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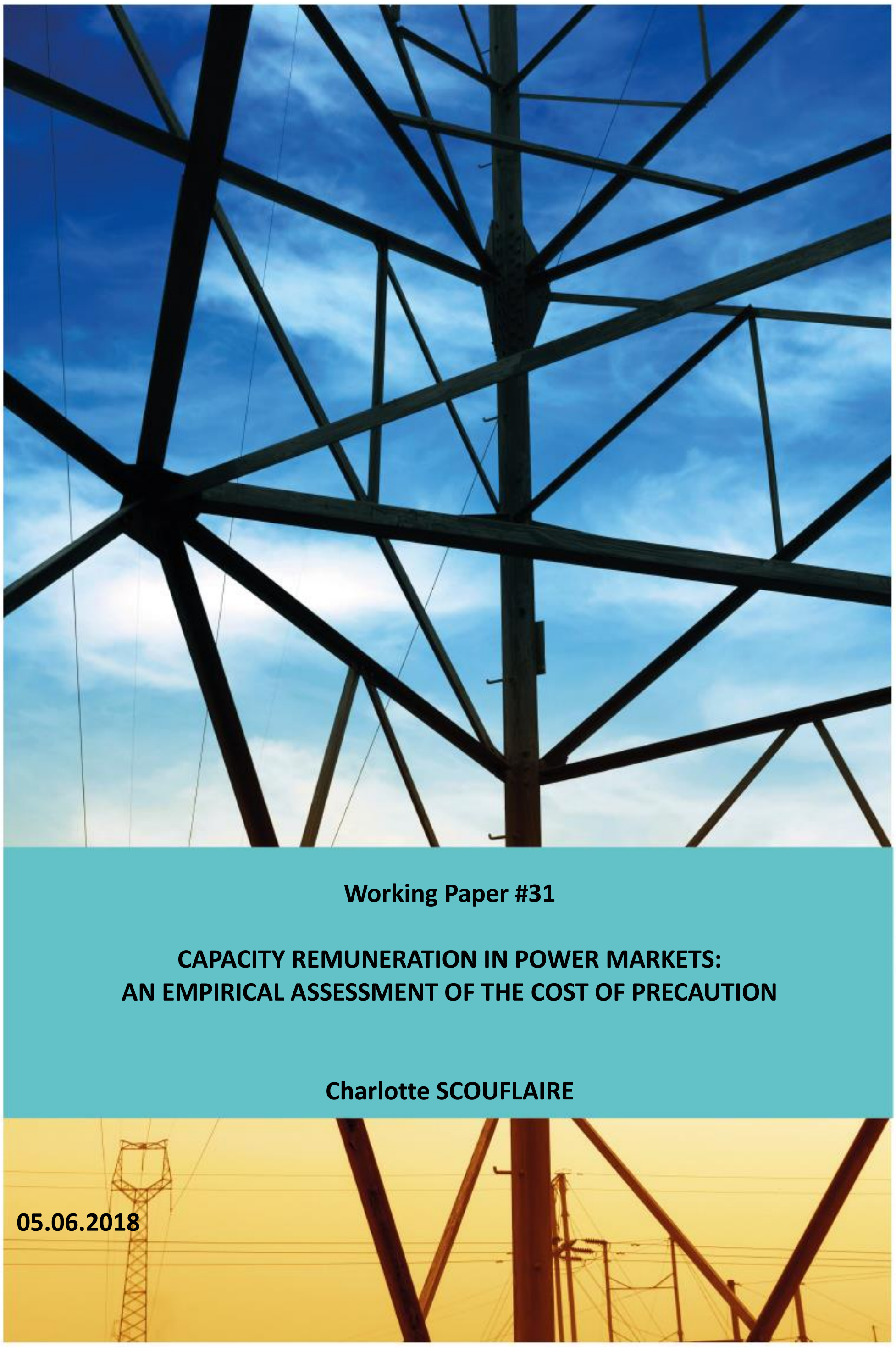

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CAPACITY REMUNERATION IN POWER MARKETS: AN EMPIRICAL ASSESSMENT OF THE COST OF PRECAUTION

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CAPACITY REMUNERATION IN POWER MARKETS: AN EMPIRICAL ASSESSMENT OF THE COST OF PRECAUTION

Charlotte Scouflaire [*]

Abstract

Because of market inefficiencies, it can be doubtful that the energy only market can ensure an adequate level of security of supply. If market failures have indeed been identified, the resulting deviations from the benchmark model are difficult to quantify. Regulators sometimes implement capacity remuneration mechanism (CRM) as a precautionary measure when security of supply is at risk. Plants then get paid for their very ability to produce in addition to their production. In theory, the remuneration of capacity partially or totally replaces the scarcity rent, reducing the overall price volatility on the market. The market risk is reduced and risk averse agents feel more comfortable investing. Consequently, securing a certain level of security of supply can be cheaper system wide if capacity cost do not offset the benefits of risk and energy prices reduction. Furthermore, any structural shift in remuneration is expected to have distributional effects amongst agents. This paper investigates both the net cost for the consumer and the repartition of such cost among the consumer groups (industrial versus residential). In a panel of 25 states over 24 years with both US states and European countries, a model in difference is used on industrial end user power price dynamics are assessed to set out the net cost of CRM implementation. Indeed, end user pay for the whole supply chain, their prices should reflect the overall system costs. In addition, redistribution effects are investigated using the ratio industrial power prices over residential ones to determine which class of consumer is more affected by the measure. Overall, system costs (by way of end user prices) are statistically unaffected by the CRM implementation. If any, the effect would be downward as in the US: prices have decreased by 1.2% on average. Forasmuch as the measure does not deteriorate security of supply, the financial gain then overweights the financial cost, suggesting a cost efficient internalization of the security of supply externality in the US. The implementation of CRMs also tends to brings residential and industrial end user prices closer one to another, meaning that the residential consumers benefit more from the measure than their counterpart. Considering that the cost of precaution is actually closer to a benefit, there is a dire need to fill the literature gap on CRM efficiency and on dynamics of security of supply demand to settle the argument.

Key words: Capacity remuneration, security of supply, electricity markets, cross-country analysis

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I. INTRODUCTION

In modern societies, access to electricity is the core of lifestyle, which results in power cuts being very costly at every level. Of course, backup generators do exist and are often used where black outs are the most costly, like in hospitals. But ordinary firms, administrations, individuals and agents in general are vulnerable to shortages: no computer or machinery means no work done for firms, a non-functioning traffic light could create accidents and frozen food gets lost when the power is off. The list of losses within the economy could be continued for long and no regulator can fully ignore it. With non storable electricity and inelastic demand, the ability to ensure continued power supply largely depends on installed capacity.

In energy only markets, as in any market, plants get paid in proportion to their production (Stoft, 2002)[28]. Under this framework, installed capacity is a byproduct of private equilibrium. To internalize security of supply, capacity is given intrinsic value through capacity remuneration mechanisms (CRMs). Investment incentive does not solely rely on scarcity pricing anymore, prices are less volatile and overall lower on the wholesale market (Bajo-Buenestado, 2017)[2]. In incomplete markets, it follows a drop in market risk that lowers the investment costs[1]. Risk averse agents (De Vries, 2004)[9] are more likely to invest. Both the energy produced and the installed capacity are optimized upon by the generators to ensure convergence of the private and social optima. Whether CRMs are needed or not is still in debate, but CRMs being implemented in more and more countries is a fact. It is consequently surprising that there is a lack of consensus on the empirics of CRMs, especially in terms of efficiency, cost and impact. From an empirical perspective, (Mastropietro, Rodilla, & Battle, 2015)[20] (Henriot & Glachant, 2014)[14] (Meulman & Méray, 2012)[21] (De Vries, 2007)[7] discuss the most efficient design of capacity remuneration schemes to internalize market failures. Further, numerical models allow for a good knowledge of market behavior under specific assumptions as in (Hanspeter, De Jonghe, & Belmans, 2014)[12] (Petitet, Finon, & Janssen, 2015)[25] (Petitet, 2016)[24]. However, the underlying hypothesis sometimes drive the results. This is fine as long as one acknowledges that it is not representative of real life markets. Instead of isolating effects through perfect knowledge of inputs, empirical econometrics use market outcomes to track back the effect of characteristics of interest. The two quantitative approaches are clearly complementary, and empirics always come as a second step because of its dependence on realized data.

Luckily, some CRMs have been implemented long enough to start measuring empirically their effect. Using a panel approach, this paper seeks to set out correlations between CRM implementation and price levels to get a first peak at the net cost, disregarding the efficiency in terms of security of supply. Indeed, any change of market design shall be analyzed in details, especially when it arises from a precautionary regulator with imperfect information. Improvements in terms of security of supply are only visible during extreme and rare events, hardly noticed by consumers in industrialized countries. Its cost, however, is a highly relevant topic as the financial weight of CRMs is dealt among consumers independently of their preferences. The actions of a cautious regulator in terms of security of supply will mainly impact their bills: existing CRMs spread the charge on per peak demand participation (MW) or per energy consumed

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[1] Under the hypothesis that expected total profit is maintained, risk reduction means that the return on investment is higher. Investments in power markets gain attractiveness compared to other sectors

(MWh). Following such a structural change in market organization, end users consequently face the three contradictory effects: the lower average power prices might be partially or totally compensated by the new capacity price component. In addition, keeping an appropriate reserve margin becomes cheaper when investment cost is reduced, a cost reduction supposedly passed through to end users as well. Powerful vectors of information, prices embed all electricity cost components. It might be the only way to assess the net effect of those 3 elements, which makes it the perfect playfield to catch the overall cost efficiency of CRMs. Section II. develops the conceptual framework around CRMs to set out the different possible effects of CRM implementation, which results in the net effect hereafter studied.

When considering end user consumers, redistribution effects become central: residential and industrial consumers might be affected diversely. A good illustration is the newly implemented French capacity market. Being decentralized, it is the retailer's decision to pass through the cost of capacity. On the capacity market, all residential consumers are profiled, meaning that whatever their consumption at scarcity, they all pay for the same amount of capacity. On the contrary, industrial end user can get a finer estimation of their actual consumption profile and personalize their contribution to the capacity charge. In general, industrial consumers benefit from greater bargaining power than residential ones as it is an increasing function of quantities and predictability. For the agent in charge, it generally results a trade off on how to charge capacity. The easier way to set out structural differences between the two prices is to use the ratio of industrial end user power prices over the residential ones. The former is expected to be less sticky than the later.

Standing in the continuity of cross countries liberalization□s assessments as performed by (Steiner, 2001) [27], (Nagayama, 2009)[23], (Yücel & Swadley, 2011)[29] and (Joskow P. L., 2006)[17], this paper intends to empirically give an intuition on the impact of CRMs on industrial end user power prices levels as well as on the redistribution effect of the reform amongst categories of consumers. To do so, it considers the average effect of CRM implementation and forward period set up over the time span while controlling for market fundamentals. To set out the net effect of CRMs on end user prices, an original database including 17 US states and 8 European countries over 24 years is computed (section III.). Using a differenced model, CRMs are found to decrease industrial end user price by up to 1.13% (US). The deflating effect of CRMs is significant in the US while European countries show no evidence of prices being impacted. Contrary to intuition, the existence of a forward period in the US does not increase cost efficiency (section IV.). Results also show evidence of price convergence between residential and industrial end user prices following the implementation of CRMs. If residential prices remain significantly higher than the industrial ones, CRMs tend to bridge the gap: CRMs' price decrease benefit more to residential end users than to industrial consumers. Further, results set out the relative price responsiveness of the consumer categories to market fundamentals as well as the inflating effect of renewable integration for end users.

II. CONCEPTUAL BACKGROUND

1. Electricity markets

In the 80s - 90s, the general movement towards liberalization and deregulation reached power markets. Monopolies were suspected to over procure capacity for not bearing the investment risk. The structure of the industry changed drastically. It went from regulated vertically integrated monopolies with important economies of scale, to competitive market segments in generation and retail. The resulting shift of risk from the consumers to the generators might not be neutral in terms of investment incentive and security of supply. Security of supply is usually considered as the capacity of a system to supply demand at any time, avoiding black outs. Electricity being non storable economically and the demand inelastic, it means that sufficient generation capacity needs to be installed to match instant demand.

Under a monopoly structure, consumers pay the average total cost of electricity, generators are sure to recover their costs in totality. Full cost recovery incentivizes the monopoly to bind the constraint, ensure security of supply and cover the demand. In liberalized energy markets, generators obviously face competition, non-captive consumers and market uncertainty. In a competitive environment, markets clear at marginal cost until energy becomes scarce. This very scarcity pricing should ensure security of supply: the higher the frequency and size of price spikes, the bigger the capacity gap and the higher the incentive to invest (Stoft, 2002)[28]. The implicit dynamic is that investment incentives rely on rare extreme event with tremendous uncertainty. Under this framework, the market should clear when the long run marginal cost of the most expensive unit equates the consumer’s willingness to pay for the last unit of electricity consumed (Value of Lost Load)[2] at equilibrium. Reliability supplied is then optimal. This theoretical framework is the reference benchmark against which any market design should be tested (Joskow, 2010)[18]. Unfortunately, in presence of market imperfections, optimal reliability remains a concept that cannot be assessed.

2. Rationale for CRMs

On the demand side, most consumers are captive as electricity responds to essential needs. Demand inelasticity renders uncovering consumers’willingness to pay for the marginal unit of energy hardly possible, thus making its equalization with the long run marginal cost of the most expensive units improbable (Crampton & Ockenfels, 2012)[5]. Under such circumstances, it is doubtful that market could ever reach true optimal reliability.

