single input $x$ and emissions $e : q = f(x, e)$, with $\frac{\partial q}{\partial x} > 0$ and $\frac{\partial q}{\partial e} > 0$.

Assume that the firm is within a TPS system, faces the benchmark emissions - output ratio $\beta$, and regards its output price $p$, the cost of input $c$, and the price of emissions allowances $p_e$ as exogenous.

Under a TPS, each firm's profit $\pi^{TPS}$, is given by

$$\pi^{TPS} = pq - cx - p_e\left(e - q\beta\right) \tag{9}$$

The corresponding expression for each firm's profit under a conventional mass-based system MBS, $\pi^{MBS}$, is:

$$\pi^{MBS} = pq - cx - p_e e$$

One can immediately see that the first order conditions for profit maximization under TPS and MBS are different. For TPS, first order conditions read:

$$\frac{\partial \pi^{TPS}}{\partial e} = p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) - c\frac{\partial x}{\partial e} + p_e\beta\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) - p_e = 0$$

$$\underbrace{p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) - c\frac{\partial x}{\partial e}}_{MAC} + p_e\beta\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) = p_e$$

The first order condition for the emissions choice under an MBS instead reads as:

$$\begin{aligned}\frac{\partial \pi^{MBS}}{\partial e} &= p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) - c\frac{\partial x}{\partial e} - p_e = 0 \\ &= \underbrace{p\left(\frac{\partial f}{\partial e} + \frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right) - c\frac{\partial x}{\partial e}}_{MAC} = p_e\end{aligned}$$

Under an MBS, each firm equates its marginal abatement cost to the allowance prices. In equilibrium with profit-maximizing firms, all marginal abatement cost are therefore equal, implying the system is efficient. Under a TPS, each firm equates its marginal benefits - composed of the abatement cost, plus the change in allowances resulting from the increase in output - to the allowances prices. Hence, except in the special case in which the marginal benefit from an emission through the increase in allocated allowances (given by $\left(\frac{\partial f}{\partial e}+\frac{\partial f}{\partial x}\frac{\partial x}{\partial e}\right)$) is equal across the various firms, marginal abatement costs are not equalized across firms.

A system such as the TPS, albeit inefficient, may better suit the transition from an administratively regulated environment to a market-based dispatch system. In particular, except for the few above mentioned local experimentation, wholesale prices in China are regulated, which prevents firms from passing through the permits prices to final customers. Pass-through of permit prices, while being an essential ingredient for the efficient operation of an MBS such as the EU ETS, is much less important in a TPS, due to the above illustrated output-based rebate component. Hence, the TPS might be an only temporary solution until market reforms in the wholesale and dispatch segments will be fully phased in. It might then bound to be replaced by a conventional MBS.

Summing up, it is conceivable to think of at least three reasons why emissions trading in China could trigger inefficiencies. Two of them have been emphasized already in previous work, and might be only temporary: the above described design of the Chinese ETS system as a TPS, and the fact that, as we have seen above, market reforms in the dispatch sector in China have not yet been fully implemented (Davidson and Perez-Arriaga 2020).

Our work emphasizes a third - perhaps more important - source of inefficiency, which will likely persist in the long-run, at least as long as Chinese generators will not be privatized, something that is not even part of the current debate in China. Our findings indeed suggest that, when generators are government controlled, inefficiencies emerge even under a conventional MBS, which up to now has been regarded as being effective and leading to an efficient abatement pattern. We have shown that these inefficiencies occur both in the short run - in terms of failure of the equality of marginal abatement costs among firms - and in the long run - in terms of failure of optimal investment patterns.

## 8 Conclusion

Carbon pricing is usually regarded as an essential tool for an efficient abatement of carbon dioxide emission (Stavins 2020). Its efficiency and its desirability, however, rest on the presumption that regulated firms internalize the emission costs and are profit-maximizers, something that is generally taken for granted in the policy debate. There are, however, reasons to believe that this is not necessarily the case, at least in the electricity sector, one of the major contributors to carbon dioxide emissions. With the exceptions of those located in the United States, Spain and Germany, the major electricity companies around the world are government-controlled.