On the supply side, price volatility creates a risky environment that tends to disincentivize investments (Crampton & Ockenfels, 2012)[5]. (Keppler, 2016)[19] shows that the lumpiness of investments makes system optimality unlikely to happen. Given such circumstances, under investment will always be a dominant strategy as firms face asymmetric incentives. All things equal, the firms’private cost of outdoing optimal capacity is much higher than the cost of underinvesting because private optimization disregards the preference for reliability. Complementarily, (Crampton & Ockenfels, 2012)[5] insist on the fact that from a social point of view, the cost of excess of capacity is relatively low compared to the cost of scarcity. It thus justifies the intervention of a central planner to explicit the optimal level of capacity. Complementarily, (Keppler,2016) [19] defines security of suppy as an externality, meaning that the social cost of a black out will always be higher than its private cost.

For a precautious regulator fearing the social impact of black outs, identified market imperfections motivate the implementation of capacity remuneration mechanisms to stabilize investment incentives. CRMs create a side market for capacity; it becomes a good on its own. Said market reduces the distortion between the social and private optimum by pricing capacity. Generators then receive a fixed capacity payment in addition to the variable energy revenue. By setting an explicit (quantity) or implicit (prices) capacity target as an estimate for consumer’s preferences, the regulator will offset the transactions costs linked to consumers’preferences

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[2] VoLL

discovery and create a price for security of supply. Generators receive retribution proportional to their participation to system reliability; investors are incentivized to reach socially optimal capacity as defined by the regulator. Naturally, the internalization of security of supply comes at cost: it is quantified and priced, tearing end user prices up.

However, the new market organization drastically changes the structure of market revenues. Where peakers used to recover their fixed and investment costs through a scarcity rent, they rely on capacity remuneration instead. As it replaces the highly volatile scarcity rent, wholesale price variance decreases[3]: the market risk is reduces, so is the total investment cost. To exemplify, let's consider an investor in a world where investors make their decision according to the net present value (NPV) criteria. Every investment with a positive NPV (expected to be profitable) is carried on[4]:

$$NPV_{inv}^{EOM} = \sum_{i=1}^{T} \frac{CF_i^{EOM} - C_i}{(1 + r^* + r_p)^i} - I \tag{1}$$

With T being the technical lifetime, I the investment cost, C_i is the annual fixed costs, CF_i^{EOM} the total annual cash flow in an energy only market (EOM). r^* is the risk free rate while r_p is the risk premium[5]. All arguments are positive. Under CRM, investment cost recovery do not rely on the volatile scarcity rent anymore. Therefore, the risk premia disappears[6]:

$$NPV_{inv}^{CRM} = \sum_{i=1}^{T} \frac{CF_i^{CRM} - C_i}{(1 + r^*)^i} - I \tag{2}$$

Consequently, if $CF_i^{EOM} = CF_i^{CRM}$, then $NPV_{inv}^{EOM} < NPV_{inv}^{CRM}$. More projects get invested in when a CRM is implemented and the reserve margin is naturally increased[7]. Under a market organization with capacity remuneration, the investor behavior does not change, but the NPV of given investments is more likely to be positive, all things equal.

Although considering CF_i^{EOM} to equal CF_i^{CRM} is a common hypothesis since (Joskow & Tirole, 2007)[16], it remains a strong assumption. With a CRM ensuring peakers' investments and fixed costs recovery, wholesale prices do not have to rise as much anymore. Both volatility and price levels are reduced[8], the net effect of CRM is uncertain and its implementation solely rely on the regulators' beliefs.

As discussed, many systems do implement CRMs in practice. The bias induced by identified market failures is impossible to assess, no model can accurately replicate reality. However, numerical models do quantify the impact of CRMs under given market imperfections. Using a system dynamics model in perfect competition, (Petitet, Finon, & Janssen, 2015)[25] find the loss of load[9] (hours per year) to be higher and installed capacity to be lower under CRM than under scarcity pricing. However, (Petitet, 2016)[24] extends the results including risk aversion

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[3] See (Hach, Chi Chyong, and Spinler, 2015)[11], (Hary, Rious and Saguan, 2016) [13], (Cepeda and Finon, 2011)[4], (de Maere, Ehrenmann and Smeers, 2017) [6], (De Vries and Heijnen, 2008)[8], (Bajo-Buenestado, 2017) [2], (Brown et al, 2015) [3]

[4] As it is usually the case in agent based models as EMLab-Generation or Power ACE models

[5] The risk premium depends on investment specific risk, which itself relates to the volatility of expected revenues

[6] For the sake of simplification, we consider that it disapears, but it most probably only reduces

[7] Reserve margin: share of capacity that exceeds the expected peak demand

[8] (De Vries & Heijen, 2008)[8]

[9] Loss of load: demand not satisfied

and shows that the loss of load grows with the risk aversion of the agents under scarcity pricing. On the contrary, risk aversion has very little impact on the loss of load under CRM. (De Vries & Heijen, 2008)[8] tests the efficiency of the energy only market, capacity payment and obligations under demand uncertainty. They find all alternative market designs to perform better than the energy only market and the capacity obligation to be more efficient both in terms of price levels (energy and capacity) and shortages.

3. Taxonomy

As discussed, the implementation of CRMs is a precautionary measure considering that optimal reliability cannot be effectively quantified. If, for some reason, the regulator believes the investors to be risk averse, a CRM would alleviate risk and restore optimal investment. Similarly, when consumers are expected to highly value security of supply[10], the regulator would be willing to limit potential black outs by setting up a CRM. Several kinds of CRMs have been tailored, the design of the CRM itself is driven by the relative cost of each security of supply related market imperfection into the regulator□s expectations.

In most studies, CRMs designs are classified depending on the way the price is set and to whom it is granted. Straight forward enough, a quantity based CRM requires capacity to be set while the price can vary against the supply. Price based is the opposite. The price is set and the quantity is left to the market to decide. Ultimately, the CRM implemented can either be targeted when only selected units receive the remuneration, or market wide when all of them are to get paid for capacity. Literature usually recognizes five types of CRMs (Figure 1): capacity obligation, capacity payments, strategic reserve, capacity auctions, and reliability options (Henriot & Glachant, 2014)[14] (Meulman & Méray, 2012)[21] (De Vries, 2007)[7]. The strategic reserve is excluded from the scope of the study for being a targeted out of the market capacity procurement. Indeed, in such a CRM construction, plants joining the reserve cannot participate in the energy market anymore; they only get activated in times of scarcity by the regulator in exchange for costs recovery. It is considered as a CRM because it does secure capacity in order to increase the reserve margin. However, the strategic reserve does not actually correct any of the potential market imperfections and having additional energy produced out of the market at scarcity most certainly lowers the scarcity rent and investment incentives. Another kind of CRM falls out of the scope: the reliability auction. The main illustration of a reliability auction is the Colombian market for firm energy (Mercado de Energia Firme). It consists in a call option on the energy market usually procured through an auction. When the spot price gets higher than the strike price defined by the TSO, the option providers must produce and pay back the difference between the spot and the strike price to the TSO. The strike price thus works as a revenue cap.

This study therefore focuses on the three main alternatives. Capacity payments have been the first CRM design to be implemented and are little by little replaced by reliability or capacity auctions or obligations worldwide. Under capacity payments, the regulator estimates the complementary remuneration needed by the actors for the reserve margin to be optimal [11]. Such a payment is then dealt amongst generators depending on their availability at peak. In our panel, Spain and Portugal did keep capacity payments for a long period of time although

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[10] Most consumers are price taker and do not have access to real time prices. They are then unable to send a signal on their preferences for security of supply. Reliability being a public good, they have an incentive to reveal their preferences.

[11] Reserve margin: expected total available capacity at peak divided by expected peak demand

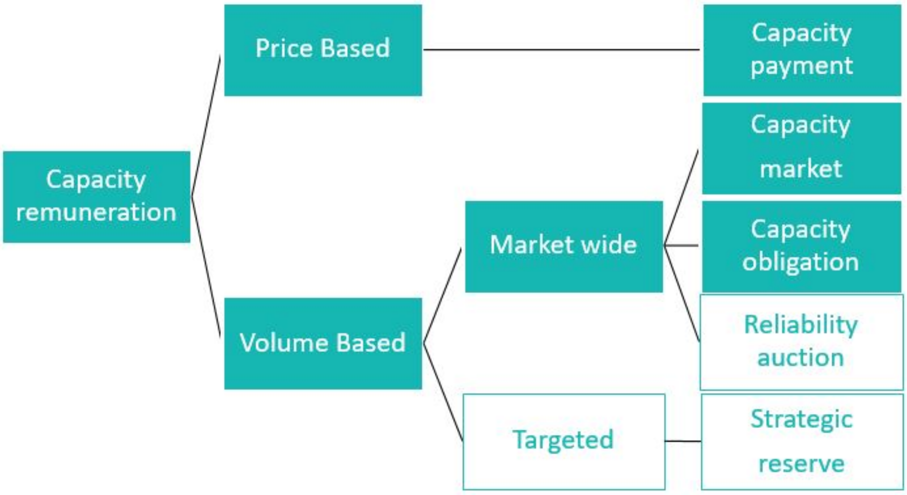

Figure 1: Taxonomy of CRMs

reforms have been implemented through. Ireland has had a capacity payment implemented since 2007. The market operator calculates the missing money of a new peaker, which, multiplied by the available capacity at peak, makes the total sum of capacity payment. This amount is then redistributed amongst generators depending on their forecasted availability, participation to LOLP reduction as well as their realized contribution to the later. The capacity market and capacity obligation are quite similar. In a capacity market, the regulator centrally procures a targeted level of capacity. For instance, in the PJM, the capacity demand curve is determined by the regulator through a predefined process, the market clears where the supply curve meets the demand curve. Under the obligation scheme, retailers have to secure their supply in order to be able to meet their peak in the future, leading to a decentralized total capacity procured. In France, capacity has to get certified, retailers and network operators can then acquire those certificates through bilateral contracts or auctions to cover their peak demand.

Further to this usual taxonomy, an additional feature is here considered of interest: the existence of a forward period. This specific feature is little studied in the literature. The amount of available installed capacity in a given system can follow two complementary strategies: ensuring availability via demand side management, storage, demothballing etc, or favoring commissionings. A momentary restoration of expected revenues enhances overall availability in the system. However, for new investments, the investor needs to be reassured not only for the short term but he wants to hedge market risks as much as possible on the investment horizon. Without a forward period, the remuneration will only be granted once the decision to invest (the risk) is taken. Short term designs are also known to be more easily modifiable adding up regulatory uncertainty. The forward period allows market participants to secure part of their revenues in advance and more importantly before the investment is completed. In addition, the capacity market clearing provides information on capacity needs in a transparent way. Such information tends to reduce investment cycles as shown by (Ford, 2001)[10]. Capacity remuneration is not secured for the investment lifetime, but yet, it lowers revenue uncertainty for the investor (Pfeifenberger, Spees, & Schumacher, 2009)[26]. This makes a quite significant difference in terms of investment incentives. Unfortunately, this evolution is quite recent and has been implemented along with other improvements in the US states. Indeed, the CRM version from the end of the nineteens lacked obligations and gave limited incentive to invest due to the very short term framework (daily products) and the related capacity price volatility.

All in all, the net cost of CRMs is not straightforward as it impacts market dynamics through three possible channels: the cost of security of supply internalization (payments for capacity), the reduced energy prices and lower perceived investment risk. In addition, the extend to which each of these vectors of transmission are efficient remain empirically unassessed. Yet, CRMs are imposed on agents independently of their actual willingness to pay. To set out the net impact, end user prices evolutions are analysed on the ground that end users are to pay for every cost component of electricity, whatever the market organization.

III. DATA AND METHODOLOGY

1. Variables and sources

To the author knowledge, no homogeneous database is available at the power system level in order to analyze regulation. Aggregated national data are usually published in a homogeneous way by the IEA, but the country scale is not always the relevant degree to efficiently study power markets, especially from a regulation perspective. For instance, the North American power sector comprises a diversity of coexisting power systems with distinct market organizations. To build up the sample, focus is set on Europe and the US for being the two regions where CRMs have been most discussed. The US are naturally considered at the state level as in (Joskow P. L., 2006)[17] and (Yücel & Swadley, 2011)[29][12]. In an effort to include both the EU and the US experiences in the analysis, the database is built relying on different sources in order to have the desired level of detail. Nine variables are created using separate data sources for the two regions [13]. The in depth analysis of existing CRMs (see appendix B) combined with publicly available homogeneous data lead to a panel of 25 states / countries over the period 1991-2014. The 25 states (17 US states and 8 European countries) composing the panel are: France, Belgium, Germany, the United Kingdom, Ireland, Spain, Portugal, Italy, states part of the ISO New England system (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont), of the PJM (Kentucky, New Jersey, Ohio, Pennsylvania, Virginia, West Virginia), of Southwestern Power Pool (Kansas, Nebraska, Oklahoma) as well as Texas (ERCOT) and the state of New York (NYISO). Among those, only the UK, Ireland, Spain, Portugal, Italy, ISO-NE, NY-ISO and the PJM have implemented a CRM at some point[14]. ISO-NE and the PJM have added a forward period in the late 2000s while the UK, France, Italy and Ireland are just implementing it[15].

Social surplus maximizing regulators implement CRMs as a way to ensure security of supply. Considering that CRM's efficiency in terms of security of supply has not been assessed, it is thus fundamental to know how it financially affects mandating agents for the regulator to make informed decisions. To understand better CRMs' net cost, yearly averages of residential and industrial end user prices are taken at the country level in Europe and state level in the US while the CRM implementation variable is built from systems regulation assessment. Because end user prices include all electricity cost factors, this aggregate is the only way to assess the

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[12] Both examine state level panel to assess the impact of liberalization reforms on end user prices

[13] See appendix A for further details on the data ans variables

[14] The remaining systems have been added for the robustness of control coefficients.

[15] See Appendix B for further information on the status of CRM implementation in the different countries of the panel

State	System	Current CRM	Short term	Forward
FR	France	-	-	2017
BE	Belgium	-	-	-
DE	Germany	-	-	-
UK	United Kingdom	Short Term	Until 2001	2018
IE	Ireland	Short Term	2007	2017
ES	Spain	Short Term	1997	-
PT	Portugal	Short Term	2010	-
IT	Italy	Short Term	2004	2017
CT	ISO-NE	Forward	1998	2010
MA	ISO-NE	Forward	1998	2010
ME	ISO-NE	Forward	1998	2010
NH	ISO-NE	Forward	1998	2010
RI	ISO-NE	Forward	1998	2010
VT	ISO-NE	Forward	1998	2010
NY	NYISO	Short Term	1999	-
KY	PJM	Forward	1999	2008
NJ	PJM	Forward	1999	2008
OH	PJM	Forward	1999	2008
PA	PJM	Forward	1999	2008
VA	PJM	Forward	1999	2008
WV	PJM	Forward	1999	2008
KS	SPP	-	-	-
NE	SPP	-	-	-
OK	SPP	-	-	-
TX	ERCOT	-	-	-

Table 1: CRMs description

net effect of CRM implementation on the overall cost of electricity, accounting for all possible interactions. Industrial and residential prices supposedly have the same structure: an energy component, based on the wholesale price, a transport component (network costs) and the taxes and levies. This last category usually gathers miscellaneous elements ranging from subsidy pass through to green tax. The cost of CRMs should also lie in in this last component, but it might as well be accounted for differently in some countries. In addition, each component is not spread alike amongst categories of consumers [16]. This is driven by inner differences in bargaining power both with their retailer and politicians: residential consumers are captive and inelastic, exposed to energy poverty while industrial ones have some bargaining power and are subject to international cost competition. Consequently, end user prices are affected by a wide range of factors (see figure C.1 & C.2 in appendix C) and unfortunately, the split by component is not available for the whole period. The focus will be on industrial end user prices rather than residential because it is driven by the energy component, which respond to market dynamics easier to quantify (see figure C.1 & C.2). It will be controled for by market fundamentals: the mix of producing technologies and their respective costs which are compiled

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[16] see C.1 in appendix C

Variable [18]	Variable name	Description	Type	Expected impact
Real Industrial Power price	Price_Real	$ /MWh	Dependant	-
Real Residential Power price	ResPrice_Real	$/MWh	Dependant	-
Ratio Industrial/Residential prices	RatioIndRes	$/MWh	Dependant	-
CRM	CRM	Dummy	Independant	Positive
Forward	Forward	Dummy	Independant	Positive
Real Gas price	GasPriceReal	$/GJ	Control	Positive
Hydro share	HydroProd	%	Control	Negative
RES share	ResProd	%	Control	Negative
Nuclear share	NukeProd	%	Control	Negative
Coal share	CoalProd	%	Control	Negative

Table 2: Variables

as control variables[17]. As for the cost and benefits of CRM implementation, it can be included in any component depending on the actual design.

The variables of CRM implementation (CRM and Forward) are self-constructed. Although CRM design is an ongoing learning process, the variable of CRM implementation is modeled as a dummy. This reflects the average effect of CRM implementation on en user prices, leaving the ideas of price inertia and market convergence for further research. Based on each country or state□s regulation analysis, dummy variables are built. They take the value 1 the first year plants actually receive the capacity remuneration[19]. Afterwards, the variable remain at the same level until capacity remuneration is eventually removed. In this panel, only the UK have ever removed a CRM, other systems only upgraded it with additional features, including a forward period. The discriminating criteria between a forward and a short term mechanism is the length of the forward period: is considered as forward mechanism any CRM with a forward period of at least a year. Indeed, for a forward period to have a hedging effect, it needs a minimum duration allowing investors to anticipate market evolution. The two explanatory variables are defined as follow: one accounting for CRM implementation and the second one for the existence of a forward period. For instance, a state with a forward capacity market would get non-zero CRM and forward variables. Any additional specificities in CRM design is not accounted for.

The production mix is a powerful price driver. Indeed, renewable technologies have a null marginal cost but their intermittency generates stress in the power system. On the contrary, hydro power usually have a stabilizing effect on prices given there is enough water storage. Nuclear generation is cheap but little flexible while coal plants are mid merit technologies, both more flexible and expensive than nuclear. Their relative repartition in terms of production does alter price levels at any point in time. However, using production in megawatt hours without accounting for market size would bias estimates: the system with the highest demand would drive results. Using the share of each fuel in the mix by dividing production by total demand provides comparable data for every state. Gas production is excluded from the mix variables to avoid collinearity. Its effect on end user prices is taken into account through industrial gas prices. Gas plants being often marginal, it does make sense to consider its fuel cost instead[20].

For the European countries, main data sources are Eurostats and the International Energy

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[17] Table 2 sums up the variables of interest.

[18] See appendix A for additional information on variables.

[19] For the Forward CRM, the relevant date is the first delivery year

[20] The unavailability of long series on gas prices to the power sector, industrial gas prices are used as a proxy

Agency (IEA). Following (Hyland, 2016)[15], industrial electricity prices are the ones faced by medium-size firms and households. The same choice is made regarding gas prices for data availability reasons. Information on the electricity mix is gathered from the IEA series on electricity production by fuel and country.

In the US, the Energy Information Agency is the primary source of per state data for the US. Industrial electricity and gas price series are industry wide but calculated for each state. As for Europe, production by fuel by state is publicly available. Choice has been made to normalize the mix variables in order to make it comparable over the regions. Productions per fuel become shares when divided by the total production.

2. Descriptive statistics

Table 3 provides an elemental description of the dataset. The panel seems rather heterogeneous in terms of mix as the standard deviation is high compared to the mean and even higher in some cases. This is fairly intuitive; each country has the mix matching its natural endowments and demand shape. Interestingly, industrial consumers pay an average annual price 35% lower than residential consumers, reflecting both the negotiating power of industrial consumers compared to residential ones and their finer view on their load's shape. This is consistent with economic theory as residential customers are both more captive and with less bargaining power.

Variable	All Mean	All Std. Dev.
Price_Real	61.91	24.03
lnPrice_Real	4.05	0.39
ResPrice_Real	96.35	33.20
lnResPrice_Real	4.77	0.38
RatioIndRes	0.63	0.10
GasPrice	4.51	0.33
HydroProd	6.99	8.41
ResProd	1.89	4.58
NukeProd	24.50	23.48
CoalProd	35.95	29.02
Observations	600	

Table 3: Descriptive statistics for the panel

Table 4 gives a quantitative view on the evolution of CRMs in the panel. Following table 1, all states have had several years without CRM between 1991 and 2014. In turn, Table C.1 describes the dataset discriminating for states which implemented a CRM at some point. Statistically, the countries which decided to implement a CRM are different from the ones which declined the option. It is rather unsurprising considering that the mix variables mainly control for between variations. Specific mixes do have an excessive impact on means. In addition, the test for mean difference tends to support the hypothesis that CRM implementation increases prices. Contrastingly, the standard deviation of industrial prices is somewhat similar for the two groups whereas the standard deviation for residential prices is 30% lower for the countries that did decide to implement a CRM. Statistics suggest that residential customers under CRM are more protected against price variation than their counter parts that do not benefit from this measure. Industrial consumers probably use their bargaining power so they can adjust better to wholesale prices evolution. Gas prices are naturally similar under the two designs as they typically converge on a regional basis.

Implementation	**CRM** Freq. Between	**CRM** Percent Between	**CRM** Percent Within	**Forward** Freq. Between	**Forward** Percent Between	**Forward** Percent Within
0	25	100.00	55.50	25	100.00	88.00
1	18	72.00	61.81	12	48.00	25.00
Total	43	172.00	8.59	37	148.00	67.57

Table 4: Descriptive statistics on CRM implementation and the Forward feature

Coherently with the hypothesis of sticky residential power prices, the ratio should be driven by industrial end user prices variations, figures C.4 and C.6 show such relationship. Each state/country has both a different price level and standard deviation over time, suggesting strong individual effects. The private and public choices in terms of cost allocation discussed earlier is reflected in the dissimilarities between figures C.3 and C.5. Countries make diverse decisions, but the range is reduced. This upward trend of gas price average in figure C.8 echoes the industrial power prices variations. Interestingly, gas prices tend to diverge over the period with an increasing standard deviation[21]. Simultaneously, gas price differences between the countries/states are very small compared with what is observed in end user power prices. Assuredly, industrial gas price is a relevant price driver, but country specificities should complete the understanding of end user power prices.

Figure 2 shows the shape of the relation between the variables. All variables have a rather linear relationship with the logarithm of industrial power prices. Two way representations of the control variables with industrial and residential power prices display similar patterns although the distribution of the dots is broader in the case of residential consumers. Hydroelectric production□s share in total production along with nuclear share show no clear correlation with the logarithm of power prices at the pooled level. Considering they are both baseload technologies whose production depends mainly on installed capacity, it is rather unsurpising [22]. On the contrary, industrial gas prices do present a rather positive correlation with end user power prices as expected. Increasing coal production in the mix would somewhat lower prices. The case of renewables is more peculiar: a higher share in the mix is positively correlated with end user prices. Green technologies have benefited from important cost reductions during the period allowing for large scale development, although adoption rates largely depend on state support, be it on a regulatory or financial level[23].

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[21] The statement valid at the regional level as well. It thus cannot be fully seen as a consequence of the shale gas revolution.

[22] See Figures C.9, C.10, C.13 and C.14 for more information on the data structure

[23] See Figure C.16 and C.15

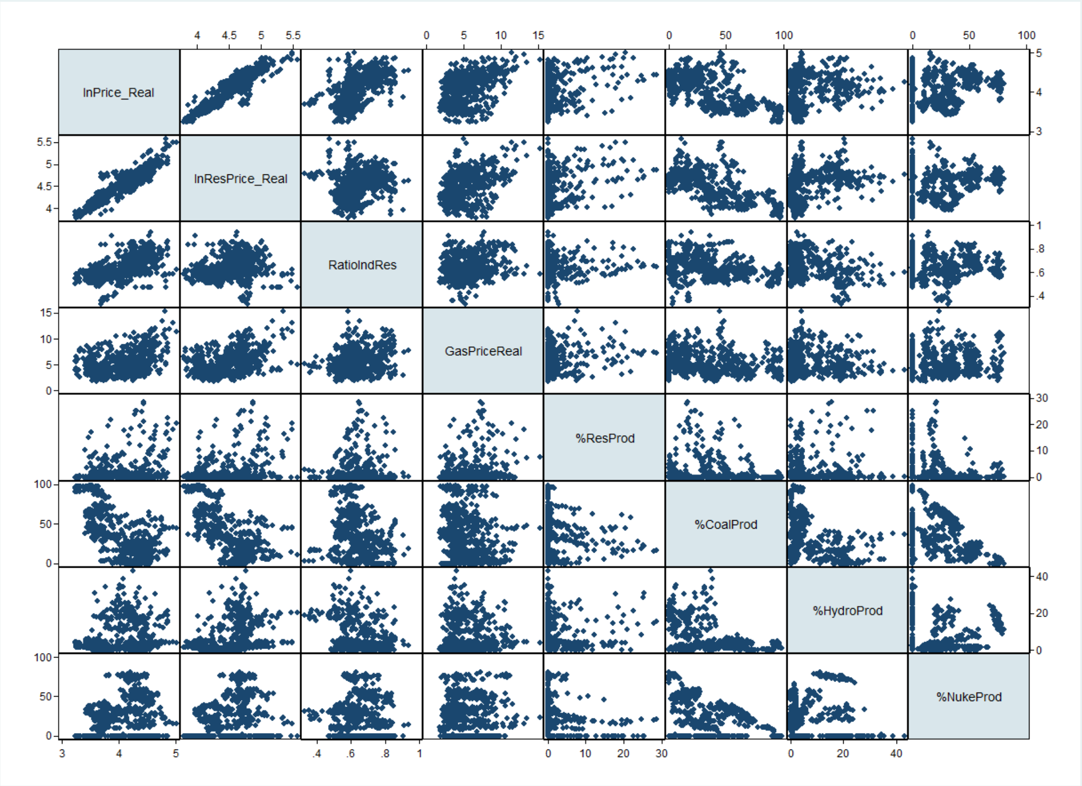

Figure 2: Two way plots of the variables

3. Methodology

As discussed earlier, CRM implementation depends on the regulators' expectations on the risk aversion of investors as well as the consumers preferences in terms of reliability. While it is difficult to conclude whether there actually is a social benefit to the measure, the implementation is based on the belief that the costs of inaction are higher than the costs of precaution. Indeed, utilities tend to be international and present in different countries while the regulators□decisions vary from one to another. Consumers□preferences most probably vary from one state to another, but the capacity of the regulator to uncover said preferences is questionable. Those beliefs on investors and consumers preferences are thus supposed exogenous to the regressors. Similarly, the electricity mix (hydroelectric, nuclear, renewable and coal share in total production) and gas price levels will mainly depend on natural endowment which is also exogenous. Yet, the mix variables by state[24] clearly suggest individual specificities, while prices also display a dominant time dimension[25]. Allegedly, individual and time fixed effects should be controlled for as well as spatial effects. The model will have the following form:

$$P_{it} = C_{it}\beta_1 + C_{it-1}\beta_2 + X_{it}\alpha + \sigma_i + \eta_{ij} + \omega t + \gamma_{rt} + \epsilon_{it} \tag{3}$$

P_{it} represents either the series of industrial end user power price in logarithm or the ratio industrial end user power price over residential one in country $\boldsymbol{i}$ at year $\boldsymbol{t}$ and X_{it} is the matrix

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[24] See Figures C.9, C.13, C.11, C.15

[25] See Figures C.4, C.8

of the control variables as defined and described in sections 1. and 2. [26]. Individual effects are embedded in σ_i while spatial fixed effects and regional time fixed effects are respectively represented through η_{ij} and γ_{rt}, r being the index that stands for Region (US or EU). Conjuncture is indeed different in both regions, justifying specific time effects. Finally, a time trend is added[27] and the error term is ϵ_{it}. C_{it} is the set of CRMs variables as previously defined [28]. Using dummy variables is a modeling choice: the coefficient reflects the average change in end user power prices since implementation. Since the shape of the convergence toward a new equilibrium is unknown, the average effect is assumed to be flat and constant over the implementation period.