We use the example of Italy to show that Enel, the major government-controlled electricity generator, behaves differently than privately owned companies. It does not internalize and pass through emission costs stemming from the EU-ETS system, and it does not maximize profit. Marginal abatement costs are therefore not equalized across firms. This undermines what is generally considered the pre-eminent benefit of a carbon pricing system, that is its short run efficiency. We then show that Enel reacts much less than its private counterpart to prices of emission allowances in terms of emission intensity of its inputs. This is suggestive of the EU ETS's inability to induce an efficient pattern of investment in emission reduction, and, as a result, of the failure of its efficiency properties even in the medium and long run.

Our results cast serious doubts on the efficiency properties of the ETS system that is due to be introduced in China, where all the electricity generation is government controlled, by 2021.

While we study a cap-and-trade system, our results apply equally to a carbon tax - the alternative form of carbon pricing. In fact, a carbon tax might have even more adverse welfare effects than a cap-and-trade under government controlled companies. While, under a cap-and-trade, the amount of pollution reduction is fixed by construction, a carbon tax applied to firms that are not maximizing profits may fail to achieve the desired target of emission abatement altogether.

Contrary to conventional wisdom, our paper suggest that a command and control approach, in the form of emission standards, might be more suitable especially given the reliability of the estimates of the production functions in the electricity generation sector. The suboptimality of emission standards, resulting from their inability to efficiently accommodate heterogeneous abatement costs, are well-known, but they should be traded off against the inefficiencies of carbon pricing under government controlled companies.

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# Appendix: Resampling algorithm

Our algorithm builds on Kastl (2011). We compute the expected residual demand for each bid in the data and use the first order condition to invert the optimal markup. Denote $(b_k, q_k)$ the $k^{th}$ step of the supply schedule of generator $i$. We calculate the markups in the following steps:

1. We define the market on the hour / day /zone level. Where we reduce all possible zones in the Italian electricity market into two main zones: North and South. This is a valid approximation for almost all of our data. The zones might be occasionally further decomposed even into smaller regional markets (within our two zones) if the electricity transmission is overloaded, but this is very rare.

2. We calculate the total demand in our markets. The electricity market needs to clear in any point of time so we calculate the aggregate demand by summing up all actually supplied electricity. For the purpose of our model we assume that quantities of bilateral contracts and renewable energy are common knowledge. We therefore subtract these supply schedules from the realized demand to obtain demand $Q_D^{'}$.

3. Denote $n_1$ the number of supply schedules by private generators and by $n_2$ the number of supply schedules in the market. Denote these supply schedules by $s_j$. For public generators we sample with replacement $n_1$ bid schedules from the set of all schedules submitted by privately owned generators and $n_2$ from those submitted by publicly owned ones. The residual demand is $D_{R,S-i}(p) = Q_D^{'} - \sum_{-i} s_j(p)$

4. We intersect the residual demand with the supply schedule of generator $i$ and obtain a market clearing price $P^c$ and quantity by $i$ $Q_i^C(p)$.

5. Repeat the steps 3 and 4 many times to obtain a distribution of the market clearing prices and quantities.

6. Perturb the offer of $i$ to calculate $\frac{\partial \mathbb{E}_{S_{-i},D|s_i}\left[Q_i^c(S,D)|P^c=b_k\right]}{\partial b_k}$

7. Calculate the markups $M(b_k, q_k)= \frac{\mathbb{E}_{S_{-i},D|s_i}\left[Q_i^c(S,D)|P^c=b_k\right]}{\frac{\partial \mathbb{E}_{S_{-i},D|s_i}\left[Q_i^c(S,D)|P^c=b_k\right]}{\partial b_k}}$