The robust Hausman test rejects the convergence of random effect and fixed effect estimators in almost all cases. The existence of individual fixed effects is confirmed. Differencing equation (3) removes the individual effects[29] which are not time dependent and variables become stationary. In a differenced model, the constant stands for a trend. The following equation is then to be estimated:

$$\Delta P_{it} = \omega' + \Delta C_{it}\beta_1' + \Delta C_{it-1}\beta_2' + \Delta X_{it}\alpha' + \Delta\gamma_t' + \Delta\epsilon_{it} \tag{4}$$

Under such specification, serial correlation disappears but evidence of heteroscedasticity and cross sectional dependence remains. Reported standard errors thus account for the non-orthogonality of the error (Driscoll and Kraay (1998)). β_1' and β_2' would be interpreted as the average effect of CRM implementation on the real industrial power price in percent. If the coefficient is negative, the shift in surplus is quite straightforward: end user benefit from additional or equal security of supply (by hypotheses) for a lower price. Their surplus increases with the introduction of a capacity remuneration mechanism and a market with CRM is definitely a much better design than the energy only. However, when the coefficient is positive, the financial costs overweight the financial gain at the end user level. The coefficient for industrial real gas prices should also come out positive and significant while the hydroelectric share, renewable share and nuclear share should theoretically have a negative impact on prices as these kinds of generation are quite inexpensive. The coefficient for coal production could be positive or negative depending on all those elements, even though descriptive statistics suggest a negative correlation with end user prices. To account for market tensions, GDP has been tried out as well but reveled insignificant. It has not been included in the model to avoid any kind of endogeneity between prices and demand. A similar reasoning applies to the reserve margin. As the panel has an equal number of time and individual dimensions, adding up the time dummies tend to remove most significativity from the regressors, but such a control seems necessary. Similarly, states that never implemented a CRM are kept in the panel for the robustness of the control coefficients, even though they have no impact on our variables of interest in a within dimension.
In a first stage, the full model is estimated (Model 1). Further, the forward feature variable is excluded (Model 2) to assess how results are affected. Then, the two models are applied to regional sub panels: European countries on the one hand, and US states on the other hand. Indeed, pooling state level data with country level data makes economic and statistical sense in order to have large enough panel with variability in the data so that a global effect can be derived. But it is also a leap of faith that needs to be investigated at a more granular level: the

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[26] To test for level effects, the exercise has been performed with prices in level and prices indices. Results are rather similar. The log level model has been chosen to ease interpretation.

[27] This is especially needed for the regression with the ratio as both prices diverge more and more over time

[28] To account for a potential delay in the pass through of the cost of CRMs, the lagged dummy regulation variables are added to the model. Coefficients then add up.

[29] BM-LM test rejects the presence of individual effects

panel is aggregated from different datasources, only US states have a forward period, European CRMs have been less profoundly reformed and the regulation history of the two regions is different. All those elements as well as different data sources might affect poolability in a way that the Chow test does not foresee. The described models will be run at a regional level to set out potential differences. When running the models at the regional level, only the American systems do have a forward period feature, models 1 is irrelevant at the European level. Industrial and residential end user power prices display similar results: only results corresponding to the former will be displayed. To complete the analysis in terms of distribution effect, the methodology is applied to the ratio of the two prices[30].

IV. RESULTS

1. Capacity remuneration

To the inconvenience of capacity remuneration detractors, the implementation of such a measure does not have a net inflating effect on end user prices (table 5). If any, the effect would rather be negative as suggested by the results at the US sub regional level. In a more economical sense, the decrease in wholesale prices more than compensates the costs associated with the new remuneration leading to price decrease.

The insignificance of the effect at the pooled level is actually unsurprising considering the heterogeneity of CRMs in Europe and the level of state intervention. Indeed, over the first times of liberalization, governments have tried to protect their consumers, especially the most vulnerable ones: residential end users. In a context of increasing European integration[32], the Spanish government took action against inflation by reducing electricity tariffs[33]. The structural deficit in tariff structure have only been taking care of at the beginning of 2013[34]. Under a framework of structural interventionism in end user prices until recent time, strong results would require a broader and longer panel, including the most recent CRM experiences and regulatory changes in France, the UK as well in Italy and Ireland.

On the contrary, the implementation of a reliability standard through centralized capacity remuneration decreases industrial end user prices by 1.13% on average in the US states of the panel. The lagged policy variable do not have a significant effect. The amendment of such CRM in order to include a forward period does not significantly affect prices neither. The gains in efficiency that were expected through in depth reform of the mechanism are not reflected on end user prices, even though the underlying dynamics of investment and availability are very different under such a framework. This tends to oppose the hypothesis of greater efficiency of the forward mechanisms over the short term ones as if all the gains already kicked in with CRM implementation. In the European panel as well as in the pooled sample, policy variables do not stand out as significantly different from zero.

In a framework with two categories of consumers: the industrial and residential end user, the distributional effect of a measure is of great interest. Results in table 6 suggest that CRM implementation creates a convergence between industrial and residential end user power prices

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[30] The ratio of industrial over residential power prices cancels out some fixed effects. Global time fixed effects replace regional ones in that case

[31] Only countries which implemented a CRM are taken into account

[32] Fixed exchange rates with the Euro were set at the end 1998

[33] ***A new reign in Spain***, Oscar Arnedillo, Power economics May 2004

[34] ***Deficit de tarifa o sobrecoste de capacidad***, Andrés Seco, El Pais, 19 Dic 2016

	(1)	(2)	(3)	(4)	(5)
	Model 1	Model 2	Model 2	Model 1	Model 2
	Pooled	Pooled	EU	US	US
VARIABLES	$\Delta\ln$(Price)	$\Delta\ln$(Price)	$\Delta\ln$(Price)	$\Delta\ln$(Price)	$\Delta\ln$(Price)
ΔCRM	0.000270	0.000147	0.00962	-0.0113***	-0.0117***
	(0.0162)	(0.0162)	(0.0299)	(0.00264)	(0.00249)
ΔCRM1	0.0192	0.0190	0.0569	-0.00426	-0.00469
	(0.0238)	(0.0237)	(0.0396)	(0.00587)	(0.00576)
ΔForward	-0.00953			-0.00966	
	(0.0248)			(0.0220)	
ΔForward1	0.0506			0.0537	
	(0.0424)			(0.0422)	
ΔGasPriceReal	7.60e-05	8.33e-05	0.000173	4.29e-06	1.83e-05
	(0.000209)	(0.000210)	(0.000187)	(0.000440)	(0.000438)
ΔHydroProd	-0.00116	-0.00115	-0.000634	-0.00258	-0.00232
	(0.000800)	(0.000825)	(0.000795)	(0.00171)	(0.00177)
ΔResProd	0.00567***	0.00519***	0.00452	0.00793***	0.00689**
	(0.00190)	(0.00159)	(0.00284)	(0.00269)	(0.00302)
ΔNukeProd	-0.000430	-0.000512	-0.000642	-0.000517	-0.000603
	(0.000445)	(0.000469)	(0.00398)	(0.000471)	(0.000495)
ΔCoalProd	0.000538	0.000249	-7.14e-05	0.000895	0.000429
	(0.000883)	(0.00103)	(0.00215)	(0.000753)	(0.000781)
Constant	-0.00298	-0.00317	0.0144**	-0.0106*	-0.0109*
	(0.00341)	(0.00342)	(0.00593)	(0.00562)	(0.00553)
Regional time fixed effects	YES	YES	YES	YES	YES
Observations	575	575	184	391	391
R-squared	0.496	0.492	0.716	0.257	0.246
Number of groups	25	25	8	17	17

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5: Regression results on industrial prices (1992-2014)

	(1)	(2)	(3)	(4)	(5)
	Model 1	Model 2	Model 2	Model 1	Model 2
	Pooled	Pooled	EU	US	US
VARIABLES	ΔRatioIndRes	ΔRatioIndRes	ΔRatioIndRes	ΔRatioIndRes	ΔRatioIndRes
ΔCRM	0.00602	0.00576	0.0128	0.00278**	0.00261*
	(0.00386)	(0.00385)	(0.00990)	(0.00130)	(0.00129)
ΔCRM1	0.0140**	0.0135**	0.0149	0.00628*	0.00606*
	(0.00613)	(0.00584)	(0.0126)	(0.00325)	(0.00328)
ΔForward	0.0162***			0.0119***	
	(0.00400)			(0.00404)	
ΔForward1	0.0129**			0.0225*	
	(0.00464)			(0.0110)	
ΔGasPriceReal	-2.82e-06	-4.01e-06	3.97e-05	2.02e-06	1.72e-05
	(4.74e-05)	(4.82e-05)	(0.000117)	(0.000156)	(0.000145)
ΔHydroProd	-0.000661*	-0.000709**	-0.000508	-0.000695	-0.000761
	(0.000329)	(0.000334)	(0.000552)	(0.000726)	(0.000740)
ΔResProd	0.00317***	0.00260***	0.00167	0.00380**	0.00312*
	(0.000834)	(0.000839)	(0.00240)	(0.00174)	(0.00155)
ΔNukeProd	-0.000111	-0.000126	2.31e-05	-0.000156	-0.000205
	(0.000248)	(0.000248)	(0.00220)	(0.000312)	(0.000309)
ΔCoalProd	0.000990**	0.000903**	0.000631	0.000796	0.000551
	(0.000373)	(0.000355)	(0.000674)	(0.000574)	(0.000514)
Constant	-0.0101***	-0.0102***	-0.0121**	-0.00980***	-0.0100***
	(0.000814)	(0.000830)	(0.00389)	(0.00204)	(0.00192)
Time fixed effects	YES	YES	YES	YES	YES
Observations	575	575	184	391	391
R-squared	0.144	0.139	0.225	0.188	0.177
Number of groups	25	25	8	17	17

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: Regression results on the ratio industrial prices over residential prices (1992-2014)

through a positive effect on the ratio[35]. Indeed, the ratio is positive by essence and residential prices are higher than industrial ones at all time in all states [36]. Assuming CRMs do lower end user prices (as suggested by table 5 and D.1), residential consumers have to benefit more from the price reduction induced by CRM and forward period implementation than the industrial ones for the gap between prices to decrease. The effect is persistent and often hits harder with one year lag. This is due to residential price stickiness and specially true for CRM implementation where only the lagged policy variable, significantly affect the ratio. It holds to a lower extent for the forward feature implementation.

2. Electricity mix

Control variable coefficients are very little impacted by specification, their sign remains coherent with market fundamentals although mostly insignificant. As meaningful price drivers, higher industrial gas prices are consistently linked to higher industrial power prices. Regarding hydroelectric production and nuclear, the coefficient is naturally negative. Both benefit from low marginal costs which tend to lower power prices on average. The insignificance was expected here because of the low variability of the hydroelectric and nuclear production in the time dimension. Indeed, (Yücel & Swadley, 2011)[29] and (Steiner, 2001)[27] also find the coefficients for hydroelectric production and nuclear to be insignificant respectively in the US and in a cross country study. Other than having a fairly intuitive sign, the effect of control variables remain too small to be considered as different from zero in all cases except renewables, which positive coefficient is both unexpected and significant.

Indeed, increasing renewable penetration would have two contradictory effects on prices (Moreno, Lopez, & Garcia-Alvarez, 2012)[22]. A downward influence would be because of the so called merit order effect. The upward effect kicks in when subsidies for renewable development and flexibility costs are passed through to the end user. The inflating effect seems here to dominate. An increase of one point in renewable production increases industrial power prices by 0.06% on average and even 0.08% in the case of the US states. The effect is only significant at the 15% level in the european countries, and the order of magnitude supports also support the hypothesis.

The regression on the ratio is instructive on the link between market fundamentals and end user prices. Curiously, all the control variables in table 6 display coefficients of the same sign as in table 5. This backs up the hypothesis of stickier residential prices. Indeed, if a positive shock on industrial prices also reduces the gap between industrial and residential prices and a distress in prices tears them further apart, the natural conclusion is that industrial end user power prices are more responsive to market fundamentals than residential ones. The later see market fluctuations averaged out rather than passed through at full variance, be it instantaneously or the next year[37].

However, this hypothesis does not hold true for renewable production. As stated above, an increase in renewable production drives end user prices up, meaning that the effect of renewables on the power component [38] of the end user prices is overstepped by the effect on the

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[35] An increasing the ratio converges towards one, meaning that the two prices get closer one to another

[36] see figures C.5 and C.6

[37] Hypothesis tested but not discussed here: residential end user power prices actually respond to contemporaneous market fundamentals and not their lagged value.

[38] So called merit order effect

other elements: network, levies and taxes. If the more renewable production, the more industrial and residential prices converge, it is unlikely to be due to residential price stickiness to market fundamentals. A simpler inference is that industrial end users bear the cost of renewable integration in a greater extent than residential end users, causing their prices to increase more quickly than those of their counterpart.

3. Robustness

Table D.1 displays the results for residential end user prices, they do not differ much from those of industrial end user prices. The effect of CRM implementation remains statistically insignificant in all regressions except for the American panel. As the regression on the ratio suggests, the reduction in prices appears more important for residential than industrial consumers with an average decrease around 3%, half of it being passed through with a one year lag. The inflating effect of renewable production does not seem to affect residential end users at all, supporting previous statements as well: when policies result from institutional will, market fundamentals cease to be price drivers.

The size and heterogeneity of the panel does not allow for strongly significant results, but OLS estimators should converge towards their true value, so consistency among specifications results is an important verification to do. Indeed, table C.1 shows significant differences between the countries which decided to implement a CRM and the other. In a long panel, the incorporation of time fixed effects largely affect degrees of freedom and consequently the standard errors. Similarly, the will to detect potential response following the implementation of a forward period might create a spurious regression. Lastly, the UK is the only country to remove a CRM in the panel. It is consistent to consider the situation where CRM removal does not bring price levels back to their former level, but rather towards a new height. The UK is thus excluded from the panel for robustness. Overall, robustness checks confirm previous results.

Figures D.7 to D.12 present the regulation coefficients either under different specifications or with distinct standard errors. The reference coefficient (baseline) is the one from Model 1 as displayed in tables 5 and 6. For both industrial end user power prices[39] and the ratio industrial over residential end user prices[40], the baseline coefficient is displayed along with the Newey estimator[41], the cluster robust standard errors from OLS as well as the modified model [42] removing alternatively the states which never implemented a CRM, the time fixed effects (TFE) and the UK. In general, results under the different specifications are rather consistent one with the other. The choice of standard errors is not determinant neither. The Driscoll Kraay standard errors account for cross sectional dependence contrary to the cluster robust and the Newey. None of the alternative regressions seriously question the results as all coefficients converge both in terms of standard errors and in levels. Even taking a larger confidence interval (80%), the implementation of capacity remuneration struggles to give a significant effect but in the American panel.

The other main finding is that increasing renewable production in the mix does increase end user prices. This effect is robust at the 10% level under almost all specifications and in all regions. Similarly, the cost of renewable integration is born in a greater extent by the industrial

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[39] See figures D.7, D.9 and D.11

[40] see figures D.8, D.10 and D.12

[41] Only standard errors differ.

[42] Using Dris Kaay standard errors

consumers the ratio industrial over residential increases with additional renewable generation. Differences appear when only considering the states which implemented a CRM. Indeed, the US states which did so, have rather limited renewable production, so the dynamics might sightly differ as the additional cost of grid integration kicks in pass a certain level of integration.

V. DISCUSSION

The ongoing debate on capacity remuneration has mainly gravitated around the concept of security of supply as an externality, the efficiency of the benchmark model (EOM) and the need to correct given imperfections. The three main effects of CRMs according to theory are the cost of capacity remuneration itself combined with the expected wholesale energy price decrease and the diminution of risk premium. The only way to assess the joint effect of those is through global system costs, here approximated by end user prices. Present results give a broader dimension to the argument suggesting that CRMs are probably neutral in terms of costs, and even potentially financially beneficial to end users. If further research prove so, the debate about the energy only market's efficiency becomes irrelevant. However, those results have to be taken with caution as no causal relationship is proven with this study. At the macro level, many interactions are possible and it is impossible to control for all of them. For instance, end user prices are the only metric that could give a net effect of CRMs, but it is also an aggregate subject to numerous social, economic and political forces that are difficult to account for. In addition to energy prices, end user prices include transport costs and taxes and levies. Using this aggregates is a way to make sure the capacity costs and benefits are included. As a drawback, structural changes in transport costs or taxes and levies are not controlled for due to the lack of information.

Lower end user prices under a capacity remuneration framework is possible, but theoretically improbable. This is why this option has been little discussed. As shown in section 2., the cost of capacity remuneration should be at least equal to the reduction in scarcity rent. CRMs also alleviate the market risk, favoring investments. None of these elements drastically impact prices. But relaxing the assumption that $CF_i^{EOM} = CF_i^{CRM}$ from section 2., prices become an adjustment variable. Instead of maintaining the revenues of plants, the regulator might decides to maintain the reserve margin. When the official argument of the precocious regulator to implement capacity remuneration is that the missing money creates risks on systems' security of supply, a target in terms of reserve margin is highly probable[43], even though security of supply was never actually in danger. In that case, the remuneration of the plants does not have to be as high as under the energy only market. The market risk decreases, and so does the expected return on investment. Achieving the same reserve margin as under the EOM results less costly.

Comparing with numerical models, the main difference is the scarcity pricing: in real markets, prices never even get close to the VoLL. Markets without capacity remuneration do not value reliability per se. It then comes naturally to mind that internalization of security of supply will be costly. And yet, the whole argument around CRMs is about the very low probability of black out even without CRMs: is intervention needed? To account for the social cost of black out, most numerical models price scarcity at the estimated VoLL (usually higher than 1000€). This makes the underlying hypoteses of the two approaches fundamentally differ, yet this points to

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[43] Figure B.1 displays no structural changes in the reserve margin over time. Considering the reserve margin not to be a variable of adjustment is a credible hypothesis both because security of supply is rarely actually at risk, and the reserve margin does not show structural evolutions under the different market designs.

similar intuitions. (De Vries & Heijen, 2007)[8] find that under demand uncertainty, all types of CRM lead to lower prices (capacity plus energy) than the energy only market. With and without a CRM, markets never actually reach the scarcity price of 8600 €/MWh used in their study (although it might be needed), but empirical results also show a decrease in prices, suggesting a strong effect of uncertainty and risk on system costs. Both results seem to support the idea that the risk factor is undervalued in CRMs' assessments. For instance, the DECC estimates the net cost of the first auction will be of £2 while the gross cost is more around £11. The DECC clearly foresees a strong reduction in energy prices, leading to a 9£ difference between the gross and net cost[44]. This represents a 1.3% increase[45], an order of magnitude that lends in the confidence interval of the present results[46].

Further, renewable integration results costly considering that an increase of 1% in production increases industrial end user prices between 0.5% and 0.8% depending on the panel considered. This partially confirms[47] and extends results from (Moreno, Lopez, & Garcia-Alvarez, 2012) [22]. They find that an increase of 1% in the electricity generated from renewable sources (including hydro) as percentage of total gross electricity production leads to a 0.018% increase in household prices in the EU-27. Taken alone, an increase of 1% of the electricity generated from the wind would raise prices by 0.03%, indicating that the higher the share of renewable, the higher the financial weight on end user customers. This interpretation is backed by several studies, among which a report produced by Aurora Energy Research[1] which estimates the current cost of solar integration to be £1.3/MWh[48]. Compared to the present results, £1.3/MWh represents 0.8% of the 2015 residential prices in the UK. The share is obviously higher with respect to end users industrial prices[49]. Increasing renewable penetration appears quite costly for consumers. In addition to subsidies, systems need additional flexibility and grid investments to cope with renewables intermittency which is unlikely to be paid for on the spot market but rather appears on the retail prices.

Energy poverty is a growing political concern in developed countries as lifestyle increasingly relies on electricity. Decision makers seem to have addressed the problem reducing the relative burden borne by residential consumers. Indeed, results suggest an implicit decision to favor residential end users by reducing the gap between their prices and those of industrial consumers. This holds true both for CRM implementation and renewable integration. It might rise concern on competitiveness in the long run if industrial end users are structurally penalized compared to other groups of consumers.

VI. CONCLUSION

Capacity remuneration is quite controversial. It is broadly admitted that the energy only market is the first best equilibrium under perfect competition. However, electricity markets are also commonly recognized not to operate under such circumstances and no consensus has emerged so far on the second best. Meanwhile, more and more CRMs are being implemented.

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[44] The total cost of the auction being £0.96bn (in 2012 prices), DECC estimates that the average gross cost per household to be around £11 for year 2018 (first delivery year). When including wholesale price reduction, the net cost goes down to £2.

[45] household prices in 2015 were around £150 including VAT according to Eurostats

[46] See figure D.9

[47] the effect is much lower and non significant on residential end users

[48] Cost for the current 11GW on the system. If capacity reaches 40GW in 2030, the cost goes up to £6.8/MWh

[49] According to Eurostat, UK residential prices for medium consumption where around £150 and £130 for medium industrial consumers (VAT included).

East US regulators acknowledged the limits of the initial short term mechanisms in the mid 2000s and made the necessary adjustments. All capacity schemes based on “installed capacity” have been turned into “available capacity” based mechanisms. Price based mechanisms are being changed for volume based ones and more and more systems go for a forward period. Now, such evolutions are also being implemented in Italy, Ireland, the UK and France. Although current evolutions indicate a consensus on some key features of CRMs, the links with the relevant market failures remain blur which toughen efficiency assessment. The efficacy of a CRM appears through two different channels: price efficiency and security of supply efficiency. Contributing to the literature on the first element, this study finds CRMs to decrease industrial end user power prices by 1.2% per year in US states. Contrary to expectations, changes to improve CRM efficiency result equally costly for end consumers as the implementation itself. The reforms of CRMs in the US implemented simultaneously a forward period, changes in the demand curve and more stringent criteria on availability without seemingly affecting price levels. It is as if neither the increased obligations nor the forward faced by producers affect prices. The most probable inference is consequently that it did not affect their costs because the incentive to produce at peak have always existed, be it in energy only markets or under CRM. Unfortunately, too few systems have implemented the forward period so far to truly isolate the effect. In Europe, governments efforts to limit end user price variations, alongside with limited panel size, blur the message. Although results have there to be taken with caution for methodological and theoretical reasons, the overall results still suggest that CRM implementation is financially neutral for end users. Altogether, this supports previous results: CRMs are not so costly. Regulators intervention seems to limit the cost of CRM, so that it does not exceed the reduction in scarcity rent[50].

Finally, this study presents one of the first attempt to empirically estimate the average cost of CRM for the end users. The cost of precaution can go up to 3% decrease in end user prices per year (case of US residential users). This is a strong result that suggests that the risk reduction have been underestimated in a debate where CRMs are naturally seen as costly, or at best neutral and unneeded. Neutral and unneeded; it may be, but costly, probably not. Giving ground to its defenders, CRMs should not be seen solely as a precaution: a precaution that comes for free deserves attention. It should raise regulators’ awarness regarding the cost efficiency of CRMs. It is also the regulator’s choice to improve the quality and detail of published data so researchers can investigate potential improvements in security of supply or system costs. Unfortunately, data availability does not allow differentiating between network failures and capacity inadequacy for now, nor to investigate at a more granular level.

References

[1] Aurora Energy Research. Intermittency and the cost of integrating solar in the GB power market About Aurora Energy Research. 2016.

[2] R. Bajo-Buenestado. Welfare implications of capacity payments in a price-capped electricity sector: A case study of the Texas market (ERCOT). ***Energy Economics***, 64:272–285, 2017.

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[50] If there is a reduction in missing money thanks to CRM implementation (lower risk), it suggests that even though reliability is not valued in the energy market, producers do benefit of alternative revenues so the reserve margin in all the states of our panel is not at risk.

[3] T. Brown, S. A. Newell, D. L. Oates, and K. Spees. International Review of Demand Response Mechanisms. Technical report, 2015.

[4] M. Cepeda and D. Finon. Generation capacity adequacy in interdependent electricity markets. ***Energy Policy***, 39:3128–3143, 2011.

[5] P. Cramton and A. Ockenfels. Economics and design of capacity markets for the power sector. ***Zeitschrift f{ü}r Energiewirtschaft***, 36(2):113–134, 2012.

[6] G. de Maere, A. Ehrenmann, and Y. Smeers. Investment with incomplete markets for risk: The need for long-term contracts. ***Energy Policy***, 105:571–583, 2017.

[7] L. De Vries. Generation adequacy: Helping the market do its job. ***Utilities Policy***, 15(1):20–35, 2007.

[8] L. De Vries and P. Heijnen. The impact of electricity market design upon investment under uncertainty: The effectiveness of capacity mechanisms. ***Utilities Policy***, 16(3):215–227, 2008.

[9] L. J. De Vries. ***Securing the public interest in electricity generation markets, the myths of the invisible hand and the copper plate***. PhD thesis, Technische Universiteit Delft, 2004.

[10] A. Ford. Waiting for the boom: a simulation study of power plant construction in California. ***Energy Policy***, 2001.

[11] D. Hach, C. K. Chyong, and S. Spinler. Capacity market design options: A dynamic capacity investment model and a GB case study. ***European Journal of Operational Research***, 249:691–705, 2015.

[12] H. Hanspeter, C. D. Jonghe, and R. Belmans. Optimal Level of Remuneration for Capacity to Ensure Adequacy. 2014.

[13] N. Hary, V. Rious, and M. Saguan. The electricity generation adequacy problem: Assessing dynamic effects of capacity remuneration mechanisms. ***Energy policy***, 2016.

[14] A. Henriot and J.-M. Glachant. Capacity Remuneration Mechanisms in the European Market: Now but How. ***European University Institute Working Paper***, 2014.

[15] M. Hyland. Restructuring European electricity markets e A panel data analysis. ***Utilities Policy***, 38:33–42, 2016.

[16] P. Joskow and J. Tirole. Reliability and competitive electricity markets. ***The RAND Journal of Economics,***, 38(1):60–84, 2007.

[17] P. L. Joskow. Markets for power in the United States: An Interim Assessment. ***The Energy Journal***, 2006.

[18] P. L. Joskow. Market imperfections versus regulatory imperfections. ***CESifo DICE Report***, 8(3):1–7, 2010.

[19] J. H. Keppler. Rationales for capacity remuneration mechanisms: Security of supply externalities and asymmetric investment incentives. ***Energy Policy***, 2016.

[20] P. Mastropietro, P. Rodilla, and C. Batle. Capacity Mechanisms and Performance Incentives: Avoiding the "Money for Nothing Problem". 2015.

[21] L. Meulman and N. Méray. Capacity Mechanisms in Nortwest Europe -Between a Rock and a Hard Place. ***Clingendael International Energy Programme***, 2012.

[22] B. Moreno, A. J. Lopez, and M. T. Garcia-Alvarez. The Electricity Prices in the European Union. The Role of Renewable Energies and Regulatory Market Reforms. ***Energy***, 2012.

[23] H. Nagayama. Electric power sector reform liberalization models and electric power prices in developing countries: An empirical analysis using international data. ***Energy Economics***, 2009.

[24] M. Petitet. Effects of Risk Aversion on Ivestment Decisions in Electricity Generation: What Consequences for Market Design? 2016.

[25] M. Petitet, D. Finon, and T. Janssen. Ensuring Capacity Adequacy During Energy Transition in Mature Power Market: A Social Efficiency Comparison of Scarcity Pricing and Capacity Mechanism. ***CEEM Working Paper***, 2015.

[26] J. Pfeifenberger, K. Spees, D. L. Oates, and A. Schumacher. A comparison of RPM with Alternative Energy and Capacity Market Designs. 2009.

[27] F. Steiner. Regulation, Industry Structure and Performence in Electricity Supply Industry. ***OECD Economic studies***, 2001.

[28] S. Stoft. ***Power System Economics: Designing Markets for Electricity***. 2002.

[29] M. Yücel and A. Swadley. Did Residential Electricity Rates Fall After Retail Competition? A Dynamic Panel Analysis. ***Energy Policy***, 2011.

Appendices

A Database

European electricity price to the industrial end user: The original eurostats series “Ie” (1991-2007) and then “IC” (2007-2015), representing medium size firms with an average consumption of 2000MWh/year approximatively. Data are taken excluding VAT and other recoverable taxes and levies. Eurostats industrial data may include any non-domestic consumer depending on country coverage.

European electricity price to the residential end user (household): The original eurostats series “DC”, representing middle range households with an average consumption of 3500kWh/year approximatively. Data are taken excluding VAT and other recoverable taxes and levies for consistency with industrial end user prices.

European gas prices to the industrial end user: The eurostats serie “I3-I” (1997-2007) and then “I3”, representing medium size firms with an average of 50000GJ/Year approximatively. Data are taken excluding VAT and other recoverable taxes and levies.

European electricity fuel mix: The International Energy Agency publishes the electricity production by fuel by country which divided by the total production gives a percentage. Hydroelectric and nuclear production are straight forward and respectively correspond to the items “hydro” and “Nuclear”

US industrial electricity price: The EIA publishes directly the yearly average industrial power prices for each state for the 1990-2014 period.

US residential electricity price: The EIA publishes directly the yearly average Residential power prices for each state for the 1990-2014 period.

US industrial gas price: The EIA publishes directly the yearly industrial gas prices for each state for the 1997-2014 period. To extend the series and complete missing values, the wellhead prices variation are used.

Us electricity fuel mix: The EIA openly publishes production by fuel for each state. Hydroelectric production gathers conventional “hydro” and “pumped storage” while renewable production is composed of “solar thermal” and “photovoltaic” as well as “wind”. Coal and gas and nuclear items are used as such. Productions by fuel are then divided by total production to get a share.

B Capacity remuneration in our panel

The load duration curve of **France** is quite steep and by 2012, the TSO started to bother about investments trends due to the mothballing of several plants. Forward capacity obligations is implemented with a first delivery year in 2017.

In the fear of aging nuclear plants, **Belgium** has decided to keep the energy only market going by implementing a strategic reserve in 2014. The strategic reserve is not supposed to be price distortive when well managed. **Germany** has temporarily considered capacity remuneration, but finally decided to implement a targeted strategic reserve with the double aim to take old polluting plants out of the market, but keep them into a reserve in order not to lower security of supply.

The United Kingdom implemented capacity payments from 1990 to 2001. The capacity payments were calculated ex post based on the realized scarcity in market for 30 minutes slots. In 2013, National Grid decided to implement a capacity market from delivery years 2017 on.

In **Ireland**, since 2007, the total sum of capacity payment is calculated by the market operator as the product of the targeted quantity with the estimated missing money of a new peaker (fixed costs minus the infra marginal rent and the ancillary services revenues. This sum is then charged allocated to generators according to three principles. 30% is paid every month as a fixed payment. Ex post payments also represent a 30% of the annual capacity payment sum based on the ex post loss of load probability in each trading period and finally, a 40% of the sum is allocated according to the forecasted LOLP in each trading period of the month.

Spain has had capacity payments since 1997. Prices were then set by the government according to expected adequacy needs and would differ depending on fuel. In 2007, the system was reformed to become more targeted. Only new built or existing plants not recovering fixed costs would then possibly receive a capacity payment.

In 2007, **Portugal** decided to follows Spain with the new capacity payment.

Following the 2003 black out, **Italy** implemented a temporary mechanism. Allocated on a daily basis, the payment has two component. One is based on the forecasted hourly supply and demand, the second one depends on realized day ahead prices.

ISO New England first implemented a capacity market as soon as 1998. In 2006, it decided to change for a forward capacity market and set a transition period of 3 years (2007-2010) during which capacity payments would bridge in between the two mechanisms. As of auctions for delivery year 2010/2011, the forward period has been 3 years with one year commitment.

Although **NYISO** has changed it mechanism in place since 1999 to a forward capacity mechanism in 2006, it kept its short term feature with a forward period of only one month. This paper considers a forward period to be implemented when it is of at least on year.

The **PJM** decided in 1999 for a daily capacity market where utilities would buy and sell capacity to comply with their obligation. In 2007, it has been reformed to become a forward capacity market with a 3 year forward period. 2007-2011 has been a transition period with increasing forward period for delivery year to delivery year. 2008 is the first delivery year benefiting from several months of forward period.

SPP and **ERCOT** have not implemented any capacity mechanism so far. Contrary to the other system considered, SPP does not have an independent system operator. We also act as if the whole state of Texas was in the ERCOT which is only a proxy, several counties being actually in the SPP.

Figure B.1 displays roughly calculated reserve margins[51] for respectively Belgium, France, Ireland, Portugal, Spain and Great Britain based on IAE data on peak load and capacity. As for ISO-NE and NY-ISO, the same formula is applied on data from the North American Reliability Corporation (NERC).

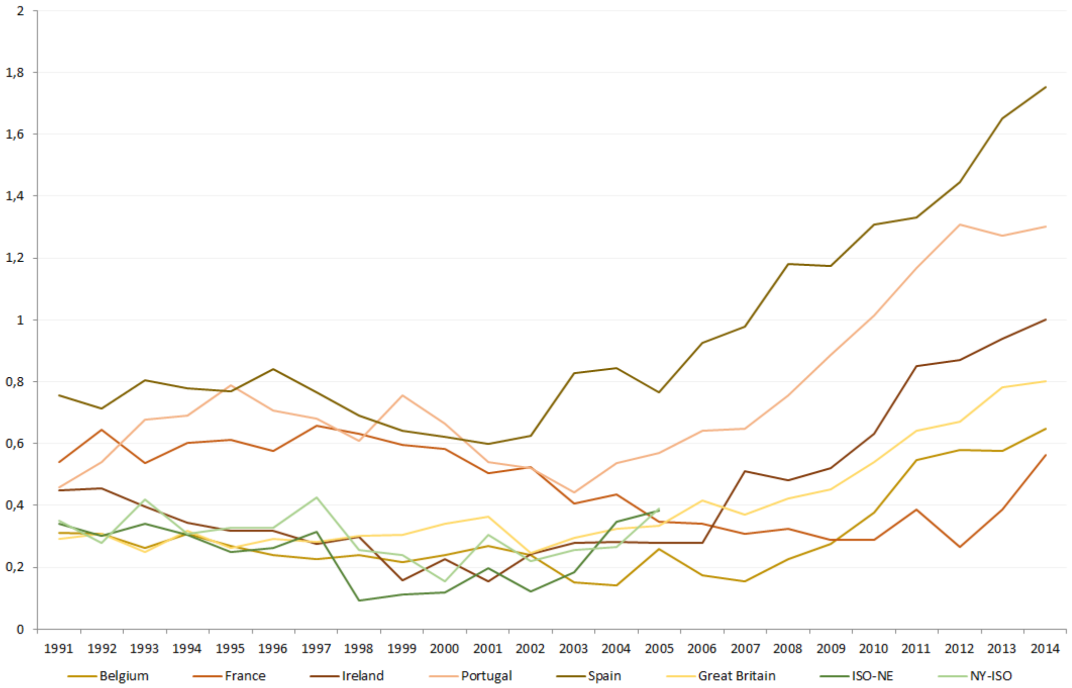

Figure B.1: Evolution of the reserve margin in selected countries

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[51] The reserve margin is calculated with the following formula: $ResMargin = \frac{Capacity}{PeakLoad} - 1$.As reserves margins are here calculated on all capacities, meaning that non reliable technologies are also embedded, the actual one is over estimated.

C Descriptive statistics figures and tables

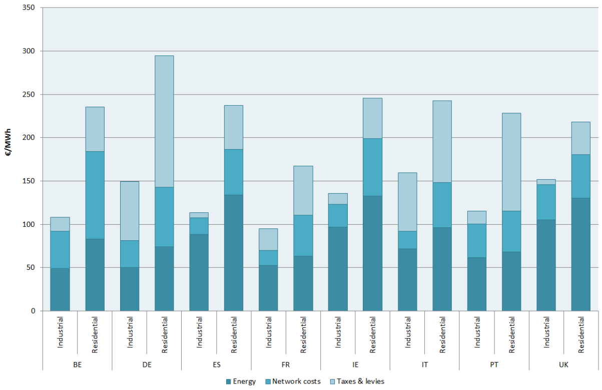
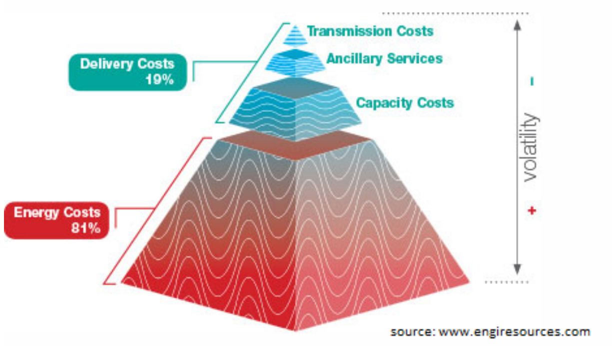


Figure C.1: Breakdown of end user electricity prices including all taxes and charges in some European countries in 2015 (data: Eurostats)



source: www.engiresources.com

Figure C.2: Breakdown of US end user electricity prices (January 2014)

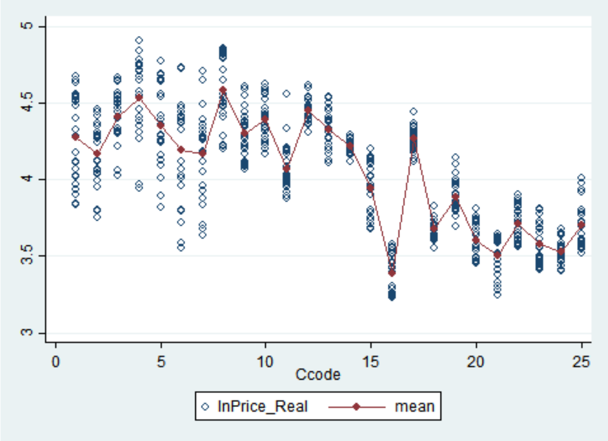


Figure C.3: Real industrial power prices per state

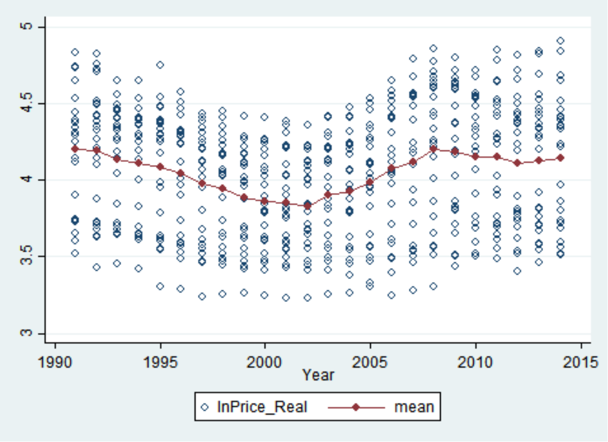


Figure C.4: Evolution of real industrial power prices over time

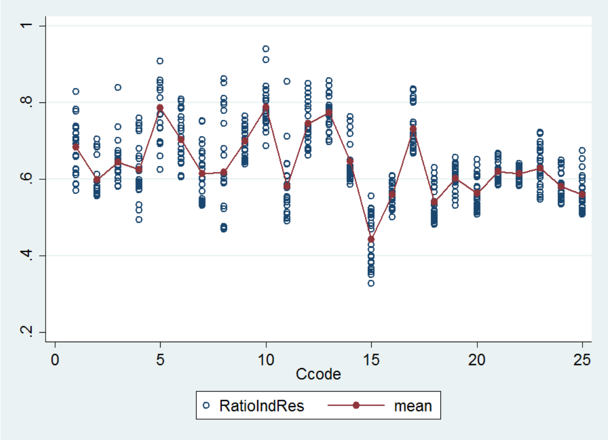


Figure C.5: Ratio industrial over residential prices per state

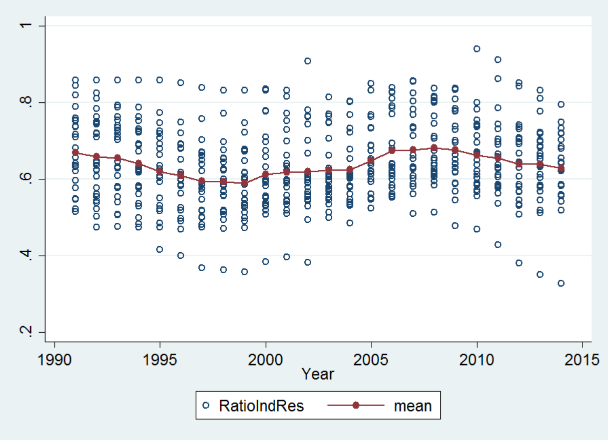


Figure C.6: Ratio industrial over residential prices over time

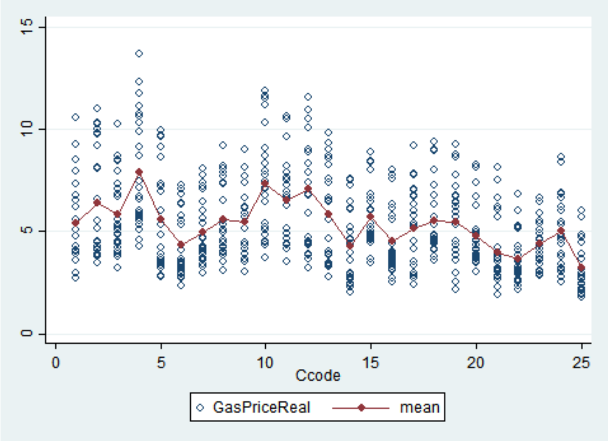


Figure C.7: Real industrial gas prices per state

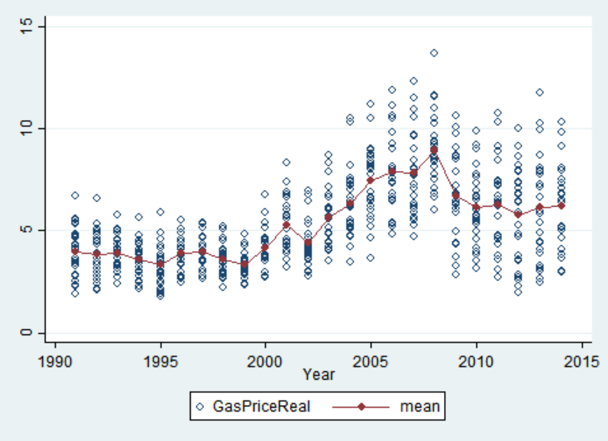


Figure C.8: Evolution of real industrial gas prices over time

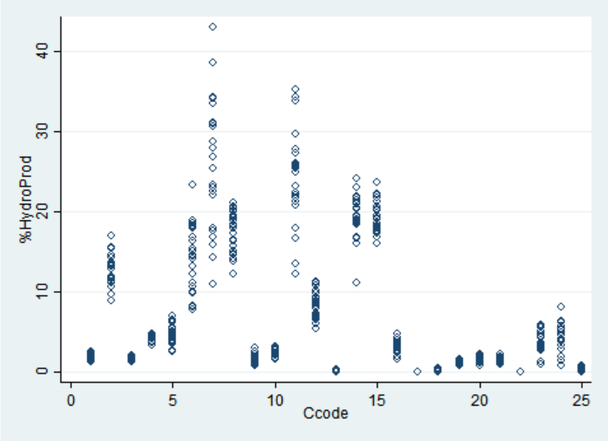


Figure C.9: Hydrolelectric share in total power production per state

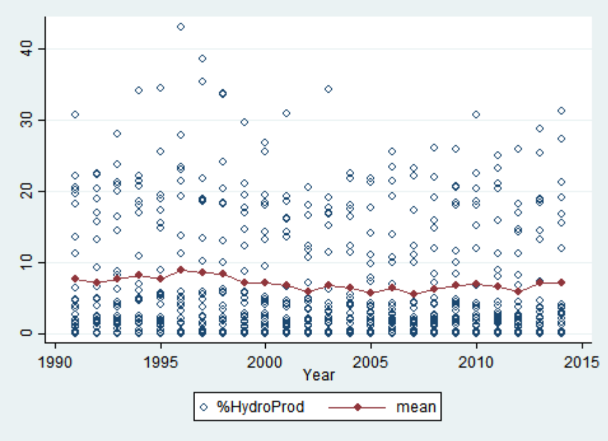


Figure C.10: Evolution of the hydroelectric share of total power production over time

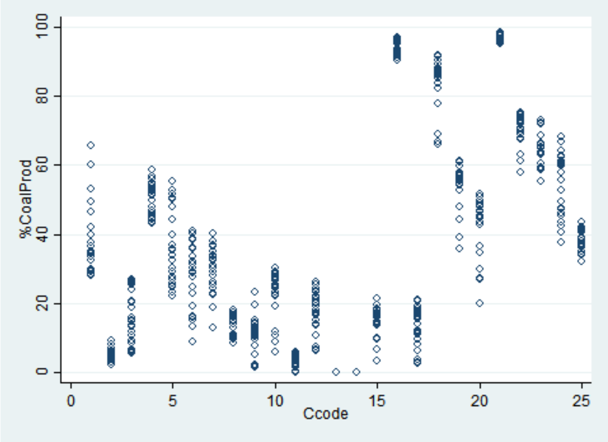


Figure C.11: Share of power production from coal per state

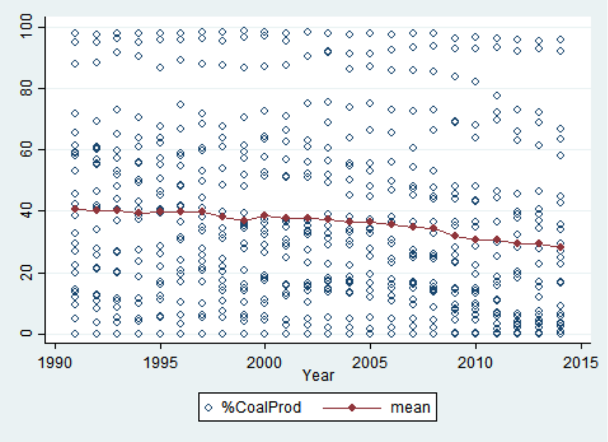


Figure C.12: Evolution of share of coal fired power production over time

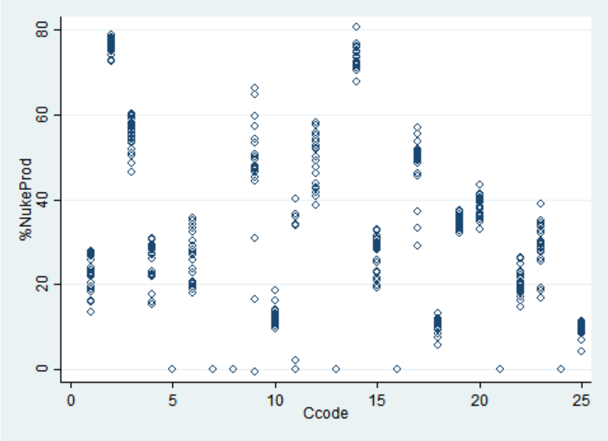


Figure C.13: Share of power production from nuclear per State

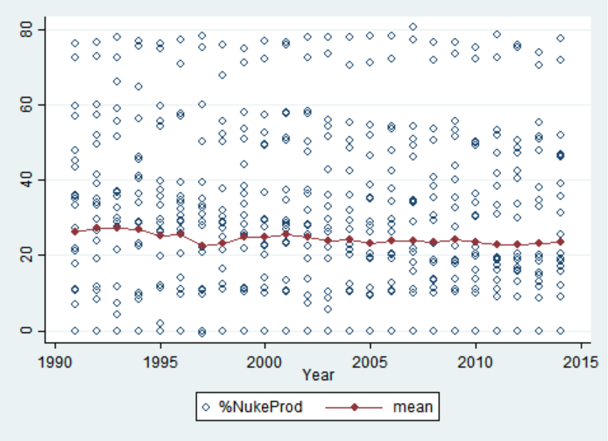


Figure C.14: Evolution of the share of nuclear power production over time

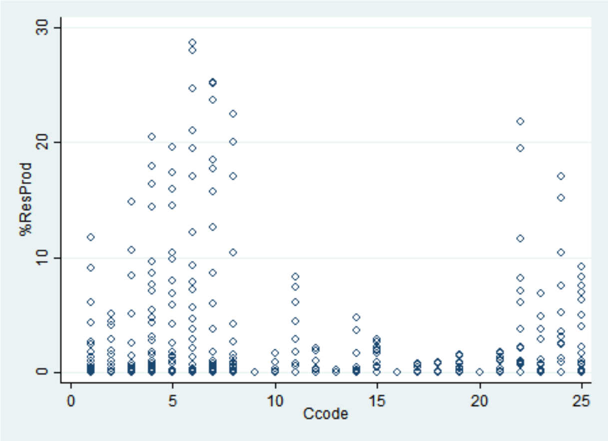


Figure C.15: Share of power production from Renewable sources per state

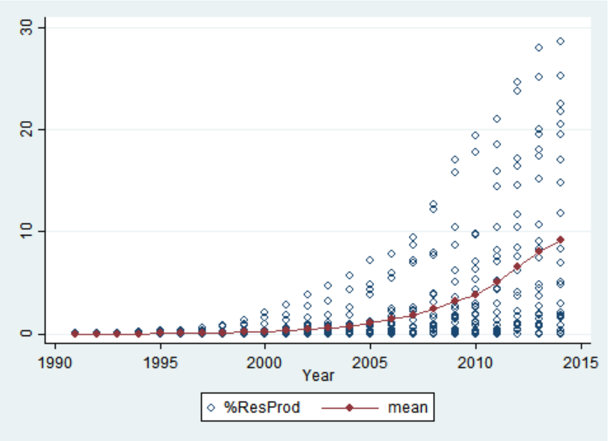


Figure C.16: Evolution of the share of renewable power production over time

Variable	**EOM** Mean	**EOM** Std. Dev.	**CRM** Mean	**CRM** Std. Dev.	**CRM-EOM** mean difference	**CRM-EOM** SD difference
Price_Real	56.11	28.22	63.02	22.72	Statistically different	Statistically different
lnPrice_Real	3.96	0.44	4.08	0.38	Statistically different	Statistically different
ResPrice_Real	94.85	43.53	96.79	30.29	**Statistically similar**	Statistically different
lnResPrice_Real	4.46	0.40	4.52	0.31	Statistically different	Statistically different
RatioIndRes	0.60	0.06	0.64	0.11	Statistically different	Statistically different
GasPriceReal	5.32	2.65	5.36	2.14	**Statistically similar**	Statistically different
HydroProd	3.88	4.12	8.19	9.30	Statistically different	Statistically different
ResProd	2.57	4.49	1.63	4.59	**Statistically similar**	**Statistically similar**
NukeProd	30.89	24.86	22.01	22.47	Statistically different	**Statistically similar**
CoalProd	42.61	23.42	33.35	30.56	Statistically different	Statistically different
number of observations	168		432			

Table C.1: Differences in mean and standard deviation between two groups of states (5% sign level)

D Robustness

	(1)	(2)	(3)	(4)	(5)
	Model 1	Model 2	Model 2	Model 1	Model 2
	Pooled	Pooled	EU	US	US
VARIABLES	Δln($Price_{Res}$)	Δln($Price_{Res}$)	Δln(Price)	Δln($Price_{Res}$)	Δln($Price_{Res}$)
ΔCRM	-0.00964	-0.00972	-0.00688	-0.0161***	-0.0162***
	(0.00867)	(0.00861)	(0.0169)	(0.00216)	(0.00211)
ΔCRM1	0.00262	0.00263	0.0315	-0.0142***	-0.0142***
	(0.0154)	(0.0154)	(0.0245)	(0.00125)	(0.00122)
ΔForward	-0.0229			-0.0239	
	(0.0177)			(0.0162)	
ΔForward1	0.0104			0.0121	
	(0.0261)			(0.0256)	
ΔGasPriceReal	6.08e-05	5.63e-05	0.000119	1.32e-05	3.66e-06
	(0.000152)	(0.000159)	(0.000104)	(0.000271)	(0.000286)
ΔHydroProd	-0.000436	-0.000370	0.000178	-0.00181	-0.00152
	(0.000548)	(0.000568)	(0.000621)	(0.00111)	(0.00109)
ΔResProd	0.00173	0.00177	0.00221	0.00171	0.00180
	(0.00237)	(0.00214)	(0.00450)	(0.00100)	(0.00117)
ΔNukeProd	-0.000319	-0.000345	-0.000685	-0.000430	-0.000431
	(0.000341)	(0.000349)	(0.00245)	(0.000317)	(0.000336)
ΔCoalProd	-0.000851	-0.000867	-0.00109	-0.000650	-0.000687
	(0.000764)	(0.000853)	(0.00178)	(0.000562)	(0.000647)
Constant	0.0141***	0.0142***	0.0348***	0.00525	0.00531
	(0.00258)	(0.00276)	(0.00329)	(0.00339)	(0.00352)
Time fixed effects	YES	YES	YES	YES	YES
Observations	575	575	184	391	391
R-squared	0.600	0.598	0.771	0.238	0.232
Number of groups	25	25	8	17	17

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table D.1: Residential power prices: Regression results

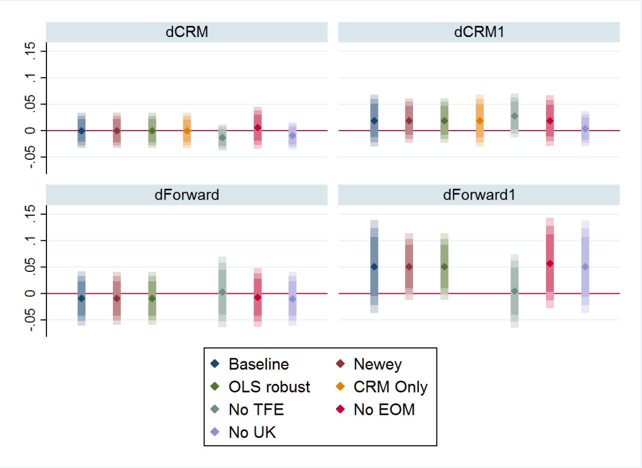


Figure D.1: Industrial power prices (Pooled panel): CRM & Forward (SE 95, 90 & 80%)

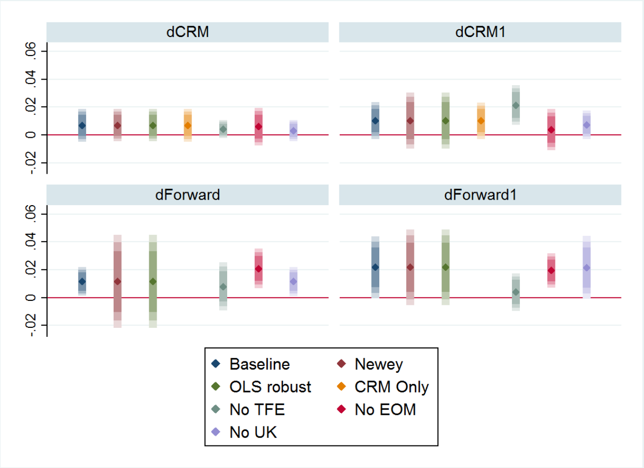


Figure D.2: Ratio industrial over residential power prices (Pooled panel): CRM & Forward (SE 95, 90 & 80%)

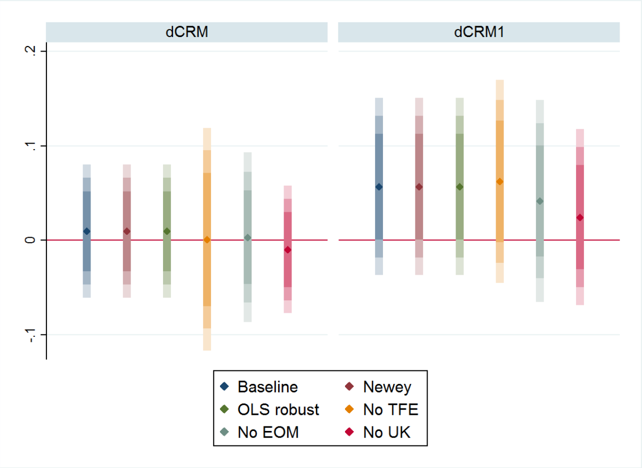


Figure D.3: Industrial power prices (EU): CRM & Forward (SE 95, 90 & 80%)

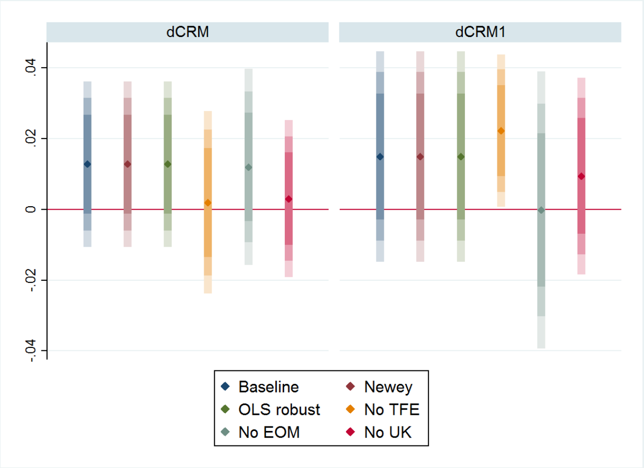


Figure D.4: Ratio industrial over residential power prices (EU): CRM & Forward (SE 95, 90 & 80%)

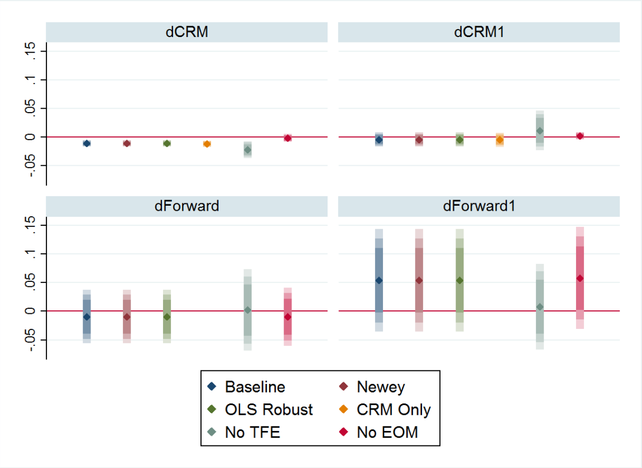


Figure D.5: Industrial power prices (US): CRM & Forward (SE 95, 90 & 80%)

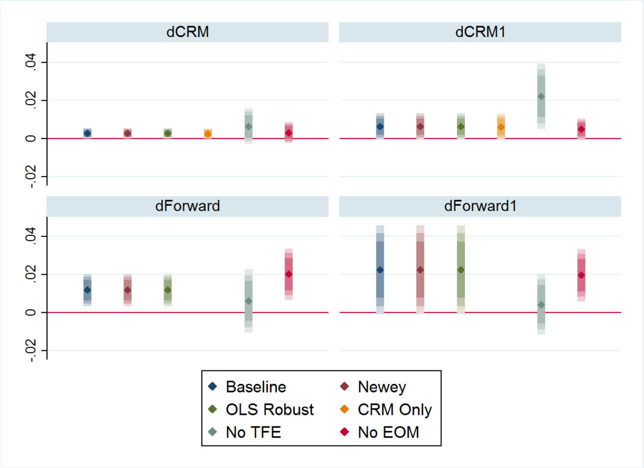


Figure D.6: Ratio industrial over residential power prices (US): CRM & Forward (SE 95, 90 & 80%)

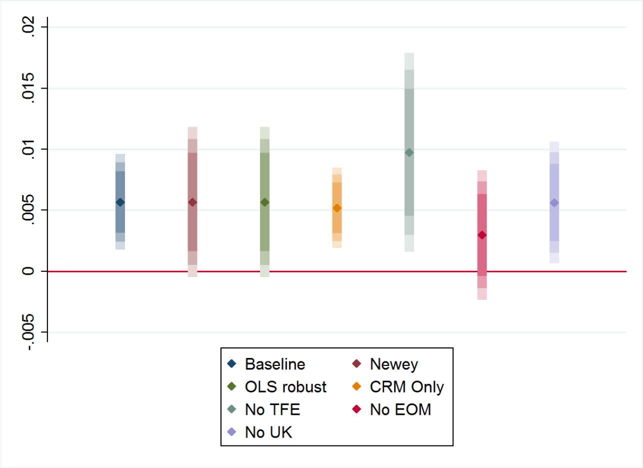


Figure D.7: Industrial power prices (Pooled panel): Renewable production (SE 95, 90 & 80%)

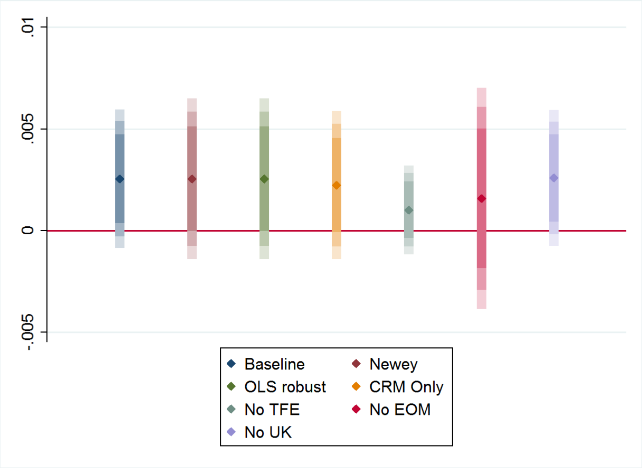


Figure D.8: Ratio industrial over residential power prices (Pooled panel): Renewable production (SE 95, 90 & 80%)

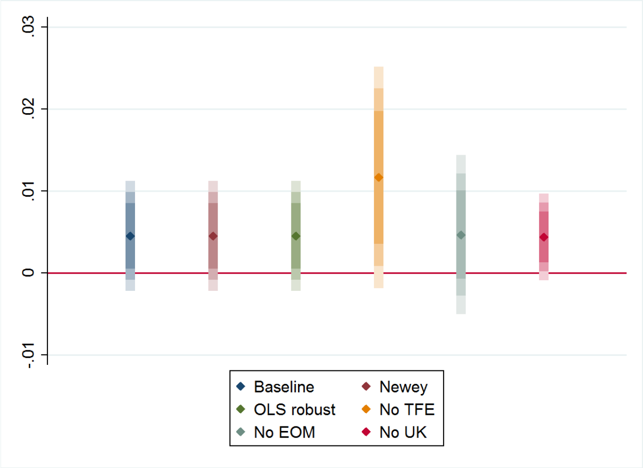


Figure D.9: Industrial power prices (EU): Renewable production (SE 95, 90 & 80%)

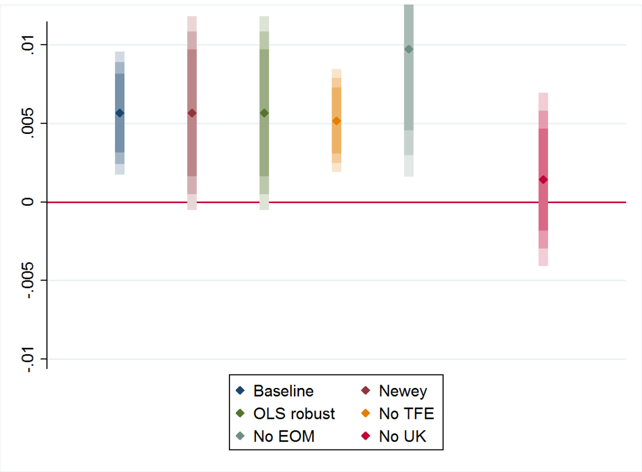


Figure D.10: Ratio industrial over residential power prices (EU): Renewable production (SE 95, 90 & 80%)

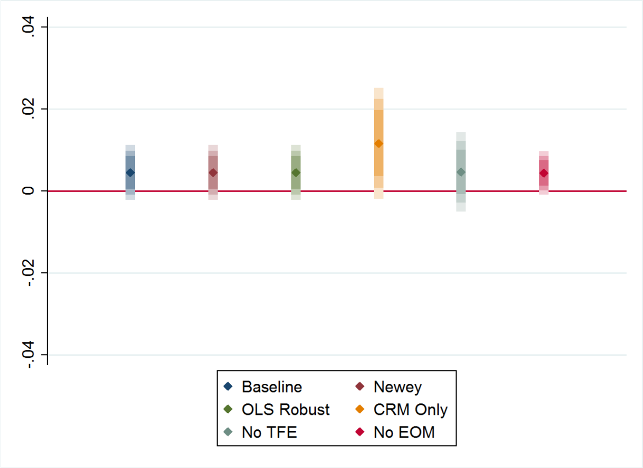


Figure D.11: Industrial power prices (US): Renewable production (SE 95, 90 & 80%)

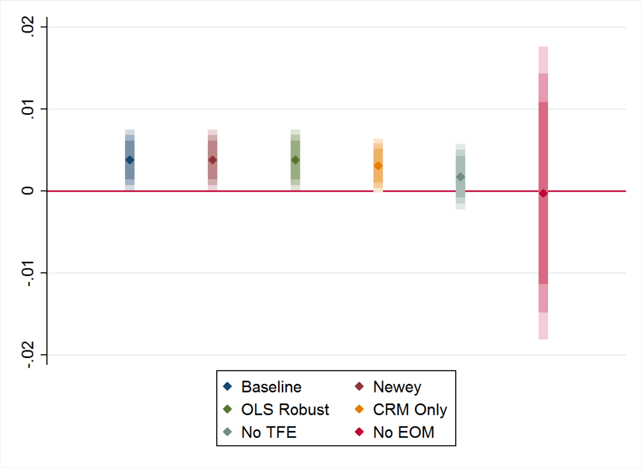


Figure D.12: Ratio industrial over residential power prices (US): Renewable production (SE 95, 90 & 80%)